

National Environmental Monitoring Standards

# Dissolved Oxygen

Continuous Measurement of Dissolved Oxygen for  
Environmental Monitoring Purposes

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## Change register

Version Number	Revision Date	Section	Topic	Revision Summary
1.0	June 2013			Initial release
2.0	July 2016			Format changes
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. Scope excludes groundwater.
		The Standard – Dissolved oxygen		Updated and restructured. New tables clarify requirements for QC 600 vs lower quality codes. New quality coding flowchart adds QC 0.
		1.3	Site factors	Additional considerations, including cross section variation and vertical stratification
		2.2	Sensors	Updated details and specifications, including requirement to use optical sensors.
		2.7	Interferences	Updated explanation.
		2.8	Reference method	Updated details and specifications, including removal of Winkler titration.
		3.3	Installation and commissioning	Expanded commentary.
		4.3	Reference instruments	Updated sensor calibration requirements, including sensors for supplementary variables.
		4.4	In-situ sensors	
		5.3	Reference instruments	Updated sensor validation requirements, including sensors for supplementary variables.
		5.4	In-situ sensors	
		6.2	Equipment maintenance	Updated details and specifications, including sensor cap or foil replacement.
		7.2	Measurement	Updated to clarify requirements for supplementary measurements and added complementary measurements
		7.5	Verification	Updated method requirements. Reduced minimum verification frequency but tightened verification tolerance. Included requirements for supplementary measurements.
		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 <i>Data Processing</i> 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.
		Annexes		Previous Annexes A to G replaced with Annexes A to E as outlined below. Most content of removed annexes appears elsewhere. Former Annex E (Options for Editing Data) is in NEMS <i>Data Processing</i> .
		Annex A	Quality Coding Matrices	New.
		Annex B	Sensor Deployment Field Form Checklist	New.
		Annex C	Data Tables	Was previously Annex F. Minor corrections to both tables.
		Annex D	Dissolved Oxygen Calculations	Combines previous Annexes D and G. Adds calculation examples.
		Annex E	Site Visit Form Checklist	New.

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# 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](http://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](http://www.nems.org).

## Review

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

The presence of dissolved oxygen (DO) in surface and ground waters is essential for the survival and growth of many aquatic organisms. Concentrations of DO also influence many biological and chemical and reactions. As such DO is routinely monitored in surface and ground waters as an indicator of the ecosystem health and geochemical quality.

The concentration of DO in water is affected by many factors, including ambient temperature, atmospheric pressure, aquatic plant respiration and growth, and ion activity (e.g. arising from aerobic decomposition processes and nitrification of ammonia in wastewater inputs). Because DO concentrations can vary widely across the course of a day, DO measurements are often made at high frequency (i.e. on a near-continuous basis). Continuous monitoring of DO, together with water temperature, is needed to calculate ecosystem metabolism.

Each monitoring situation provides its own challenges and it is important that the measured data are fit for purpose. Key to monitoring DO at high frequency is the understanding of and catering for stationarity. Supporting variables that influence DO also need to be monitored to obtain an accurate DO time series, specifically water temperature, barometric pressure and conductivity or salinity.

There have been many advances in DO measurements and sensors over time. Today, luminescence-based (optical) sensors are generally considered the standard field sensor for routine in-situ measurement of DO in surface and ground waters.

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) and Hamish Carrad (Environmental Canterbury), with significant 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 DO sensor selection guidance developed by NIWA (McKergow 2025).

## Objective

The objective of this Standard is to ensure that continuous DO data measured in rivers, lakes, estuaries 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 DO in rivers, lakes and coastal waters, including:

- design, installation and operation of a monitoring site
- permanent and short-term (e.g. seasonal) in-situ sensor deployments, and
- collection and management of original data.

## Exclusions

This Standard does not address where monitoring may be required within a river, lake or coastal system. That is a matter for consideration during the design of a monitoring programme and will depend on the programme's purpose.

This Standard also does not apply to:

- discrete DO measurements or vertical profiles other than for initial characterisation of a site's mixing properties, or

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

- the continuous monitoring of DO in groundwater or for industrial applications.

*Note: Continuous monitoring of DO is not a common component of routine groundwater quality monitoring programmes in New Zealand. It is more likely to be carried out for specific investigations, such as to understand the interaction between surface water and groundwater. NEMS users interested in continuous monitoring of DO in groundwater may find the guidance in Mathany et al. (2019) useful.*

## 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](http://www.nems.org.nz).

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

## Normative references

This code of practice shall be read in conjunction with the following references:

- *NEMS Data Processing – Processing of Environmental Time-series Data*
- *NEMS Water Temperature – Continuous Measurement of Water Temperature for Environmental Monitoring Purposes*
- *NEMS Glossary – Terms, Definitions and Symbols*
- *NEMS National Quality Code Schema*
- *NEMS Safe Collection of Environmental Data – Guideline for safe working when undertaking environmental monitoring.*
- *NEMS Guidelines for Hydrological and Meteorological Structures*

# The Standard – Dissolved Oxygen

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 dissolved oxygen data irrespective of quality.
- Additional requirements for dissolved oxygen 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 DO 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		<ul style="list-style-type: none"> <li>• Maintained wherever possible.</li> <li>• Documented in metadata if change occurs or is likely to occur.</li> <li>• If significant change (as defined in site requirements), create a new site.</li> </ul>
Units of measurement		<ul style="list-style-type: none"> <li>• Metric system.</li> <li>• SI units, unless stated otherwise (in the relevant Standard).</li> </ul>
Timing of measurements	Time zone	<ul style="list-style-type: none"> <li>• Use New Zealand Standard Time (NZST), or Chatham Is. Standard Time (CHAST) as applicable.</li> <li>• Do not use Daylight Time (NZDT or CHADT).</li> </ul>
Metadata	Scope	<ul style="list-style-type: none"> <li>• Recorded for all sites and measurements.</li> <li>• Permanently archived and discoverable.</li> </ul>
	Identification of Standards	Standards and versions applied shall be tracked over time in time-stamped Stationarity Comments.
	Identification of data	<p>All data shall be identified by a minimum of:</p> <ul style="list-style-type: none"> <li>• a unique site name and/or identifier</li> <li>• the variable's name and units (as defined in its relevant NEMS), and</li> <li>• date and time of the measurement or record.</li> </ul>
	Quality coding	All data shall be quality coded using the NEMS <i>National Quality Code Schema</i> .
Archiving	Original and final records	<p>Store, retain indefinitely, and if electronic, back up regularly:</p> <ul style="list-style-type: none"> <li>• Original data (as defined by the recording agency).</li> <li>• Final data (as verified).</li> <li>• Supplementary measurements.</li> <li>• All required metadata (including all calibration, validation, verification and editing information).</li> <li>• Additional time series and/or metadata used and/or generated during data processing.</li> </ul>

# Requirements for dissolved oxygen data irrespective of quality

**Table 2 – Requirements for dissolved oxygen (DO) data irrespective of quality.**

Measurement	Units (7.2.1)	<ul style="list-style-type: none"> <li>• DO saturation as % saturation, and/or</li> <li>• DO concentration in mg/L</li> </ul> <p><i>Note: mg/L is equivalent to g m<sup>-3</sup> or g/m<sup>3</sup>, and parts per million (ppm).</i></p>
	Minimum resolution (2.2.1.2)	<ul style="list-style-type: none"> <li>• 0.1% for saturation</li> <li>• 0.01 mg/L for concentrations</li> </ul>
	Method (2.2)	Optical DO sensor deployed in situ.
	DO saturation reference (2.8)	<ul style="list-style-type: none"> <li>• Standard barometric pressure at sea level (uncorrected, DO% Ref), or</li> <li>• Local barometric pressure (corrected, DO% Local), and</li> <li>• Identified at each stage of data acquisition.</li> </ul>
	Reference method (2.8.1)	Calibrated, independent, and portable optical DO sensor.
	Reference sensor accuracy (2.2.1.1)	<p>Manufacturer’s stated accuracy of at least:</p> <ul style="list-style-type: none"> <li>• ±3% saturation for measurements between 0 and 200% saturation, or</li> <li>• ±0.3 mg/L for measurements between 0 and 20 mg/L if manufacturer only states as a concentration, and</li> <li>• ±5% of reading above 200% saturation or 20 mg/L.</li> </ul>
Timing of measurements	Sampling method (7.2.2)	<p>Point sample stored as an instantaneous value.</p> <p><i>Note: A representative value average of a burst of measurements may be used but must result in a point sample.</i></p>
	Resolution (7.2.1.3)	1 second
Calibration	Method (4.3.3.1)	<ul style="list-style-type: none"> <li>• Stable environment.</li> <li>• Two-point at 0 and 100% saturation, or as per manufacturer’s specification.</li> <li>• Air-saturated water or water-saturated air.</li> </ul> <p><i>Note: Some manufacturers recommend omitting the zero point.</i></p> <p><i>Note: Calibration value for DO% Ref. at full saturation may not be 100%.</i></p>

Validation	Method (5.3.3.1)	<ul style="list-style-type: none"> <li>• Stable environment.</li> <li>• One-point at 100% saturation.</li> <li>• Air-saturated water or water-saturated air.</li> </ul> <p><i>Note: Expected value for DO% Ref. at full saturation may not be 100%.</i></p>
Maintenance	DO sensor cap or foil replacement (6.2.2)	<ul style="list-style-type: none"> <li>• Guided by manufacturer’s instructions and/or recommendations, and</li> <li>• Subject to monitored sensor performance, if no explicit expiry date.</li> </ul>
Verification	Method (all variables) (7.5.4)	<ul style="list-style-type: none"> <li>• All variables recorded continuously at site shall be verified together.</li> <li>• Reference measurements shall be made using validated and/or calibrated reference sensors, as close to time and place of in-situ measurement as possible.</li> <li>• Calculate difference between reference measurement and simultaneous logged value from in-situ sensor (ensuring the same form and units of measurement).</li> <li>• Compare difference to verification tolerance (for each variable).</li> </ul>
Supplementary measurements	Water temperature	Required for DO concentration.
	Method (7.2.4.1)	<ul style="list-style-type: none"> <li>• Temperature sensor built into, or integrated with, the in-situ optical DO sensor, and</li> <li>• Logged concurrently with DO.</li> </ul>
	Units (7.2.4.1)	Degrees Celsius (°C)
	Minimum resolution (7.2.4.1)	0.02°C
	Sensor accuracy (reference and in situ) (2.8.1.1 & 7.2.4.1)	Manufacturer’s stated accuracy of ±0.5°C or better.
	Primary reference method (4.2)	Certified traceable reference thermometer, as per NEMS <i>Water Temperature</i> .
	Reference method (2.8.1.1 & 5.3)	Independent, portable temperature sensor or field reference thermometer. <i>Note: Sensor may be built-in to a multi-variable and/or handheld instrument.</i>
	Reference sensor validation method (5.3.3.2)	Minimum 5-point check in water bath against two primary references, as per NEMS <i>Water Temperature</i> .

Supplementary measurements (cont.)	Barometric pressure	Required for DO% Local.
	Method (7.2.4.2)	At site, using a reference barometer: <ul style="list-style-type: none"> <li>• at the start and end of in situ DO sensor deployment, and</li> <li>• during DO sensor verifications.</li> </ul>
	Units (7.2.4.2)	Hectopascals (hPa) <i>Note: hPa is equivalent to millibars (mbar). 1.33 hPa is equivalent to 0.133 kPa and 1 mmHg.</i>
	Minimum resolution (7.2.4.2)	0.1 hPa
	Primary reference method (4.2)	Traceable primary reference barometer.
	Reference method (2.8.1.1 & 4.3.1.2)	<ul style="list-style-type: none"> <li>• Barometer built-in to reference DO sensor, or</li> <li>• Independent, portable barometer.</li> </ul>
	Reference barometer accuracy (2.8.1.1)	Manufacturer's stated accuracy of $\pm 2$ hPa or better.
	Reference barometer validation method (5.3.3.2)	One-point check against primary reference.
	Salinity	Required for DO concentration, if salinity is greater than 8 ppt or varies.
	Method (2.7.3 & 7.2.4.3)	<ul style="list-style-type: none"> <li>• Salinity sensor</li> <li>• Calculated from combined conductivity and water temperature sensors, or</li> <li>• Correction factor.</li> </ul>
	Units (7.2.4.3)	<ul style="list-style-type: none"> <li>• Salinity: parts per thousand (ppt)</li> <li>• Conductivity: mS/m at 25°C</li> </ul>
	Minimum resolution (7.2.4.3)	<ul style="list-style-type: none"> <li>• Salinity: 0.2 ppt</li> <li>• Conductivity: 1 mS/m</li> </ul>
	Sensor accuracy (reference and in situ) (2.8.1.1 & 7.2.4.3)	Manufacturer's stated accuracy of: <ul style="list-style-type: none"> <li>• Salinity: <math>\pm 0.5</math> ppt or better.</li> <li>• Conductivity: <math>\pm 5</math> mS/m (or <math>\pm 0.5\%</math> for full scale error), or better.</li> </ul>
	Sensor calibration method (4.3.3.2)	Set to value of standard solution for estuarine (1,288 mS/m) or open coastal (5,300 mS/m) waters as applicable.

Supplementary measurements (cont.)	Primary reference method (4.2)	Standard conductivity solution(s).
	Reference method (5.3.2.2)	Portable, independent from in-situ sensors: <ul style="list-style-type: none"> <li>• Salinity sensor, or</li> <li>• Combined conductivity and water temperature sensor.</li> </ul>
	Reference sensor validation method (5.3.3.2)	Checked against the standard solution for estuarine (1,288 mS/m) or open coastal (5,300 mS/m) waters as applicable.
Metadata	Site records (1.4, 3.4, 6.3, 7.2.4 & 10.1.2)	<ul style="list-style-type: none"> <li>• All stations shall have a unique identifier.</li> <li>• The altitude of the site shall be recorded.</li> <li>• A Station History (or site file) shall be established and maintained.</li> <li>• Remote telemetry station configuration changes shall be controlled and recorded.</li> <li>• All supplementary data shall be identified and described.</li> <li>• 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.</li> <li>• 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.</li> </ul>
	Site visit records (6.3 & 7.2.8)	<ul style="list-style-type: none"> <li>• A record of every site visit shall be made, including routine cleaning and maintenance and verification details.</li> <li>• The records shall be accessible when data are processed and retained indefinitely as original data.</li> </ul>
	Instrument records (2.9, 3.3.2, 4.5, 5.5, 6.2.2 & 6.3)	<ul style="list-style-type: none"> <li>• All specification, configuration, servicing and replacement, calibration and validation records shall be accessible and retained indefinitely.</li> </ul> <p><i>Note: Include timing method used if part of instrument specification.</i></p> <ul style="list-style-type: none"> <li>• Expiry date or typical lifespan of every DO sensor cap or foil shall be documented and their replacement actively managed.</li> <li>• Logger software (documented code and versions) shall be controlled and their history maintained and preserved.</li> </ul>
	Sampling method (7.2.2 & 7.2.7)	Any algorithm used to obtain point samples from a measurement burst shall be described and justified.

Metadata (cont.)	Change of method (8.2)	<p>Every method change shall be:</p> <ul style="list-style-type: none"> <li>• noted in the site visit records at the time,</li> <li>• added to the relevant history, and</li> <li>• summarised in a filed comment (and in a Stationarity Comment if significant change).</li> </ul>
	Processing of data (7.2.4 & 7.7)	<ul style="list-style-type: none"> <li>• Incoming data shall be tracked, and records of quality checks maintained and available.</li> <li>• All supplementary data shall be available.</li> <li>• All changes from raw data shall be documented.</li> <li>• Automated facilities shall be controlled, documented, and regularly evaluated.</li> <li>• Time-series comments shall be timestamped at the start of the applicable record period or gap.</li> </ul>
	Derived values (10.2)	<p>Any derived values shall be:</p> <ul style="list-style-type: none"> <li>• fully traceable back to the sensor or logger output</li> <li>• labelled, and kept separate from measured data, and</li> <li>• summarised in the time-series metadata.</li> </ul>
Quality assurance	Field and office manual (8.1.1 & 8.1.2)	<ul style="list-style-type: none"> <li>• Monitoring agency shall develop SOP(s) or equivalent.</li> <li>• Monitoring personnel shall be conversant with the SOP(s) and competent to perform required tasks.</li> </ul>

# Additional requirements for dissolved oxygen 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 dissolved oxygen (DO) data irrespective of quality:

**Table 3 – Additional requirements for dissolved oxygen data of good quality.**

Site selection	Location (1.3.2 & 3.3.3)	<ul style="list-style-type: none"> <li>• Representative of the target characteristics of the water body or location to be measured.</li> <li>• Not influenced by radiant heat sources and/or obvious heat sinks.</li> </ul> <p><i>Note: In most cases, the above will also require a well-mixed location.</i></p>
Timing of measurements	Maximum recording interval (for continuous data) (7.2.2)	<ul style="list-style-type: none"> <li>• 5 minutes (estuarine).</li> <li>• 15 minutes (rivers, lakes and the open coast).</li> </ul>
	Accuracy (7.2.3.1)	<ul style="list-style-type: none"> <li>• Within <math>\pm 90</math> s of actual NZST, and</li> <li>• Clock drift <math>&lt; \pm 90</math> s over 30 days.</li> </ul>
Instrumentation	External data logger (2.4.2)	Stores the data without compromising the accuracy, resolution, and recording interval also required for QC 600.
	DO sensor cap or foil replacement (6.2.2)	<ul style="list-style-type: none"> <li>• No later than any explicit expiry date</li> <li>• When they appear damaged, and</li> <li>• When validation and/or calibration shows declining sensor performance, attributable to the cap or foil.</li> </ul>
Reference DO sensor	Calibration frequency (4.3.2.1)	<ul style="list-style-type: none"> <li>• At least every 12 months</li> <li>• Immediately after replacing the sensor cap or foil, and</li> <li>• When validation fails.</li> </ul>
	Validation frequency (5.3.2.1)	<ul style="list-style-type: none"> <li>• No more than 48 hr before use to verify in-situ data at site</li> <li>• At the end of the day of use, if not done prior, or</li> <li>• Calibrated on day, before use at site.</li> </ul>
	Validation acceptance criteria (5.3.4.1)	No more than $\pm 0.5\%$ saturation (or $\pm 0.05$ mg/L) from the expected fully saturated DO value.

In-situ DO sensor	Accuracy (2.2.1.1)	<p>Manufacturer's stated accuracy of at least:</p> <ul style="list-style-type: none"> <li>• <math>\pm 3\%</math>, or <math>\pm 3\%</math> of reading, whichever is greater, when measuring DO percent (%) saturation</li> <li>• <math>\pm 0.3</math> mg/L, or <math>\pm 3\%</math> of reading, whichever is greater, when measuring DO concentration</li> <li>• <math>\pm 5\%</math> of reading above 200% saturation or 20 mg/L.</li> </ul>
	Range (2.3.1 & 9.4.3)	<ul style="list-style-type: none"> <li>• Measures the full range of DO values to the accuracy and resolution required for QC 600.</li> <li>• Supersaturated values are within the manufacturer's stated calibrated range.</li> </ul> <p><i>Note: For some sensors, calibrated range is less than measurement range.</i></p>
	Operation (3.3.4 & 6.2)	Sensor and shroud are clean, and not obstructed or buried, or exposed to the air, or damaged or disturbed.
	Calibration frequency (4.4.2.1)	<ul style="list-style-type: none"> <li>• Prior to deployment</li> <li>• Immediately after replacing the sensor cap or foil</li> <li>• When validation fails (unless replaced), and</li> <li>• At least every 12 months.</li> </ul>
	Validation frequency (5.4.2.1)	<ul style="list-style-type: none"> <li>• At site before deploying if measuring DO% Local or deploying at depth (e.g. in lakes)</li> <li>• When verification fails, and</li> <li>• On retrieval at the end of any monitoring period.</li> </ul>
	Validation acceptance criteria (5.3.4.1)	No more than $\pm 0.5\%$ (or $\pm 0.05$ mg/L) from the expected fully saturated DO value.
Verification	Verification tolerance (7.5.5.2)	<ul style="list-style-type: none"> <li>• DO saturation: <math>\pm 3\%</math> saturation + (3% of reference value)</li> <li>• DO concentration: <math>\pm 0.3</math> mg/L + (3% of reference value)</li> <li>• Water temperature: <math>\pm 0.5^\circ\text{C}</math></li> <li>• Salinity (conductivity): <math>\pm 5\%</math> of reference value</li> </ul>
	Frequency (for all continuous data logged at site) (6.2 & 7.5.3)	<p>Logged values for each variable shall be verified:</p> <ul style="list-style-type: none"> <li>• immediately following sensor deployment.</li> <li>• during every verification visit.</li> <li>• before and after sensor cleaning.</li> <li>• prior to sensor replacement or retrieval, and</li> <li>• at least once every 90 days.</li> </ul>

Supplementary measurements	Water temperature	Required for DO concentration.
	Reference sensor validation frequency and acceptance criteria (5.3.2.2 & 5.3.4.2)	<ul style="list-style-type: none"> <li>• Within the last 12 months.</li> <li>• Disagrees by no more than <math>\pm 0.3^{\circ}\text{C}</math> from the mean of the two primary references across all validation points.</li> </ul>
	Barometric pressure	Required for DO% Local.
	Measurement method (7.2.4.2)	Continuous record from any location within 30 km of site, adjusted for altitude difference between locations.
	Reference barometer validation frequency and acceptance criteria (5.3.2.2 & 5.3.4.2)	<ul style="list-style-type: none"> <li>• Within the last 6 months.</li> <li>• Disagrees by no more than <math>\pm 4</math> hPa from the primary reference.</li> </ul>
	Salinity	Required for DO concentration, if salinity is greater than 8 ppt or varies.
	Measurement method (2.7.3 & 7.2.4.3)	<ul style="list-style-type: none"> <li>• Continuous at site record of conductivity and water temperature.</li> <li>• Logged concurrently with DO.</li> </ul>
	Calibration frequency (4.3.2.2 & 4.4.2.2)	<ul style="list-style-type: none"> <li>• Prior to deployment (in-situ conductivity only)</li> <li>• When validation fails (unless replaced), and</li> <li>• At least every 12 months.</li> </ul>
	In-situ conductivity sensor validation frequency and acceptance criteria (5.3.2.2 & 5.3.4.2)	<ul style="list-style-type: none"> <li>• When repeat verification fails (unless replaced).</li> <li>• Conductivity disagrees by no more than <math>\pm 5\%</math> from the value of the standard solution.</li> </ul>
	Reference sensor validation frequency and acceptance criteria (5.3.2.2 & 5.3.4.2)	<ul style="list-style-type: none"> <li>• Within the last 7 days.</li> <li>• Conductivity disagrees by no more than <math>\pm 5\%</math> from the value of the standard solution.</li> </ul>

## 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.

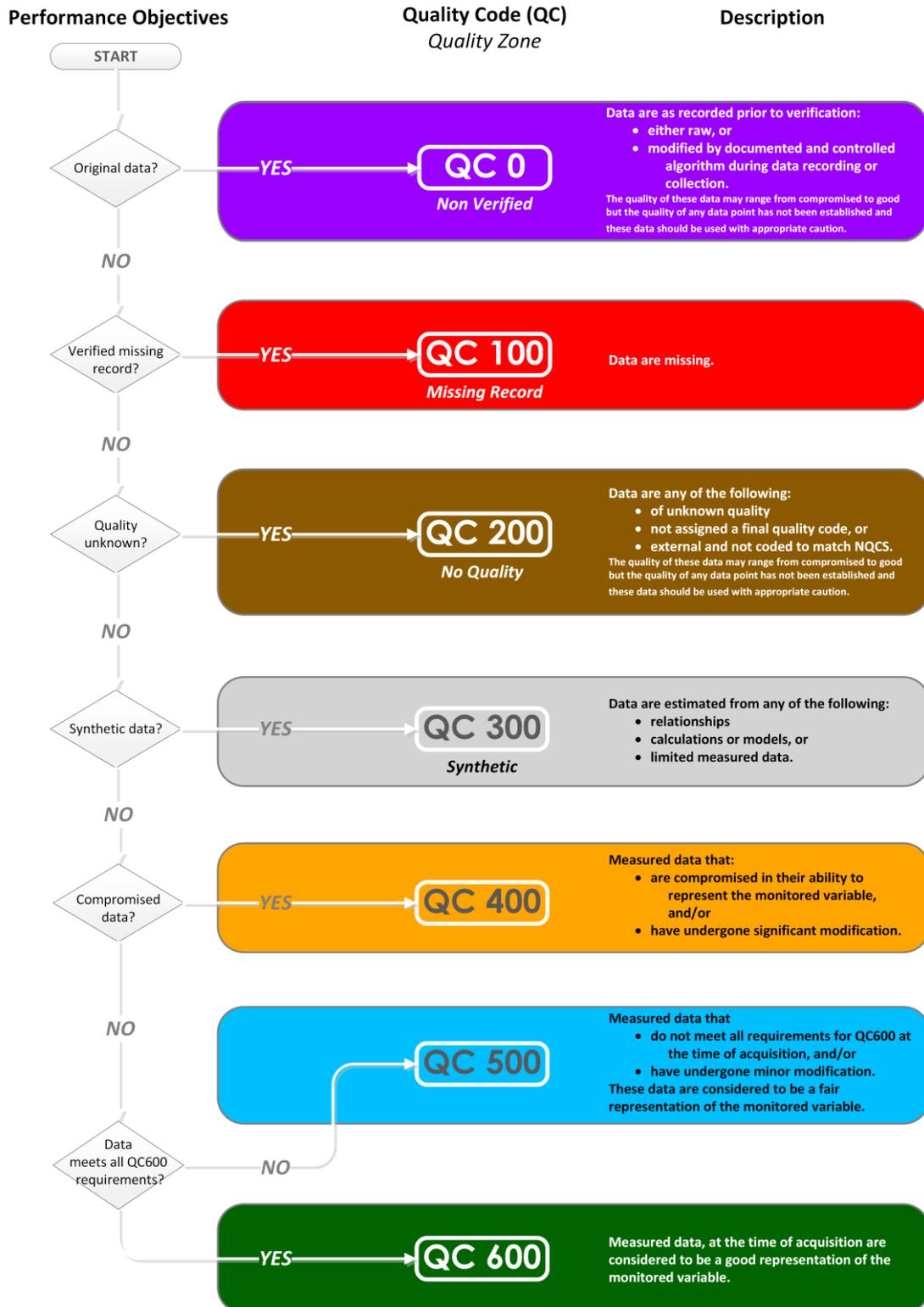
**Table 4 – Other requirements, guidelines, and recommendations**

Risk management	Scope (1.2 & 3.2)	<ul style="list-style-type: none"> <li>• Secure and safe access.</li> <li>• Hazards identified (initial and on-going).</li> <li>• Compliance with regulations as required.</li> </ul>
	Site access and security (1.2.1, 1.3.2, 1.3.3 & 3.1)	<ul style="list-style-type: none"> <li>• Adequate for all equipment and conditions.</li> <li>• Permissions, consents, and engineered design, as required.</li> <li>• Signage and security devices as needed.</li> <li>• Long-term access agreement recommended.</li> </ul>
Site selection	Mixing considerations (1.3.2.1)	Horizontal (rivers) or vertical (lakes and estuaries) cross-section survey recommended.
Calibration	Frequency (4.1 & 4.4.2)	<p>Recommended:</p> <ul style="list-style-type: none"> <li>• Calibrate in-situ sensors on the day of deployment before departing for the site.</li> <li>• May be required to reconfigure an in-situ sensor measuring DO% Local (approx.) using a fixed value of barometric pressure.</li> <li>• Return DO sensors for routine manufacturer re-calibration as and when recommended by the manufacturer.</li> </ul>
Validation	Reference DO sensor (5.3.2.1)	<p>Recommended:</p> <ul style="list-style-type: none"> <li>• On day of and prior to intended use.</li> <li>• When troubleshooting a failed verification.</li> </ul>
	Supplementary sensors (5.4.3.2 & 3.3.1)	Recommended before validating the DO sensor during pre-deployment checks.
	In situ water temperature (5.4.2.2)	Recommended under some circumstances (see <i>NEMS Water Temperature</i> ).
Verification	Frequency (7.5.3)	Recommended at least every 60 days during warmer months (e.g. December to March) or for deployments prone to high biofouling.

	Method (7.5.4 & 7.5.5.2)	<p>Recommended:</p> <ul style="list-style-type: none"> <li>• In still, poorly mixed or saline waters, take side-by-side reference and in-situ sensor measurements in a well-mixed bucket containing the water of interest. <i>Note: Measurements in a bucket are in addition to side-by-side in-situ measurements.</i></li> <li>• Periodically verify an in-situ sensor that regularly records DO values above 100% saturation with a reference sensor that uses a different sensing technique.</li> <li>• Use electronic field forms to calculate verification tolerances that include proportion of reference reading.</li> </ul>
Maintenance	In-situ sensors (2.6.2 & 6.2.1)	<ul style="list-style-type: none"> <li>• Biofouling management plan recommended.</li> <li>• Wiper system recommended to reduce biofouling.</li> </ul>
Supplementary measurements	Reference sensor(s) (2.8.1.1)	Instruments with all sensors built-in to the reference DO sensor are preferred.
	Barometric pressure (7.2.4.2, 7.5.4 & 7.5.5)	<p>Correction to DO% Local using continuous on-site barometric pressure record is preferred.</p> <ul style="list-style-type: none"> <li>• In-situ barometer accuracy of <math>\pm 2</math> hPa or better.</li> <li>• Recorded at same frequency and time as the DO measurements.</li> <li>• Verified using a validated reference barometer.</li> <li>• Verification tolerance: <math>\pm 4</math> hPa</li> </ul>
Complementary measurements	Air temperature (7.2.5)	May assist with infilling of missing data, identifying sensor dewatering, and/or interpretation of DO and water temperature data.
	Water level (1.3.2.1, 1.3.5 & 7.2.5)	Can identify sensor dewatering events and track sensor depth or bed clearance when not reasonably static due to changing water levels.
	Archiving (7.2.5)	<p>If collected, complementary data shall be:</p> <ul style="list-style-type: none"> <li>• identified</li> <li>• available during data processing, and</li> <li>• stored indefinitely.</li> </ul>
Metadata	Instrument history (2.9)	Dedicated instrument database or asset management system recommended.

Stationarity	Change of sensor location or method (8.2)	<p>Recommended to co-locate new sensor type with existing for a period of overlap that captures typical range of measurement.</p> <p>Create a new site if:</p> <ul style="list-style-type: none"> <li>• Change of location alters site factors (e.g. range or characteristics), or</li> <li>• Analysis of co-located data identifies significant difference following the change of sensor technology.</li> </ul>
Quality assurance	Telemetered sites (7.7)	<p>Recommended:</p> <ul style="list-style-type: none"> <li>• Daily check of data collection, at-site power status, and sensor function.</li> <li>• Use logs and alerts to help maintain data integrity.</li> </ul>
	Station inspection (8.1.3)	<p>Visual inspection of structures and all on-site equipment recommended at least once every 12 months at long-term or permanent stations.</p>
	Field site audit (8.1.4)	<p>Independent check of deployment and field activities at permanent stations.</p>

# Quality coding of dissolved oxygen 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 dissolved oxygen 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.

Dissolved oxygen 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 Selection

## In this section

This section covers the factors to consider when selecting a deployment site for continuous dissolved oxygen (DO) 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, 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 monitoring site within a river reach, lake or coastal embayment:

- 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.

## 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 water levels and flow conditions that may be encountered.

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

Dissolved oxygen is commonly measured at continuous intervals to understand diurnal variation, and interactions with other variables (e.g. temperature) and processes (e.g. ecosystem metabolism). It may also be measured for long-term temporal trends. The National Policy Statement for Freshwater Management 2020 has ecosystem health attributes for rivers based on continuous monitoring of DO, including downstream of point source discharges. Dissolved oxygen is also commonly monitored as part of lake and coastal buoy water quality deployments.

It is important to identify the target characteristics of the water body to be measured 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)
- representative of the location being monitored, and
- 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. in lakes).

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).

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

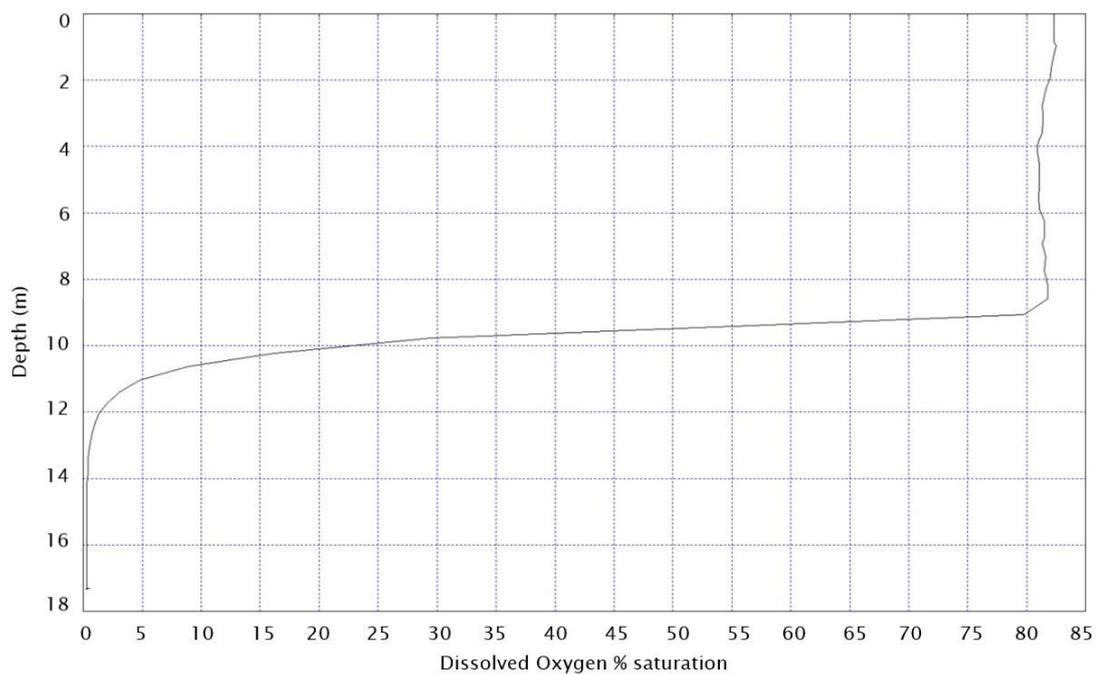
Horizontal and/or vertical mixing may need to be characterised by in-situ discrete measurements of DO to determine the most representative measurement point. Measurement profiles are usually not required for sites that are well-mixed.

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 (Figure 1). A multi-variable sonde or meter that also measures water temperature and conductivity is useful as variability in either could indicate sources of thermal variation.

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



**Figure 1 – Example of a DO% saturation depth profile from a lake showing stratification.**

Source: Horizons Regional Council

### 1.3.3 Access and legal requirements

Consider the following, in addition to section 1.2.1:

- accessibility of the site, including parking or boat access, and during extreme conditions or events (e.g. floods, high winds)
- resource consents or other permits required before deployment can begin (e.g. for a mooring), and
- 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 DO 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 DO 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 DO sensor may be exposed.

*Note: In rivers, a good flow recording site is not usually an ideal water quality site and vice versa because continuous measurement of flow via water level as a surrogate requires discharge and velocity to be as uniform and steady as possible, while water quality monitoring usually requires more turbulent flow to ensure good mixing. However, it may be possible to install in close enough proximity to share some of the existing infrastructure.*

If a new site is needed, consider the following, in addition to sections 1.2.1 and 1.3.1 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.

### 1.3.6 Other considerations

The following shall be considered for lakes and coastal waters:

- the depth of measurement with respect to possible stratification (see Figure 1), and
- the influence of any saltwater-freshwater interface.

### 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
- altitude of the site
- 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 supplementary and/or complementary data, and
- relevant water abstraction and/or discharge data.

## 2 Method and Equipment Selection

In this section

This section contains information about the methods and equipment for continuous measurement and recording of dissolved oxygen (DO). It also includes information on reference methods.

### 2.1 Method principles

Continuous DO measurements are made through deployment of an in-situ DO 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).

Solubility of oxygen in water is affected by the temperature and salinity of the water and by barometric (i.e. atmospheric) and hydrostatic pressures. These interferences, their effects, and consequent requirements, are discussed further in section 2.7.

*Note: Hydrostatic pressure is usually ignored but may contribute to supersaturation below the thermocline in deep deployments.*

Dissolved oxygen may be measured as a percentage of saturation or as a concentration. Saturation values may be referenced to standard or local barometric pressure (see section 2.7.2). Several forms of DO measurement are therefore possible, often from the same instrument. Correct identification of the form of DO measurement is essential to calibration and validation of DO sensors (see sections 4 and 5), and verification and interpretation of a record of DO (see section 7).

### 2.2 Sensors

There are two main groups of DO sensors: electrochemical and optical (optodes). Electrochemical sensors measure DO concentration based on electrical current produced and can be further divided into two types (galvanic and polarographic). Optical sensors measure luminescence (which is affected by oxygen).

*Note: Electrochemical sensors are also known as amperometric or Clark-type sensors. Optical DO sensors are also known as luminescent DO sensors (LDO), but some are called fluorescent sensors.*

This Standard requires the use of optical sensors for continuous DO monitoring. Optical DO sensors are superior to electrochemical DO sensors for continuous monitoring because they:

- do not consume oxygen during measurement and therefore do not require water movement past the sensor
- have good precision and accuracy, including at low DO concentrations (e.g. <2 mg/L)
- are relatively stable, maintaining calibration over long periods (if kept clean), and
- are simpler to clean and maintain, which is important for long-term deployments.

*Note: Previous versions of this Standard did not preclude the use of electrochemical sensors but did recommend optical sensors for most deployments. The reader is referred to the previous version of this Standard for more information on electrochemical sensors.*

Optical sensor technology, software and apps, and measurement and configuration options are evolving rapidly with a broad range of capability available. Most manufacturers provide comprehensive documentation and training material for their products and research beyond the content of this Standard is strongly recommended before making a choice of instrumentation.

## 2.2.1 Principles of operation

McKergow (2025) provide a detailed description of optical DO sensors and their principles of operation. An optical DO sensor usually consists of:

- a light source, typically a LED
- a luminescent dye suspended in a matrix, typically in a replaceable and/or serviceable foil or cap
- a permeable membrane which lets oxygen interact with the dye, and
- a photo detector to measure the response.

Optical DO sensor technology is based on the principle that DO quenches (reduces) the luminescence associated with chemical dyes in the sensor. Oxygen affects both the intensity and the lifetime of the luminescence, so optical sensors can use either an intensity-based or a lifetime-based method to measure DO. Lifetime-based methods measure degradation (decay) of the dye in the sensor which has less effect on DO measurement than the intensity method. This makes lifetime sensors more stable in the long-term (i.e. calibration is required less frequently).

In the absence of any oxygen, the lifetime and intensity of the signal are at their maximum. As oxygen is introduced to the sensing element, such as when the sensor is

immersed in a river, both the lifetime and intensity of the luminescence become shorter. Therefore, the lifetime and intensity of the luminescence are inversely proportional to the amount of oxygen present, as described by the Stern-Volmer equation (see McKergow (2025) for details).

*Note: The Stern-Volmer equation implies an inverse linear relationship which is not strictly true, especially at higher oxygen concentrations. Some sensors have a built-in algorithm to correct for non-linearity.*

Optical sensors measure the pressure of oxygen dissolved in a water body or sample and therefore directly determine DO percent saturation (%). Raw values from the sensor may be concentrations (mg/L or ppm) if calculated by the instrument from DO%, water temperature, and salinity (see Section 7 and Annex D).

*Note: In some oceanographic monitoring, DO may also be reported in micromoles, where 1 micromole of oxygen is equal to 0.022391 milligrams.*

The oxygen-sensitive luminophore matrix in the foil or cap of an optical sensor degrades over time. Foil or cap life is specific to sensor make and model and is heavily dependent on the environmental conditions to which it is exposed. Manufacturers may recommend a typical lifetime or state an explicit expiry date. Replacing the cap or foil as needed is a necessary part of maintaining the DO sensor (see section 6.2.2).

#### 2.2.1.1 Accuracy and range

The manufacturer's stated accuracy of an optical DO sensor may vary over its operating (measurement) range and is typically poorest in the supersaturated range (i.e. >100% saturation). At many sites, DO measurements will extend above 100% saturation. Ensure the sensor selected can meet the desired accuracy over the full range of expected DO values.

Some manufacturers specify both a calibrated range and a measurement range for DO sensors. The measurement range typically extends further into the supersaturated range than the calibrated range. Where only a measurement range is given, a sensor is assumed to be calibrated over that range.

Under this Standard, a reference DO sensor shall have a manufacturer's stated accuracy of at least:

- $\pm 3\%$  saturation for measurements between 0 and 200% saturation, or
- $\pm 0.3$  mg/L for measurements between 0 and 20 mg/L, if accuracy is stated only as a concentration, and
- $\pm 5\%$  of reading above 200% saturation or 20 mg/L.

*Note: DO sensors with accuracies of  $\pm 1\%$  saturation or  $\pm 0.1$  mg/L in the 0 to 200% range are readily available.*

Eligibility for QC 600 requires the in-situ DO sensor to have a manufacturer's stated accuracy of at least:

- $\pm 3\%$  saturation, or  $\pm 3\%$  of reading, whichever is greater, or
- $\pm 0.3$  mg/L, or  $\pm 3\%$  of reading, whichever is greater, if accuracy is stated only as a concentration, and
- $\pm 5\%$  of reading above 200% saturation or 20 mg/L.

*Note: In situ DO sensors may therefore be less accurate than reference DO sensors in the measurement range between 100% and 200% saturation.*

Lesser accuracy is acceptable for lower quality codes. QC 500 requires an in-situ sensor with manufacturer's stated accuracy of at least:

- $\pm 3\%$  saturation, or  $\pm 5\%$  of reading, whichever is greater, or
- $\pm 0.3$  mg/L, or  $\pm 5\%$  of reading, whichever is greater, if accuracy is stated only as a concentration.

QC 400 requires an in-situ sensor with manufacturer's stated accuracy of at least:

- $\pm 3\%$  saturation, or  $\pm 7\%$  of reading, whichever is greater, or
- $\pm 0.3$  mg/L, or  $\pm 7\%$  of reading, whichever is greater, if accuracy is stated only as a concentration.

*Note: QC 400 accuracy may be adequate for a backup sensor at an important long-term site, or for sensors deployed in addition to a high accuracy instrument to provide data on spatial variations in DO.*

In-situ sensors with a stated accuracy outside of the QC400 specification are not acceptable for continuous DO monitoring under this Standard.

#### 2.2.1.2 Resolution

For both reference and in-situ DO sensors, the minimum measurement resolution shall be:

- 0.1% saturation, and
- 0.01 mg/L.

#### 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 DO sensor, and
- do not reduce the accuracy, resolution, or range of measured values of DO, or any required supplementary variables, below their respective minimum requirements when the measured values are stored.

#### 2.2.1.4 Other considerations

Dissolved oxygen sensors are prone to biofouling. This can be minimised by a combination of sensor accessories (see section 2.6) and routine maintenance (see section 6.2).

## 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 Measurement range

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

*Note: In most monitored natural waters, the DO range will typically be between 0 and ~150% saturation or 0 and ~15 mg/L but DO values above 150% saturation and 15 mg/L will occur in some waters.*

### 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 DO 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 DO 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. Where AC (mains) power is not practically available, direct current (e.g. from 12-volt batteries and/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. a sudden drop in DO to levels that may stress 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. water temperature, salinity)
- 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)
- ability to apply compensations (e.g. barometric) prior to data collection
- 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 DO and has been deliberately omitted.

## 2.6 Ancillary equipment

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

- a wiper system (to reduce biofouling)  
*Note 1: Wipers may reduce the lifespan of some sensor caps or foils.*  
*Note 2: A compressed air cleaning system is unsuitable near any DO sensor.*
- a radiation shield (to minimise radiant heating/cooling of a supplementary water temperature sensor)
- 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).

### 2.6.1 Pumps

Flow-through installations usually require a pump to extract then move the water continuously or as a slug past the sensors. This Standard does not recommend pumped flow-through systems for DO monitoring of surface waters because of the possibility of cavitation, temperature variations, and organic matter accumulating in the pipework. Pumps and pipe work will quite often increase the temperature of the water being measured.

If a pump is used, careful consideration should be given to minimising the above issues, in addition to ensuring the pump has sufficient capacity, power supply, protection, and maintenance to ensure reliable continual operation.

### 2.6.2 Wiper systems

A wiper system is a recommended addition to a DO sensor deployed in situ to reduce the degree of biofouling that occurs and therefore the amount of sensor maintenance required. Some sensors come with a built-in wiper, or an optional wiper can be purchased separately (Figure 2). Some DO instruments also incorporate specific materials (e.g. copper rings) to help reduce biofouling of the sensor face.



**Figure 2 – Examples of anti-fouling devices to reduce DO sensor cleaning and maintenance, and adjustment of collected data for fouling-related sensor drift.** Left: A brush wiper attached to a YSI EXO sonde (Image © YSI). Right: A mechanical shutter for a Zebra-Tech D-Opto sensor; the shutter only opens when a measurement is required, protecting the optical sensing window from biofouling, sediment build up and physical damage (Image © Zebra-Tech Ltd).

See McKergow (2025) for more detailed advice on equipment to reduce biofouling.

## 2.7 Interferences

Dissolved oxygen measurements are affected by water temperature, barometric (atmospheric) pressure and salinity. Therefore, water temperature, barometric pressure and, in brackish or coastal waters, salinity are supplementary measurements for DO monitoring. Specifications for these measurements are set out in section 7.2.4.

### 2.7.1 Water temperature

Water temperature has the greatest effect on DO values. It affects DO measurements in two ways, by:

- altering the rate of oxygen diffusion through the sensing element (i.e. the permeability of the sensing element); rates increase with increasing water temperature, and
- influencing the ability of water to dissolve oxygen (i.e. the solubility of oxygen); warmer water cannot dissolve as much oxygen as colder water.

Optical DO sensors may incorporate a thermistor to compensate for changes in the sensing element permeability, but this should not be confused with measuring water temperature to compensate for changes in the solubility of oxygen.

Some instruments may include two thermistors (or other type of temperature sensor) and have built-in software that compensates for both temperature-related effects during measurement. Others must be operated in conjunction with a separate but integrated water temperature sensor (e.g. on a multi-variable sonde) to allow the influence of water temperature on solubility of oxygen to be factored into the conversion of the sensor signal to a mg/L DO concentration.

### 2.7.2 Barometric pressure

Barometric pressure affects the pressure of oxygen in water. At sea level, the standard barometric pressure is 1013.25 hectopascals (or 101.325 kPa) and the pressure of oxygen is 21.3 kPa. However, because barometric pressure decreases with altitude, so too does the pressure of oxygen.

*For example: A sensor measuring 100% saturation when placed in fully saturated water with a temperature of 20°C at sea level will read less than 100% in fully saturated water at the same temperature at higher altitude, decreasing by about 1% saturation for every 100 m increase in altitude above sea level.*

Local weather, as well as altitude, influences local barometric pressure and therefore affects DO measurements.

*Note: Weather system barometric pressures are normally within the range of 970 to 1050 hectopascals, corresponding to a DO saturation variation of  $\pm 4\%$  (i.e. from 96% to 104% of the value at the standard atmospheric pressure of 1013.25 hectopascals).*

It is possible to remove the effect of barometric pressure variations by referencing DO saturation measurements to the local barometric pressure rather than the pressure at sea level (see section 2.8).

*Note: Barometric pressures used in DO monitoring are 'station' barometric pressures, i.e. not corrected to mean sea level as is used in weather forecasts and meteorological surface pressure maps.*

### 2.7.3 Salinity

As the salinity of water increases, its ability to dissolve oxygen decreases. At a salinity of 8 parts per thousand (ppt), DO concentrations are 5% to 6% lower than in freshwater at 5°C to 20°C. Therefore, because the concentration of DO in water varies with salinity, salinity, along with water temperature, must be factored into the calculation of mg/L DO concentration.

*Note: DO saturation is not affected by salinity.*

A DO sensor used in combination with a conductivity sensor enables compensation for the effects of salinity. The conductivity sensor includes the required water temperature sensor (because conductivity also varies with water temperature).

Some multi-variable instruments (e.g. handhelds and some sondes) can report salinity directly from on-board calculations using the conductivity and water temperature measurements. Some instruments may provide automatic on-board compensation of the DO concentrations. Others may only permit the conductivity and water temperature to be logged, with calculation of salinity values and compensation of every DO measurement needing to be performed after data collection (e.g. on export from the proprietary sensor software, or on the data logger, or within the data collection system, or during data processing). In some cases, the only compensation option provided is for the user to manually enter a correction factor.

It is a requirement of this Standard, when monitoring estuarine and coastal waters where salinity is  $> 8$  ppt or varies with tidal range, to compensate DO concentrations for salinity. It is a QC 600 requirement that compensation be achieved using a continuous record of in-situ conductivity and water temperature collected alongside DO.

Compensation using a correction factor is acceptable for open coastal waters, but the DO concentration data obtained cannot be assigned a quality code higher than QC 500.

*Note: Salinity of seawater is reasonably constant. Estuarine and harbour waters are likely to have variable amounts of fresh and saltwater depending on the tide and salinity will depend on river flow, state of the tide, and sensor location.*

## 2.7.4 Other

It is essential to ensure that there is good water circulation around the sensor to reduce any physical interference that may arise from placement inside protective housing or attachment to a deployment structure (see section 3.3.4).

Unlike some other water quality sensors, the performance of optical DO sensors is not likely to be affected by the chemical characteristics of the water body being monitored.

## 2.8 Reference method(s)

There are two accepted ways of accounting for the effects of barometric pressure on DO% saturation:

- reference each DO% saturation measurement to local (i.e. at site) barometric pressure at the time of the measurement, known as DO% Local (or corrected DO%), or
- reference all measurements of DO% saturation to standard barometric pressure at sea level, known as DO% Ref. (or raw or uncorrected DO%).

Most handheld DO sensors used for discrete monitoring have a built-in barometer and can therefore provide a choice of uncorrected or corrected DO% (i.e. DO% Ref or DO% Local).

- When DO% Ref. is selected, saturation measurements are referenced to standard barometric pressure at sea level and if barometric pressure at the time and place of DO measurement is different, that difference is reflected in the saturation reading (as per the example in section 2.7.2).
- When DO% Local is selected, the sensor automatically adjusts the saturation reading to use the current barometric pressure at the sensor's current location as its reference, thus removing the effect of the local barometric pressure from the saturation value (i.e. in fully saturated water at equilibrium with air, the sensor will read 100% saturation regardless of the barometric pressure).

In contrast, few DO sensors used for in-situ monitoring have a built-in barometer.

*Note: Barometers must be open to atmosphere so they do not work if completely sealed and submerged.*

Without a barometer, the in-situ sensor can only measure uncorrected DO% (DO% Ref.) and to obtain DO% Local, independent simultaneous barometric pressure readings must be obtained and the conversion performed by manual calculation at-site and/or during data processing (see section 7.2.7 and Annex D).

Check the manufacturer's specifications carefully. Some newer in-situ sensors (e.g. YSI EXO sondes) allow for altitude, or a representative local barometric pressure, to be entered into their configuration to enable partial on-board compensation for local

barometric pressure and may call this DO% Local. However, it is only an approximation to true DO% Local because:

- altitude is not the sole influence on local barometric pressure, and
- local barometric pressure is not static.

*Note: Differences also exist between sensor makes and models as to when and how altitude or representative local barometric pressure held in the DO sensor configuration is updated. Some sensors update automatically when a sensor calibration is accepted.*

The choice of barometric pressure reference means that four forms of DO% saturation measurement are possible (DO% Ref., DO% Local and the two approximated or 'pseudo' forms of DO% Local described above). Which measurement form is being collected must be clearly understood and identified at each stage of data acquisition.

Under this Standard, DO% Local measurements corrected only for altitude or using a fixed value representative of local barometric pressure cannot achieve higher than QC 500 (see section 9.4.3).

DO concentration is directly obtainable from DO% Ref. using standard tables or calculation. Simultaneous water temperature must also be available, and simultaneous salinity where salinity is >8 ppt or varies with time. Unless DO% Ref. is also recorded, DO% Local must be converted back to DO% Ref. (using the known values of local barometric pressure applied to obtain DO% Local) before the saturation measurements can be converted to DO concentrations.

## 2.8.1 Reference instruments

Under this Standard, a calibrated, independent and portable optical DO sensor shall be used as the reference method to verify the performance of the in-situ DO sensor. As such, the reference sensor's measurements shall also be regarded as the primary reference.

Required accuracy and resolution of a reference DO sensor are stated in sections 2.2.1.1 and 2.2.1.2.

*Note: The Winkler Titration is the traditional reference method for the determination of DO in water. While this iodometric method is highly accurate, it is time consuming and best performed in a laboratory or other controlled conditions. It also cannot be used in waters with a DO saturation greater than 100%. Therefore, titration is not recommended as a reference method.*

### 2.8.1.1 Supplementary measurements

Portable, and suitably calibrated and validated reference sensors (see sections 4.3 and 5.3) that are independent of the in-situ sensors shall be available at each verification visit for every supplementary variable measured on site (see section 7.5.4.1).

For supplementary reference sensors, minimum required accuracy, as stated by their manufacturer shall be:

- Water temperature:  $\pm 0.5^{\circ}\text{C}$
- Barometric pressure:  $\pm 2$  hPa
- Salinity:  $\pm 0.5$  ppt
- Conductivity:  $\pm 5$  mS/m (or  $\pm 5\%$  for full scale error)

Units and minimum required resolution for supplementary reference measurements shall be as for in-situ measurement of the relevant variable (see section 7.2.4).

For convenience, the reference DO sensor will usually be a handheld instrument that, along with temperature, also incorporates a built-in barometer and, for use in saline environments, a conductivity sensor. However, any combination of multi-variable or single sensor instruments is acceptable.

## 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 requirements for an in-situ dissolved oxygen (DO) 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 DO instrument is to be added to an existing station
- the type of DO instrument selected (see section 2.2)
- the type of installation (pumped flow-through or fixed in situ)
- 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 a DO sensor to an existing water quality station, suitable structures, monitoring platform, and communications will likely already exist, but the monitoring platform may require expansion to accommodate another sensor, and/or additional power supply may be needed.

If adding DO (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 DO 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 DO 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.

### 3.3.1 Pre-deployment check

Prior to every deployment:

- Verify the accuracy of the temperature sensor built into or integrated with the in-situ DO sensor, using a validated reference temperature sensor or reference thermometer. Verification tolerance is  $\pm 0.5^{\circ}\text{C}$  (see section 7.5.5.2).
- Calibrate the in-situ conductivity sensor, if fitted (see section 4.4).

*Note: The temperature sensor will typically be combined with the conductivity sensor rather than the DO sensor in this case.*

- If the above tasks are successful, proceed to calibrate the in-situ DO sensor (see section 4.4).

- Verify the accuracy of any barometer to be installed at site, using a validated reference barometer. Verification tolerance is  $\pm 4$  hPa (see section 7.5.5.2).

It is also important to check:

- the expiry date of the sensor cap or foils
- there is sufficient internal battery life remaining, where applicable, in the DO 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
  - the desired form(s) of DO measurement, i.e. percent saturation as DO% Local and/or DO% Ref., and/or mg/L DO concentration (see sections 2.7 and 7.2.1)
  - the required supplementary measurements (dependant on the form(s) of DO measurement and site location) (see sections 2.7. and 7.2.7), 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:
  - compensate for interferences (water temperature, barometric pressure, and/or salinity), if not done automatically by the DO instrument, and
  - 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 Data loggers

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 DO sensors or loggers (e.g. Onset HOB0® DO logger) can be attached to the downstream side of a waratah driven into the bed. A waratah can also be suitable for deployments in shallow lakes and estuaries. Ensure that the placement of the waratah 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 3). 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 DO measurements being influenced by interflow through the bed. For this reason, these installations are only suitable for self-contained instruments deployed for short periods of time (e.g. a few weeks or months during summer).*



**Figure 3 – Left: A bent piece of steel rebar. Right: Example of a sensor deployed for a short period of monitoring during low river flows.**

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

For longer-term deployments and in larger rivers, bridge-based (Figure 4) or bankside (Figures 5 and 6) 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.



**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 5 – 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 6 – A multi-sensor fixed in-situ installation.**

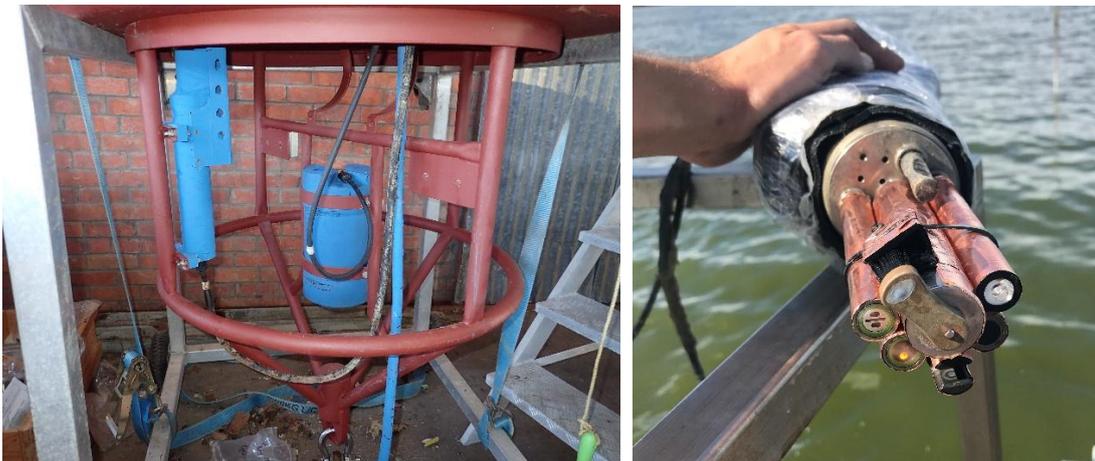
Photo: Horizons Regional Council

Mooring buoys or platforms are often used for deployment of DO (and other) sensors in lakes and coastal areas, particularly offshore applications (Figure 7). Specialist advice is needed for design and installation, including buoyancy requirements, mooring system type (e.g. surface, subsurface or stationary structure), mooring length, mooring material (e.g. synthetic rope, wire rope or chain) and mooring anchor (Figure 8).



**Figure 7 – Left – a lake water quality monitoring buoy installed on Lake Tūtira. The station includes a meteorological station and depth sensor. Right – schematic of monitoring buoy in open coastal waters off Hawke Bay held in place on the seafloor by a weighted chain (see Figure 7).**

Photo and schematic: Hawke’s Bay Regional Council





**Figure 8 – Example components of a coastal monitoring buoy and sensor installation.**

**Top left:** The cradle beneath a coastal buoy, ADCP and surface instrument (0.5 m). At the base of the cradle is the mooring cable, which doubles as the deployment and communication cable for instruments deployed at depths of 5 m and 15 m, reducing the need for a separate mooring line.

**Top right:** Copper wrapped around the sensors of the water quality sonde to reduce sensor biofouling. Cling film also wrapped around the sonde's body for easy removal of algae during maintenance visits.

**Bottom:** Concrete anchor weight used with a micro coastal buoy.

Photos: 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).

## 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 DO 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 and altitude
- 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 supplementary and/or 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 DO 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 of reference and in-situ DO and supplementary sensors.

### 4.1 Purpose

Calibration is carried out to ensure that an instrument reads the correct value. In contrast with validation, which involves only a check of an instrument's calibration (see section 5), calibration involves an adjustment to the instrument's settings.

Manufacturers do not routinely provide calibration certificates with DO sensors, and it is the monitoring agency that will carry out DO sensor calibration. However, some manufacturers recommend that DO sensors are only validated by the user and instead are returned to them if calibration is required (e.g. PME recommend its MiniDOT DO sensors are returned for annual recalibration).

Calibration requirements apply not only to deployed instruments, but also to those about to be used from storage, because the length of storage may be beyond the recommended calibration interval.

### 4.2 Primary reference(s)

Any suitable reference instrument (see section 4.3) may be used as the primary reference for the verification of continuous in-situ DO and supplementary data (see section 7.5). There is no requirement to use the same reference sensor at each verification visit.

Primary references for the calibration and/or validation of reference sensors for the supplementary variables shall be as follows:

- A certified traceable reference thermometer for water temperature (see *NEMS Water Temperature*).
- Standard solutions (see section 4.3.3.2) for conductivity and/or salinity.
- A traceable primary reference barometer, which may be one of:
  - a calibrated Fortin or Kew barometer as is required when monitoring air quality under *NEMS Air Quality Continuous Particulate Monitoring*, or
  - a certified NIST-traceable digital barometer, housed in a laboratory or other secure indoor environment, and checked at least once every 12 months against a close-by official meteorological station.

## 4.3 Reference instruments

Any calibrated independent and portable optical DO sensor shall be used as a reference instrument (see section 2.8.1). For convenience, this will usually be a handheld instrument that can also measure the relevant supplementary variables.

### 4.3.1 Factors to consider

The cap or foil on an optical DO sensor has a finite operational lifespan and may have an explicit expiry date (see section 2.2.1), with periodic replacement required (see section 6.2.2).

It is only practicable to user-calibrate optical sensors directly for DO saturation at zero and fully saturated at equilibrium (nominally 100% saturation (see section 4.3.3.1)). Linearity within this range and calibration into the supersaturated range are unable to be checked. Once established by the manufacturer's algorithm they are assumed stable provided calibration at zero and 100% saturation is maintained.

If calibrating as DO% Local, the local barometric pressure at the time is the reference for the saturation measurement (see section 2.8). If this barometric pressure is then incorporated into the sensor configuration as 'representative' of future barometric pressures to facilitate continuous measurement of (approximated) DO% Local it is important to avoid calibrating during extreme weather (e.g. a thunderstorm).

For accurate calibration (and validation) the sensor and all calibration equipment must be scrupulously clean, including the sensor shroud or casing when it is used as the calibration chamber. Ability to ensure the sensor and shroud, and other calibration equipment, are clean must be considered when deciding to calibrate (or validate) in the field.

Sensors measuring the supplementary variables also require calibration and/or validation.

#### 4.3.1.1 Water Temperature

All modern handheld optical DO sensors include a temperature sensor and will automatically compensate for the effects of water temperature on DO saturation (and/or DO concentrations) during DO sensor calibration.

If a temperature sensor is not built-in to the reference DO sensor but is integrated into the instrument (e.g. a multi-variable sonde) the manufacturer's calibration software will usually, when needed, account for the effects of water temperature during DO sensor calibration as if the temperature sensor were built in.

#### 4.3.1.2 Barometric pressure

Most handheld DO sensors include a built-in barometer.

If the reference DO sensor does not have a built-in barometer, a pocket digital handheld barometer can be used to record barometric pressure during DO sensor calibration. The

corresponding DO% calibration value can be determined from a look up table such as that provided in Annex C, or calculated (see Annex D).

Altitude shall also be recorded when calibrating a DO sensor.

#### 4.3.1.3 Salinity

The manufacturer's user manual will explain how to account for salinity when calibrating a reference DO sensor. Salinity is easier to account for if using a multi-variable instrument that includes a conductivity sensor. Alternatively, a separate reference conductivity sensor can be used to measure salinity during DO sensor calibration.

### 4.3.2 When to calibrate

#### 4.3.2.1 Dissolved oxygen

All reference DO sensors shall be calibrated:

- at least every 12 months
- immediately following replacement of the sensor cap or foil, and
- whenever a sensor validation check fails (see section 5.3.4.1).

#### 4.3.2.2 Supplementary variables

##### Water temperature

In accordance with NEMS *Water Temperature*, reference water temperature sensors, whether integrated in a multi-variable instrument or separate, are not user calibrated, but their accuracy does require validation at least annually (see section 5.3.2.2).

##### Barometric pressure

This Standard does not require routine user-calibration of reference barometers. However, the accuracy of reference barometers requires regular validation (see section 5.3.2.2).

##### Salinity

All reference conductivity sensors, whether integrated in a multi-variable instrument or separate, shall be calibrated at least every 12 months, and when validation fails. Validation is required more frequently (see section 5.3.2.2).

### 4.3.3 Calibration methods

#### 4.3.3.1 Dissolved oxygen

Calibration shall be carried out as per the manufacturer's specification for the DO sensor. Unless stated otherwise by the manufacturer, a two-point calibration shall be performed at zero and fully saturated at equilibrium (between water and air) at the frequency specified in section 4.3.2.1. If calibrated more frequently, a one-point calibration at full DO saturation should generally suffice.

The methods below assume that the sensor is being calibrated to DO% Local. On this setting, in fully saturated water at equilibrium with air, the sensor will read 100% saturation regardless of the altitude or barometric pressure at the time and place of calibration (see section 2.7.2 and 2.8). If DO% Ref. is selected, the sensor will only read 100% if calibration is performed at standard barometric pressure at sea level (1013.25 hPa). Annex D provides the equations to determine the correct calibration value for any difference in barometric pressure and/or altitude when calibrating to DO% Ref.

*Note: Although previous versions of this Standard allowed the use of the Winkler titration method for DO sensor calibration, this is no longer recommended (see section 2.8).*

*Note: Some manufacturers do not recommend a zero-point calibration because it requires great care to ensure an entirely oxygen-free test solution. Provided this is achieved, an alternative to calibration is to check (i.e. validate) the sensor is measuring in the vicinity of 0% saturation.*

Reference DO sensors shall be calibrated in a stable environment and, whenever possible, this should be indoors, such as a laboratory, workshop, or office. If calibrating a reference DO sensor in the field, the sensor shall be calibrated in a sheltered location out of the wind and sun (e.g. inside a vehicle).

The following supplementary variables influence DO measurements and therefore shall be measured using validated reference sensors, recorded, and accounted for when calibrating (and validating, see section 5.4.1) a reference DO sensor:

- water temperature
- barometric pressure
- altitude, and
- for brackish or coastal waters, salinity (i.e. where the DO sensor will be used in waters with varying salinity or a salinity of >8 ppt).

Corrections during the calibration shall be resolved according to the equations in Annex D.

*Note: Most DO sensors will store calibration details within the sensor.*

#### Zero-point (0% saturation) calibration

This calibration requires the use of a deoxygenated solution to obtain zero (0%) DO saturation. A zero solution can be made by dissolving approximately 2 g of sodium sulphite ( $\text{Na}_2\text{SO}_3$ ) into 1 L of tap or deionised water. Adding a trace of cobalt chloride to the solution will speed up the reaction. Alternatively, nitrogen gas (or argon) may be used to produce a zero DO test solution.

*Note: It may take up to 60 minutes for the solution to be oxygen free.*

## 100% saturation calibration

Depending on the manufacturer's specification for the DO sensor, this will require calibration using:

- the water-vapour-saturated air method (i.e. air that is saturated with water), or
- the air-saturated water method (i.e. water that is 100% saturated with DO).

The water-vapour-saturated air method is the calibration procedure of choice as it is quicker and may only take a few minutes to perform. However, some optical DO sensors should be calibrated using the air-saturated water method at air temperatures below 5°C. Check the manufacturer's specifications.

### *Water-vapour-saturated air method*

The water-vapour-saturated air method entails:

- placing a clean dry sensor in a vented calibration vessel containing air
- adding a small amount of water or a damp sponge into the calibration vessel, and
- when the reading has stabilised (after the calibration vessel is fully saturated), setting the DO to 100% saturation.

*Note 1: Response times vary with sensors. For example, some sensors (once temperature equilibrium has been achieved) reach 90% of the final value within 60 seconds while others may take up to six minutes.*

*Note 2: The sensor needs to remain in the calibration vessel long enough for the air to be fully saturated. This can take 30 minutes (tip: storing the sensor in the calibration vessel with a damp sponge prior to calibration (e.g. overnight) can speed this process up). Make sure the calibration vessel is not sealed tight; it needs to be open just enough to equilibrate with the outside pressure.*

### *Air-saturated water method*

The air-saturated water method entails:

- saturating water with air at a known temperature
- placing the sensor in the water, and
- when the reading has stabilised, setting the DO to 100% saturation.

Methods for ensuring that water is saturated with air (100%) include:

- using an aquarium pump and aeration stone, or
- pouring a fixed volume of water, e.g. 2 L, from one bucket to another 10 to 20 times.

Note: The APHA 4500-O H standard method recommends placing the sensor in 1.5 L of water at room temperature and bubbling compressed air at a flow rate of 10–40 mL/min for a period of at least 30 minutes.

#### 4.3.3.2 Supplementary variables

Reference conductivity sensors shall be calibrated in a stable environment and, whenever possible, this should be indoors, such as a laboratory, workshop, or office. If calibrating a reference conductivity sensor in the field, the sensor shall be calibrated in a sheltered location out of the wind and sun (e.g. inside a vehicle).

Place reference conductivity sensors in a standard solution of 1,288 mS/m (estuarine waters) or 5,300 mS/m (open coastal waters). After allowing time to stabilise, set the sensor to read the same value as the standard.

*Note: These standard solutions are consistent with those specified in the NEMS Discrete Water Quality: Part 4 (Coastal Waters).*

### 4.4 In-situ sensors

#### 4.4.1 Factors to consider

As per section 4.3.1.

#### 4.4.2 When to calibrate

##### 4.4.2.1 Dissolved oxygen

All in-situ DO sensors shall be calibrated:

- prior to deployment (preferably same day, pre-departure)
- following replacement of the sensor cap or foil
- if validation fails, unless the sensor is replaced (see section 5.4.4), and
- at least every 12 months.

##### 4.4.2.2 Supplementary variables

###### Water Temperature

In situ water temperature sensors are not required to be user calibrated under this Standard.

###### Barometric Pressure

At site (continuous recording) barometers are not required to be user calibrated under this Standard.

###### Salinity

All in-situ conductivity sensors shall be calibrated:

- prior to deployment
- if validation fails, unless the sensor is replaced (see section 5.4.4), and
- at least every 12 months.

### 4.4.3 Calibration method(s)

#### 4.4.3.1 Dissolved oxygen

A two-point calibration shall be performed as per section 4.3.3 at the frequency specified in section 4.4.2. If calibrated more frequently, a one-point calibration in fully saturated water at equilibrium (between water and air), should generally suffice for the extra calibrations.

Any instrument that has failed calibration and is destined for repair or disposal should be clearly labelled as not serviceable.

#### 4.4.3.2 Supplementary variables

As per section 4.3.3.2.

## 4.5 Required records

A record of the calibration history for each reference and in-situ DO and supplementary sensor shall be maintained and accessible. The record shall include:

- name of the person and organisation performing the calibration
- date and time of the calibration
- location and environment (e.g. laboratory, field site)
- calibration method(s) used
- the primary reference used, its calibration date and the agency responsible

*Note: The full calibration history of a primary reference thermometer or barometer is expected to be maintained by the agency responsible for maintaining the instrument.*

- water temperature, barometric pressure, altitude and salinity measurements, and details of associated corrections made to the DO calibration value
- sensor configuration changes if these are updated during calibration or when the new calibration is accepted (e.g. altitude or representative local barometric pressure (see section 2.8))
- reason for the calibration (e.g. routine, cap or foil replacement, pre-deployment, or failed validation), 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 dissolved oxygen (DO) and supplementary sensors.

### 5.1 Purpose

Validation provides a check that a sensor is performing to specification and its 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 reference(s)

As per section 4.2.

### 5.3 Reference instruments

As per section 4.3.

#### 5.3.1 Factors to consider

As per section 4.3.1.

For verification of in-situ recording (see section 7.5) to be meaningful and effective, reference readings must be reliable. Reference sensors are routinely validated to ensure their accuracy and confirm the reliability of their measurements.

#### 5.3.2 When to validate

##### 5.3.2.1 Dissolved oxygen

Reference DO sensors shall be validated:

- no more than 48 hours before being used at site to verify in-situ recording, or
- at least at the end of the day of the site visit, if not done prior.

If performed outside of these timeframes the reference sensor is considered to have not been validated and any reference measurements obtained are deemed unreliable.

Validation prior to departure on the day of intended use is preferred. It can be useful to also validate the reference DO sensor when troubleshooting a failed verification (see section 7.5.5.2).

*Note: A monitoring agency may choose to simply calibrate the reference DO sensor on the day of use (see section 4.3).*

#### 5.3.2.2 Supplementary variables

As a minimum, reference sensors used to take supplementary measurements during validation of the reference DO sensor, and when verifying in-situ recording, shall have passed their most recent validation against a certified or traceable primary reference (see section 4.2) as follows:

- Water Temperature: Within the last 12 months
- Barometric pressure: Within the last 6 months
- Conductivity: Within the last 7 days.

#### 5.3.3 Validation method(s)

Validation shall be undertaken in a stable environment.

Suitable locations for the validation of DO and conductivity sensors are the same as for their calibration (see sections 4.3.3.1 and 4.3.3.2) but it is likely that validation in the field will be undertaken more often.

Validation of temperature sensors and barometers must be done indoors at the same location as the required primary references (which must not be removed from their location).

##### 5.3.3.1 Dissolved oxygen

Perform a 100% DO saturation check as per section 4.3.3.1.

The following supplementary variables shall be measured using a validated reference sensor, and recorded, when validating a reference DO sensor: water temperature, barometric pressure, altitude and, for brackish or coastal waters, salinity. Corrections during the validation shall be resolved according to the equations in Annex D.

##### 5.3.3.2 Supplementary variables

###### Water temperature

Use a water bath to perform at least a five-point temperature check against two traceable primary reference thermometers with current certification. The NEMS *Water Temperature* details how to do this.

###### Barometric pressure

Compare the barometric pressure measurement from the reference barometer with that of a traceable primary reference barometer.

*Note: The above direction is made in the absence of a NEMS for barometric pressure.*

## Salinity

Validate the reference conductivity sensor in a standard solution of 1,288 mS/m (estuarine waters) or 5,300 mS/m (open coastal waters). Allow time for the sensor to stabilise before recording its measurement.

*Note: These requirements are consistent with those specified in the NEMS Discrete Water Quality: Part 4 (Coastal Waters).*

### 5.3.4 Acceptance criteria

#### 5.3.4.1 Dissolved oxygen

The reference DO sensor passes validation if the DO% saturation reading differs by no more than  $\pm 0.5\%$  saturation from the expected fully saturated DO% value, or  $\pm 0.05$  mg/L from the expected fully saturated DO concentration value.

*Note: As per section 4.3.3.1, the expected fully saturated DO% value will only be 100% if the sensor is measuring DO% Local (i.e. correcting for barometric pressure (including altitude) at the current time and place of measurement) or it is measuring DO% Ref. (i.e. uncorrected) and the validation is performed when local barometric pressure at the time is equal to the standard barometric pressure at sea level (1013.25 hPa).*

If validation fails, the reference DO sensor settings shall be adjusted (i.e. calibrated) to read the correct value (see section 4.3.3.1). If the failed validation was carried out at the end of the day the sensor was used, the amount of adjustment applied during the calibration shall be added to the uncertainty of all reference measurements made with the reference DO sensor on the day of use. If the calibration fails, or calibration is not performed, reference measurements made using the failed and uncalibrated reference DO sensor are deemed unreliable and cannot be used for verification of in situ recording.

*Note: Default uncertainty of all reference measurements is the specified accuracy of the reference instrument.*

Annex D provides the calculations to determine the correct validation/calibration value when DO% Ref. is selected.

#### 5.3.4.2 Supplementary variables

##### Water temperature

The reference sensor passes validation if its temperature measurements differ by no more than  $\pm 0.3^\circ\text{C}$  from the mean temperature value of the two traceable reference thermometers across all validation points. If agreement falls outside this range, use a successfully validated replacement. The failed reference sensor should be sent for repair or discarded.

See the NEMS *Water Temperature* for further details.



## Barometric pressure

The reference barometer passes validation if the reference and primary reference barometric pressure measurements differ by no more than  $\pm 4$  hPa. If agreement falls outside this range, use a successfully validated replacement reference barometer. The failed reference barometer should be sent for repair or discarded.

## Salinity

The reference sensor passes validation if its conductivity measurement differs by no more than  $\pm 5\%$  from the value of the standard solution. If agreement falls outside this range, calibrate the conductivity sensor to read the same conductivity value as the standard solution.

*Note: This is consistent with NEMS Discrete Water Quality: Part 4 (Coastal Waters).*

## 5.4 In-situ sensors

### 5.4.1 Factors to consider

See section 4.4.1. Additional considerations include:

- the manufacturer's recommended method of sensor validation
- where the validation will be performed (field, workshop, office or laboratory (preferred))
- ease of recovery and reinstallation or replacement of the in-situ sensor
- whether a freshly calibrated sensor is immediately available to replace the existing sensor (if required)
- where and how to obtain relevant required supplementary measurements, including altitude difference between calibration and field validation locations, and
- how to check the validity of supplementary measurements needed for the DO validation.

### 5.4.2 When to validate

#### 5.4.2.1 Dissolved oxygen

An in-situ DO sensor shall be validated:

- at site before deploying, if measuring DO% Local and/or deploying at depth
- whenever a sensor verification check fails (see section 7.5.5), and
- immediately after retrieval at the end of any monitoring period.

#### 5.4.2.2 Supplementary variables

##### Water temperature

Validation of in-situ water temperature sensors is not required under this Standard. If the sensor has failed repeat verifications (see section 7.5.5.2) it must instead be replaced.

The NEMS *Water Temperature* gives examples of when validating an in-situ sensor is recommended (e.g. prior to deployment of sensors in deep lakes).

##### Barometric pressure

Validation of at site (continuously recording) barometers is not required under this Standard. If the barometer has failed repeat verifications (see section 7.5.5.2) it must instead be replaced.

##### Salinity

An in-situ conductivity sensor shall be validated when repeat verification has failed, unless the sensor was replaced (see section 7.5.5.2).

#### 5.4.3 Validation method(s)

##### 5.4.3.1 Dissolved oxygen

Perform a 100% DO saturation check as per section 4.3.3.1.

The following supplementary variables shall be measured when validating an in-situ sensor: water temperature, barometric pressure, altitude and, for brackish or coastal waters, salinity. Corrections during the validation shall be resolved according to the equations in Annex D.

##### 5.4.3.2 Supplementary variables

###### Water temperature

As per section 5.3.3.2 (if undertaken).

###### Salinity

As per section 5.3.3.2.

#### 5.4.4 Acceptance criteria

##### 5.4.4.1 Dissolved oxygen

Validation tolerances are as per section 5.3.4.1. If validation fails, the in-situ DO sensor shall be calibrated or replaced, unless the monitoring period has ended.

#### 5.4.4.2 Supplementary variables

##### Salinity

Validation tolerance is as per section 5.3.4.2. If validation fails, the in-situ conductivity sensor shall be calibrated or replaced.

## 5.5 Required records

A record of the validation history for each reference and in-situ sensor or instrument 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. at site vs laboratory)
- method and reference sensor(s) used
- the target values for the validation (e.g. the DO% Ref. value at full saturation, or the five pairs of water bath temperature readings from the primary reference thermometers etc.) and the corresponding sensor readings
- sensor configuration changes if these are updated during validation (e.g. altitude or representative local barometric pressure (see section 2.8))
- water temperature, barometric pressure/altitude and salinity measurements, and details of associated corrections made to the DO validation value, and
- outcome (e.g. serviceable, repaired, or for disposal).

## 6 Maintenance

In this section

This section deals with general and routine maintenance for dissolved oxygen (DO) 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 DO 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' DO measurements. This information is needed for data processing.

Maintenance checks to include on a site visit form are provided in Annex E.

DO 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).

### 6.2.1 Biofouling

Sensor biofouling is typically the most common maintenance issue and can occur quickly during the warmer summer months, especially in nutrient-enriched and unshaded waters (Figure 9). If not managed, biofouling may degrade or even ruin much of a DO record.



**Figure 9 – Extensive biofouling of a multi-variable sonde following an approximately four-week deployment in a eutrophic coastal lagoon.** To help limit biofouling around the sensors, the sensors were wrapped in copper foil (see Figure 8, Section 3.3.4) and the standard plastic sonde guard was swapped out for a copper one.

Photo: Hawke’s Bay Regional Council

At sites prone to biofouling, a biofouling management plan is recommended. Use of a mechanical wiper or shutter is generally the best option for managing biofouling and is available for many optical sensors and multi-variable sondes (see section 2.6). Lens biofouling may also be inhibited by specialised factory-applied polymer coatings.

McKergow (2025) provide more detailed guidance on managing biofouling of DO sensors.

## 6.2.2 Sensor cap or foil replacement

The cap or foil on an optical DO sensor degrades over time and requires periodic replacement (see section 2.2.1).

- Performance of all sensor caps or foils shall be monitored, and caps or foils replaced, following the manufacturer's instructions, when they appear damaged, or their performance appears compromised, or otherwise as the manufacturer instructs and/or recommends.

*Note: Declining verification and/or validation agreement and/or failing to calibrate successfully, especially when near or beyond the typical lifetime of the cap or foil, can indicate that replacement is needed.*

- Sensor caps or foils supplied with an explicit expiry date shall be changed prior to the expiry date for the DO measurements collected to be eligible for QC 600.
- Cap or foil expiry dates or typical lifespans shall be documented in the instrument history and be subject to some form of bring-up system so that cap or foil replacement is actively managed.
- After replacement of the cap or foil, recalibration of the DO sensor is required (see section 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 7.2.8)
- 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 dissolved oxygen (DO) 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 DO sensor as possible.

If continuously measuring DO% Local (approx.), depending on the manufacturer's method of auto-compensation for altitude and/or barometric pressure (see section 2.8), recalibration and/or reconfiguration of the in-situ sensor may be required at each visit.

### 7.2 Measurement

#### 7.2.1 Units of measurement

Units of measurement for recorded data shall be:

- % saturation for DO saturation, and
- mg/L for DO concentration.

#### 7.2.2 Timing of measurements

All data shall be recorded in New Zealand Standard Time. To achieve QC 600, DO 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.

Dissolved oxygen 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 DO sensor accuracy and measurement resolution requirements.

#### 7.2.3.1 Time

Time resolution for all logged data, i.e. DO and any continuous record of supplementary variables (see section 7.2.4) 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  $\pm 90$  seconds over 30 days.

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

- QC 500 –  $\pm 90$  s and no more than  $\pm 120$  s over 30 days
- QC 400 – greater than  $\pm 120$  s but no more than  $\pm 180$  s over 30 days
- QC 200 – greater than  $\pm 180$  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 –  $\pm 90$  s and no more than  $\pm 150$  s over 30 days
- QC 400 – greater than  $\pm 150$  s but no more than  $\pm 300$  s over 30 days
- QC 200 – greater than  $\pm 300$  s over 30 days.

### 7.2.4 Supplementary measurements

This Standard requires water temperature, barometric pressure and, in brackish or coastal waters, salinity to be measured as supplementary variables (see section 2.7).

All supplementary measurements shall be:

- identified
- available during data processing
- stored indefinitely, and
- described in the site metadata.

#### 7.2.4.1 Water temperature

Water temperature shall be continuously recorded at the same frequency and time as DO (see section 7.2.3.1).

Consistent with the *NEMS Water Temperature v3.0.0*, the in-situ sensor shall have:

- a manufacturer stated accuracy of  $\pm 0.5^{\circ}\text{C}$  or better, and
- a minimum measurement resolution of  $0.02^{\circ}\text{C}$ .

The units of measurement for recorded water temperature data shall be degrees Celsius ( $^{\circ}\text{C}$ ).

#### 7.2.4.2 Barometric pressure

As a minimum, barometric pressure shall be measured on-site with a reference instrument:

- at the start of an in-situ DO sensor deployment period
- during on-site DO sensor verification (see section 7.5), and
- at the end of the in-situ DO sensor deployment period.

The units of measurement for recorded barometric pressure data shall be hectopascals (hPa). Minimum measurement resolution shall be 0.1 hPa.

To obtain a record of DO% Local, correction for local barometric pressures using a continuous on-site record is preferred:

- using a barometer with an accuracy of at least  $\pm 2$  hPa, and
- at the same frequency and time as DO (see section 7.2.3.1).

*Note: These recommendations are made in the absence of a current NEMS for continuous monitoring of barometric pressure.*

However, to achieve QC 600 under this Standard, it is sufficient for the continuous local barometric pressure data to be recorded offsite provided the data are from within a 30 km radius and are adjusted for the difference in altitude between locations.

A maximum of QC 500 shall apply to continuous DO saturation data approximating DO% Local by correcting for local barometric pressure using:

- an in-situ DO sensor that adjusts measurements on-board for altitude or a fixed 'representative' barometric pressure (see section 2.8)
- adjustment for site altitude, by calculation (see Annex D), or
- an offsite continuous barometric pressure record from a location between 30 and 50 km from the in-situ DO sensor, provided it is adjusted for the difference in altitude between locations. (see section 9.4).

#### 7.2.4.3 Salinity

Where required to be measured (see section 2.7.3), in-situ salinity shall be obtained continuously at the same time and frequency as DO (see section 7.2.2) through continuous measurement of in-situ conductivity and water temperature.

*Note: As per section 2.7.3, most conductivity instruments determine salinity using calculations derived from their conductivity and temperature sensors.*

Consistent with the NEMS *Discrete Water Quality: Part 4 (Coastal Waters)* v3.0.0:

- measurements of conductivity shall be:
  - made using an in-situ sensor with a manufacturer’s stated accuracy of at least  $\pm 5$  mS/m (or  $\pm 0.5\%$  for full scale error)
  - made at a minimum measurement resolution of 1 mS/m, and
  - recorded in units of mS/m at 25°C.
- measurements of salinity shall be:
  - recorded in units of parts per thousand (ppt), and
  - made at a minimum resolution of 0.2 ppt.

### 7.2.5 Complementary measurements

Monitoring water levels at site or close by enables identification of dewatering of the sensors provided the level of the sensors relative to the water level datum is known.

It may be beneficial to record air temperature alongside DO. Just as DO is correlated with water temperature, air and water temperature are correlated. Therefore, monitoring air temperature may be useful in understanding the relationships between these variables at a monitoring site.

Air temperature measurements can also be used in the quality assurance process (e.g. as a quality control measure to help determine whether a DO or 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.*

If collected, water level and air temperature measurements shall be:

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

### 7.2.6 Required calculation(s)

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)
- obtain salinity from conductivity and water temperature measurements (see section 7.2.4.3)
- compensate for barometric pressure and salinity as needed (see section 2.7), and
- convert between the different forms of DO measurement (see sections 2.1, 2.8, and 7.5.5)

Calculations may be performed by the instrument, data logger, data collection system (e.g. telemetry) or during data processing (see section 10.2.2).

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

### 7.2.7 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 (see section 7.2.6)
- to apply compensations (see section 7.2.6), or
- to create useful derived data, e.g. sub-interval averages, medians, and standard deviations.

All on-board processing algorithms included in logger programmes 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).

### 7.2.8 Site visit records (visit metadata)

Records 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 E.

### 7.3 Sample collection

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

### 7.4 Laboratory processing

This section is not relevant to the measurement of continuous DO 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 DO and supplementary measurements.

### 7.5.2 Factors to consider

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

- the nature and resilience of the installation
- the season, e.g. summer weed growth or biofouling
- whether data can be checked remotely, e.g. daily telemetry checks
- elapsed time between site visits
- availability and accuracy of supplementary measurements
- 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 continuous DO monitoring, verification frequency will likely be driven primarily by the nature and extent of sensor biofouling which can impact sensor performance and data quality.

For QC 600 under this Standard, as a minimum, the logged DO 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:

- biofouling of the sensor can occur faster and lead to sensor drift, and
- over this period the potential for oxygen minima stress on aquatic ecosystems is generally greatest (e.g. summer low flows in rivers, stratification in lakes).

#### 7.5.3.1 Supplementary variables

As a minimum, in addition to verifying the DO record, all supplementary variables continuously measured at site shall also be verified while on-site. This should not preclude any additional visits to investigate problems identified or suspected with recording one or more of the supplementary variables on which the in-situ DO measurements depend.

#### 7.5.4 Method

An in-situ DO sensor verification check shall be made using an independent reference DO sensor that has been successfully validated or calibrated (see sections 4.4.3.1 and 5.3.2.1).

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 DO measurement with the reference DO 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.*

It is a recommendation, but not a requirement of this Standard that:

- in still saline waters such as coastal lakes and estuaries, additional side-by-side DO sensor measurements are made in a well-mixed bucket containing the water of interest, and
- verification checks at sites that regularly record DO above 100% saturation utilise a reference DO sensor that uses a different sensing technique (e.g. quenching vs lifetime).

*Note: It is not possible for the monitoring agency to calibrate or validate a reference (or any) DO sensor above 100% saturation. Verifying the in-situ data using a different sensing technique (e.g. quenching vs lifetime) may provide increased confidence in the in-situ measurements above 100% saturation.*

All relevant supplementary variables shall be measured when verifying the in-situ DO data.

#### 7.5.4.1 Supplementary variables

Water temperature and conductivity verification checks shall be made using an independent reference sensor that has passed the validation requirements set out in section 5.3. Start with water temperature because if that is wrong, conductivity and DO will also be wrong.

Take both instantaneous water temperature and conductivity measurements with the reference sensor as close as possible to the in-situ sensor(s), allowing sufficient time for the reference sensor to stabilise. Once stable, read and record each reference measurement as close as possible to the time when the corresponding in-situ sensor's measurement is being logged, but before noting the logged in-situ values, to avoid potential confirmation bias.

If barometric pressure is logged on-site, verify the data using the built-in barometer of the handheld reference DO sensor or an independent reference barometer that meets the validation requirements set out in section 5.3.

*Note: The accuracy of any offsite continuous barometric pressure record used to convert a DO record from one form to another is a relevant consideration during data processing.*

## 7.5.5 Assessment

### 7.5.5.1 Method(s)

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

Ensure that the same form and units of DO measurement are compared. Either:

- set the reference DO sensor to the same form and units of DO measurement as the logged in-situ values (preferred), or
- manually correct (or 'uncorrect' as appropriate) the value from the in-situ or reference DO sensor.
  - Between DO% Ref. and DO% Local requires concurrent local barometric pressure (or altitude as an approximation).
  - Between DO% Ref. and DO concentration requires concurrent water temperature, and salinity where applicable.
  - Between DO% Local and DO concentration requires DO% Local to be uncorrected to DO% Ref. first.

Annex D provides examples of how to convert between different forms of DO, taking into account the effects of water temperature, barometric pressure and salinity.

#### Supplementary variables

Record the reference instrument measurement and calculate the difference between the reference instrument reading and the corresponding logged in-situ (for water temperature and potentially conductivity) or on-site (for barometric pressure) value. Ensure that the same form and units of measurement are compared for each supplementary variable.

### 7.5.5.2 Acceptance criteria

The verification tolerance for DO measurements is:

- the reference DO sensor and logged in-situ DO saturation readings shall differ by no more than  $\pm 3\% + (3\% \text{ of the reference value})$ , or
- if only a logged in-situ DO concentration is available, the reference DO sensor and logged in-situ DO readings shall differ by no more than  $\pm 0.3 \text{ mg/L} + (3\% \text{ of the reference value})$ .

*Note: This accounts for sensor accuracy of  $\pm 3\%$  (or  $\pm 0.3 \text{ mg/L}$ ) and a factor of 3% relative to the measured value. These criteria are more stringent than the previous version of this Standard to reflect improvements in sensor accuracy.*

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 (no more than twice the tolerance)
- QC 400 (no more than three times the tolerance), or
- QC 200 (greater than three times the tolerance).

For example:

When the reference value is 90.3% saturation, the in-situ sensor shall differ by no more than  $3\% + (0.03 \times 90.3)$ , equating to  $3\% + 2.7\%$  or  $\pm 5.7\%$  saturation. That is, any simultaneous logged value from 84.6% saturation to 96.0% saturation is deemed to be within verification tolerance and has “passed” the check. A logged value less than 84.6% saturation or greater than 96.0% saturation is outside the tolerance, verification has failed, and the in-situ data collected prior cannot achieve QC 600. For this example, 2x tolerance is  $\pm 11.4\%$  saturation and the simultaneous logged value can be any value from 78.9% saturation to 101.7% saturation before initial quality code must be no higher than QC 400.

When the reference value is 112% saturation, the in-situ sensor shall differ by no more than  $3\% + (0.03 \times 112)$ , equating to  $3\% + 3.4\%$ , or  $\pm 6.4\%$  saturation. That is, any simultaneous logged value from 105.6% saturation to 118.4% saturation is deemed to be within verification tolerance and has “passed” the check.

When the reference value is 9.15 mg/L concentration, the in-situ sensor shall differ by no more than  $0.3 \text{ mg/L} + (0.03 \times 9.15)$ , equating to  $0.3 + 0.27$ , or  $\pm 0.57 \text{ mg/L}$ . That is, any simultaneous logged value from 8.58 mg/L to 9.72 mg/L is deemed to have passed the verification check.

Electronic field forms are recommended for ease of calculations.

When verification fails:

- In the first instance, clean the in-situ sensor then recheck.
- If cleaning does not resolve the differences, troubleshoot to identify the source of the disagreement. If inspection reveals nothing obvious:
  - repeat the check with a different reference instrument (if possible), and/or
  - validate the reference and in-situ sensors (see section 5), or
  - swap the in-situ sensor for a calibrated replacement (required for water temperature and barometric pressure (see section 5.4.2.2)).
- Perform a final check before leaving the site (see section 7.5.4).

*Note: 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.*

### Supplementary variables

If verification of any logged supplementary variable fails (i.e. is outside the tolerances below), clean and troubleshoot as for DO (see above).

Verification tolerances for the supplementary variables are:

- For water temperature, the reference and in-situ measurements shall differ by no more than  $\pm 0.5^{\circ}\text{C}$  (consistent with NEMS *Water Temperature*).
- For salinity, the reference and in-situ conductivity measurements shall differ by no more than  $\pm 5\%$  of the reference value.

*Note: This criterion is set in the absence of a NEMS for continuous conductivity monitoring and is consistent with the validation check criterion in the NEMS Discrete Water Quality.*

- For barometric pressure, if logged at site, the reference and at-site continuous barometric pressure measurements should differ by no more than  $\pm 4$  hPa.

*Note: This Standard does not set this level of agreement as a QC 600 requirement because it is possible to achieve QC 600 using records from an off-site third-party barometer that will not be subject to verification checks by the monitoring agency (see section 7.2.4.2).*

If any of the above verification tolerances are not met, any DO data collected or derived that is dependent on the supplementary data shall be assigned a lower initial quality code as per Annex A. The QC 400 criteria are as follows:

- water temperature – the reference and in-situ measurements differ by more than  $\pm 0.8^{\circ}\text{C}$  but no more than  $\pm 1.0^{\circ}\text{C}$ .

*Note: This is consistent with NEMS Water Temperature.*

- salinity – the reference and in-situ conductivity measurements differ by more than  $\pm 8\%$  but no more than  $\pm 10\%$ .

A recommended QC 400 verification tolerance for barometric pressure recorded on site is a difference in reference and in-situ measurements of more than  $\pm 8$  but no more than  $\pm 12$  hPa. This equates to no more than three times the QC 600 verification tolerance and is provided in the absence of a NEMS for continuous monitoring of barometric pressure.

The Quality code for all checked but not fully processed supplementary data stored as supplementary time series shall be QC 200, consistent with NEMS *Data Processing*.

### 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 numbers
- 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
- relevant in situ sensor configuration details (e.g. form of DO being measured, altitude and/or 'representative' barometric pressure used for DO% Local, and/or salinity correction factor for DO concentration)
- reference values (with uncertainties) and their corresponding logged values and supplementary in-situ measurements that are not logged
- results of visual inspections, and
- verification check outcomes.

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 DO data varies according to the type of recorder used and the urgency of acquiring the data. Many permanent DO 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 DO (and any associated logged supplementary) 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 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 DO 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 DO levels can reach minima 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.

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 DO monitoring in accordance with this Standard.

#### 8.1.2 Staff training/certification

Staff carrying out deployment, operation and maintenance of continuous DO 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 visual check of the integrity of all structures, and an inspection of the DO 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.*

### 8.2 Managing method changes

Significant change to methods can disrupt stationarity of a continuous DO 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 if monitoring is conducted at a fixed depth in lake or other waters that stratify, and potentially some tidal margins of rivers.

Creating a new site is recommended if the change of location, irrespective of distance or depth, 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 DO sensor is to be changed (e.g. from an intensity-based to a lifetime-based sensor), 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 DO include the following:

- all completed site or field audits
- calibration certificates (or similar confirmation) for the primary reference thermometer and barometer (see section 4.2)
- records for DO, and the supplementary variables, of:
  - reference and in-situ sensor calibrations and validations (see sections 4.5 and 5.5)
  - in-situ sensor verification checks (see section 7.5.6).

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 DO 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 DO 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)
- site altitude (see section 3.4.2)
- location of nearest continuously recording barometer (see section 3.4.2)
- 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 instrument history (see section 2.9), which includes the records of:
  - calibration (see section 4.5)
  - validation (see section 5.5)
  - instrument servicing and maintenance (see section 6.3), and
- assessment of the maximum quality code for DO 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 7.2.8). 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 DO data (i.e. Tables 1 and 2 set out the minimum requirements for DO 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, DO 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 backup sensors and from the calculations required to compensate for one or more of the supplementary variables (see section 7.2.6) 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.

## 9.4.3 Other variable-specific requirements

### 9.4.3.1 Supersaturated values

Previous versions of this Standard limited the quality code of all DO saturation values above 100% saturation, and their corresponding concentrations, to a maximum of QC 500, and the NEMS *Data Processing Annex H* reduced it further to a maximum of QC 400.

In this version of this Standard, measurements above 100% saturation can be eligible for a quality code of QC 600 if:

- all other QC 600 requirements of this Standard are met, and
- the supersaturated values fall within the manufacturer’s stated calibrated range (see section 2.2.1.1).

DO measurements outside the manufacturer’s stated calibrated range shall be assigned a final quality code no higher than QC 400.

*Note: Where the manufacturer only specifies a measurement range, a monitoring agency may assume the measurement range is also the calibrated range.*

### 9.4.3.2 DO% Local

The maximum possible quality code is QC 500 for saturation data approximating DO% Local by compensating only for altitude or using a fixed value of at-site barometric pressure (see section 7.2.4.2).

### 9.4.3.3 Salinity

A correction factor may be applied to compensate for the effects of salinity on DO concentrations in open coastal water; instead of using a continuous at-site salinity record, but the compensated DO values cannot be assigned a quality code higher than QC 500 (see section 2.7.3).

If compensation for salinity is required (see section 2.7.3) but not applied, the archived data cannot be assigned any quality code i.e. NEMS methods have not been followed. If a correction factor is used but the site is not in open coastal water, the maximum possible quality code is QC 200 (quality unknown).

## 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 DO 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 DO measurements (see section 7.2.6)
- raw DO measurements as captured, and/or as uncorrected (DO% Ref) values, to convert to other forms of DO measurement (see section 7.2.6)
- DO 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.

## References

Mathany TM, Saraceno JF, Kulongoski JT. 2019. *Guidelines and standard procedures for high-frequency groundwater-quality monitoring stations – design, operation, and record computation*. U.S. Geological Survey, Techniques and Methods 1–D7. 54 p.

<https://doi.org/10.3133/tm1D7>.

McKergow L. 2025. Dissolved oxygen sensor selection guidance. *High frequency water quality monitoring guidance*. NIWA Client Report 2025310HN prepared for MBIE Envirolink.

U.S. Environmental Protection Agency (EPA). 2014. *Best practices for continuous monitoring of temperature and flow in wadeable streams*. Global Change Research Program, National Center for Environmental Assessment, Washington, DC; EPA/600/R-13/170F.

# 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 the matrix:

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

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

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

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

- Initial quality code cannot be higher than QC 500 if any one QC 600 performance threshold is not achieved, by definition of Table 3 of the Standard.
- Data are considered to be of 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
All sites				
<b>Site selection</b> (1.3.2 & 3.3.3)	Representative of target characteristics and/or location being monitored. <input type="checkbox"/>	<input type="checkbox"/>	Poorly representative. <input type="checkbox"/>	<input type="checkbox"/>
	Not influenced by radiant heat sources or sinks. <input type="checkbox"/>		Influenced by radiant heat source or sink. <input type="checkbox"/>	
<b>External data logger</b> (2.4.2)	Retains required accuracy, resolution and recording interval required for QC 600. <input type="checkbox"/>			<input type="checkbox"/> *
<b>Sensor accuracy (DO saturation)</b> (2.2.1.1)	At least $\pm 3\%$ saturation or $\pm 3\%$ of reading, whichever is greater AND at least $\pm 5\%$ of reading above 200% saturation. <input type="checkbox"/>	<input type="checkbox"/>	$\pm 3\%$ saturation or from $\pm 5\%$ and up to $\pm 7\%$ of reading, whichever is greater. <input type="checkbox"/>	
<b>Sensor accuracy (DO concentration)</b> (2.2.1.1)	At least $\pm 0.3$ mg/L or $\pm 3\%$ of reading, whichever is greater AND at least $\pm 5\%$ of reading above 20 mg/L. <input type="checkbox"/>	<input type="checkbox"/>	$\pm 0.3$ mg/L or from $\pm 5\%$ and up to $\pm 7\%$ of reading, whichever is greater. <input type="checkbox"/>	
<b>Supplementary measurements - water temperature</b> (7.2.4.1)	Sensor accuracy of $\pm 0.5^\circ\text{C}$ or better AND resolution $0.01^\circ\text{C}$ or better. <input type="checkbox"/>			<input type="checkbox"/> *
<b>Supplementary measurements - barometric pressure</b> (7.2.4.2)	Correction to DO% Local is, or can be, applied using a continuous, concurrent, altitude adjusted, record from within 30 km of site OR DO% Local not required. <input type="checkbox"/>	<input type="checkbox"/> **	Correction to DO% Local is, or can be, applied using a continuous, concurrent, altitude adjusted, record from between 50 km and 70 km of site. <input type="checkbox"/>	<input type="checkbox"/>

\* Degree of compromise and further effect on DO quality code to be assessed during data processing.

\*\* Additionally, measurements corrected for altitude only, or a constant barometric pressure are eligible for QC 500.

Criteria	QC 600	QC 500	QC 400	QC 200
Tidal river mouths and other estuaries, and open coast				
<b>Supplementary measurements - salinity OR conductivity with water temperature</b> (7.2.4.3)	Is measured and logged with DO, and compensation for salinity is, or can be, applied. <input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>
	Sensor accuracy at least $\pm 0.5$ ppt (salinity), or $\pm 5$ mS/m or $\pm 0.5\%$ for full scale error (conductivity) AND resolution 0.2 ppt or better, or 1 mS/m or better. <input type="checkbox"/>			<input type="checkbox"/> *
Rivers, lakes and open coast				
<b>Recording interval</b> (7.2.2)	15 minutes <input type="checkbox"/>	<input type="checkbox"/>	Greater than 30 but no more than 60 minutes. <input type="checkbox"/>	<input type="checkbox"/>
Tidal river mouths and other estuaries				
<b>Recording interval</b> (7.2.2)	5 minutes <input type="checkbox"/>	<input type="checkbox"/>	Greater than 10 but no more than 20 minutes. <input type="checkbox"/>	<input type="checkbox"/>

\* Degree of compromise and further effect on DO quality code to be assessed during data processing.

## Visit matrix

Criteria	QC 600	QC 500	QC 400	QC 200
All sites				
<b>DO sensor cap or foil</b> (6.2.2)	Not expired, damaged, <input type="checkbox"/> or otherwise needing to be replaced.			<input type="checkbox"/> *
<b>DO sensor operation</b> (3.3.4 & 6.2)	Sensor and shroud/ casing are clean. <input type="checkbox"/>	<input type="checkbox"/>	Significant biofouling or sedimentation, but not extensive. <input type="checkbox"/>	<input type="checkbox"/>
	Sensor is not obstructed or buried, or exposed to air, or disturbed, or damaged <input type="checkbox"/>			<input type="checkbox"/> *
<b>DO sensor calibration</b> (4.4.2.1)	After re-deployment, replacing cap or foil, or when validation has failed AND successful. <input type="checkbox"/>			<input type="checkbox"/> *
	As required (at least 12-monthly), and successful. <input type="checkbox"/>	<input type="checkbox"/>	Overdue by 3 to 6 months <input type="checkbox"/> OR calibration failed.	<input type="checkbox"/>
<b>DO sensor validation</b> (5.4.2, 5.3.4.1)	As required (at site pre-deployment if measuring DO% Local or deploying at depth, or when verification fails, or at end of monitoring period) <input type="checkbox"/> AND passed.  <i>Acceptance criteria: <math>\pm 0.5\%</math> saturation or <math>\pm 0.05</math> mg/L.</i>		Failed. <input type="checkbox"/>	
<b>DO verification - timing/frequency</b> (7.5.3)	On sensor deployment, replacement, or retrieval AND before and after sensor cleaning AND otherwise within 90 days of the last check. <input type="checkbox"/>	<input type="checkbox"/>	Minimum 90 day check overdue by 10 to 30 days. <input type="checkbox"/>	<input type="checkbox"/>

\* Timing and/or consequence of issue and further effect on DO quality code to be assessed during data processing.

Criteria	QC 600	QC 500	QC 400	QC 200
All sites				
<b>DO verification - reference reading</b> (7.5.4)	Reference sensor is calibrated as required (after replacing cap or foil, when validation fails, or at least every 12 months). <input type="checkbox"/>			<input type="checkbox"/> Reference reading is unreliable*.
	Reference sensor passed validation as required (up to 48 hr before use at site, or at end of day)  OR was calibrated on day before use at site. <input type="checkbox"/>			<input type="checkbox"/> Reference reading is unreliable*.
<b>DO verification - logged data</b> (7.5.5)	Logged value differs from reference sensor reading by no more than verification tolerance. <input type="checkbox"/> <i>Tolerance: ±(3% saturation (or 0.3 mg/L) +3% of reference value).</i>	<input type="checkbox"/>	Logged value differs from reference sensor reading by greater than 2 but no more than 3 times verification tolerance. <input type="checkbox"/>	<input type="checkbox"/>
<b>Supplementary measurements - verification frequency/timing</b> (7.5.3.1)	At least coincident with DO verification, for all required supplementary variables logged at site. <input type="checkbox"/>			<input type="checkbox"/> *
<b>Supplementary measurements - reference reading</b> (7.5.4.1)	Reference sensor calibrated and/or validated as required. <input type="checkbox"/>			<input type="checkbox"/> *
<b>Supplementary measurements - verification of logged water temperature data</b> (7.5.5.2)	Logged value differs from reference sensor reading by no more than ±0.5°C. <input type="checkbox"/>		Difference between logged value and reference sensor reading is between ±0.8°C and ±1.0°C. <input type="checkbox"/>	<input type="checkbox"/>
<b>Supplementary measurements - verification of logged conductivity data</b> (7.5.5.2)	In-situ conductivity sensor calibration is current <input type="checkbox"/>  AND logged value differs from reference sensor by no more than ±5%  OR is not required. <input type="checkbox"/>	<input type="checkbox"/>	Difference between logged value and reference sensor reading is between ±8% and ±10%. <input type="checkbox"/>	<input type="checkbox"/>

\* Consequence and/or further effect on DO quality code to be assessed during data processing.

Criteria	QC 600	QC 500	QC 400	QC 200
Rivers, lakes and open coast				
<b>Clock drift</b> (7.2.3.1)	Less than $\pm 90$ s over 30 days, if any. <input type="checkbox"/>	<input type="checkbox"/>	Greater than $\pm 150$ s and up to $\pm 300$ s (5 min) over 30 days. <input type="checkbox"/>	<input type="checkbox"/>
Tidal river mouths and other estuaries				
<b>Clock drift</b> (7.2.3.1)	Less than $\pm 90$ s over 30 days, if any. <input type="checkbox"/>	<input type="checkbox"/>	Greater than $\pm 120$ s and up to $\pm 180$ s (3 min) over 30 days. <input type="checkbox"/>	<input type="checkbox"/>

Initial quality code assigned from all matrices Select the lowest quality code ticked across all boxes. <i>A final quality code will be assigned during data processing.</i>	
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# 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 DO sensor details – make and model, serial number, measurement range, sensor cap or foil serial number and expiry (where applicable), pre-deployment validation performed (Y/N)
- Sensor details for supplementary 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 – form(s) of DO measurement, recording interval, start time, supplementary variables being recorded
- 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 DO sensor verification details
  - reference sensor make, model and ID
  - date and time (in NZST)
  - reference DO value (% saturation and mg/L)
  - logged DO value (% saturation and mg/L)
  - difference between reference and logged values (% saturation and mg/L)
- Post-installation verification details of supplementary measurements being recorded on-site
  - reference sensor/instrument make, model and ID
  - date and time (in NZST)
  - reference and logged values, and difference in these.

# Annex C – Data Tables

**Table C1 – Variation of (%) saturation DO with barometric pressure and altitude**

Source: YSI (2009). *The dissolved oxygen handbook: A practical guide to dissolved oxygen measurements.*

Pressure		Altitude	Calibration Value
kPa	mbar (or hPa)	m	% Saturation
102.4	1024	-84	101
101.3	1013	0	100
100.3	1002	85	99
99.3	993	170	98
98.3	983	256	97
97.3	973	343	96
96.3	963	431	95
95.2	952	519	94
94.2	942	608	93
93.2	932	698	92
92.3	923	789	91
91.2	912	880	90
90.1	901	972	89
89.2	892	1066	88
88.1	881	1106	87
87.2	872	1254	86
86.1	861	1350	85
85.1	851	1447	84
84.1	841	1544	83
83.1	831	1643	82
82.1	821	1743	81
81.1	811	1843	80
80.0	800	1945	79
79.1	791	2047	78
78.0	780	2151	77
77.1	771	2256	76
76.0	760	2362	75
74.9	749	2469	74
74.0	740	2577	73
73.0	729	2687	72
72.0	720	2797	71
71.0	709	2909	70
70.0	699	3023	69
69.0	689	3137	68
67.9	679	3253	67
66.9	669	3371	66



**Table C2 – Solubility of oxygen in mg/L in water exposed to water-saturated air at 1013 hPa atmospheric pressure**

Source: YSI (2009).

Temp °C	Chlorinity: 0	5.0 ppt	10.0 ppt	15.0 ppt	20.0 ppt	25.0 ppt
	Salinity: 0	9.0 ppt	18.1 ppt	27.1 ppt	36.1 ppt	45.2 ppt
0.0	14.621	13.728	12.888	12.097	11.355	10.657
1.0	14.216	13.356	12.545	11.783	11.066	10.392
2.0	13.829	13.000	12.218	11.483	10.790	10.139
3.0	13.460	12.660	11.906	11.195	10.526	9.897
4.0	13.107	12.335	11.607	10.920	10.273	9.664
5.0	12.770	12.024	11.320	10.656	10.031	9.441
6.0	12.447	11.727	11.046	10.404	9.799	9.228
7.0	12.139	11.442	10.783	10.162	9.576	9.023
8.0	11.843	11.169	10.531	9.930	9.362	8.826
9.0	11.559	10.907	10.290	9.707	9.156	8.636
10.0	11.288	10.656	10.058	9.493	8.959	8.454
11.0	11.027	10.415	9.835	9.287	8.769	8.279
12.0	10.777	10.183	9.621	9.089	8.586	8.111
13.0	10.537	9.961	9.416	8.899	8.411	7.949
14.0	10.306	9.747	9.218	8.716	8.242	7.792
15.0	10.084	9.541	9.027	8.540	8.079	7.642
16.0	9.870	9.344	8.844	8.370	7.922	7.496
17.0	9.665	9.153	8.667	8.207	7.770	7.356
18.0	9.467	8.969	8.497	8.049	7.624	7.221
19.0	9.276	8.792	8.333	7.896	7.483	7.090
20.0	9.092	8.621	8.174	7.749	7.346	6.964
21.0	8.915	8.456	8.021	7.607	7.214	6.842
22.0	8.743	8.297	7.873	7.470	7.087	6.723
23.0	8.578	8.143	7.730	7.337	6.963	6.609
24.0	8.418	7.994	7.591	7.208	6.844	6.498
25.0	8.263	7.850	7.457	7.093	6.728	6.390
26.0	8.113	7.711	7.327	6.962	6.615	6.285
27.0	7.968	7.575	7.201	6.845	6.506	6.184
28.0	7.827	7.444	7.079	6.731	6.400	6.085
29.0	7.691	7.317	6.961	6.621	6.297	5.990
30.0	7.559	7.194	6.845	6.513	6.197	5.896
31.0	7.430	7.073	6.733	6.409	6.100	5.806
32.0	7.305	6.957	6.624	6.307	6.005	5.717

Temp °C	Chlorinity: 0	5.0 ppt	10.0 ppt	15.0 ppt	20.0 ppt	25.0 ppt
	Salinity: 0	9.0 ppt	18.1 ppt	27.1 ppt	36.1 ppt	45.2 ppt
33.0	7.183	6.843	6.518	6.208	5.912	5.631
34.0	7.065	6.732	6.415	6.111	5.822	5.546
35.0	6.950	6.624	6.314	6.017	5.734	5.464
36.0	6.837	6.519	6.215	5.925	5.648	5.384
37.0	6.727	6.416	6.119	5.835	5.564	5.305
38.0	6.620	6.316	6.025	5.747	5.481	5.228
39.0	6.515	6.217	5.932	5.660	5.400	5.152
40.0	6.412	6.121	5.842	5.576	5.321	5.078
41.0	6.312	6.026	5.753	5.493	5.243	5.005
42.0	6.213	5.934	5.667	5.411	5.167	4.933
43.0	6.116	5.843	5.581	5.331	5.091	4.861
44.0	6.021	5.753	5.497	5.252	5.017	4.793
45.0	5.927	5.665	5.414	5.174	4.944	4.724
46.0	5.835	5.578	5.333	5.097	4.872	4.656
47.0	5.744	5.493	5.252	5.021	4.801	4.589
48.0	5.654	5.408	5.172	4.947	4.730	4.523
49.0	5.565	5.324	5.094	4.872	4.660	4.457
50.0	5.477	5.242	5.016	4.799	4.591	4.392

# Annex D – Dissolved Oxygen Calculations

**Table D1 – Percentage change in saturation DO with unit change in water temperature, atmospheric pressure and salinity, at different water temperatures.**

Variable	Change in saturation DO (%)		
	5°C	10°C	20°C
Water Temperature (°C)	-2.53	-2.31	-1.95
Barometric Pressure (kPa) <sup>1</sup>	1.02	0.98	0.98
Salinity (‰)	-0.67	-0.64	-0.59

<sup>1</sup> 1013.25 mbar (or 1013.25 hPa) = 101.325 kPa = standard atmospheric pressure.

Note:

1. An error of +1°C in the water temperature reading results in an error of about -2% in the DO (percentage saturation) reading. The effect is slightly greater at cooler temperatures.
2. An error of +1 kPa in the barometric pressure reading corresponds to an error of about 1% in DO saturation.
3. An error of +1‰ in the salinity reading corresponds to an error in the percentage saturation DO of about 0.6‰. This effect lessens as water temperature increases.

## Correcting DO% saturation for barometric pressure and altitude

The following corrections are to be applied when DO% Local (DO% corrected) is required but the DO sensor has been calibrated to standard atmospheric pressure at sea level.

In the following calculations:

- DO%<sub>(corrected)</sub> refers to DO% saturation values corrected for local barometric pressure at or near the site where DO was measured, also called DO% Local (see section 2.8).
- DO%<sub>(raw)</sub> refers to DO% saturation values that have not been corrected for local barometric pressure, also called DO%<sub>(uncorrected)</sub> or DO% reference (or DO% Ref. for short). Uncorrected DO% saturation values are referenced to standard atmospheric pressure at sea level (1013.25 hPa).
- The local barometric pressure readings are ‘station’ pressures, not reduced to mean sea level (see section 2.7.2).

1. **Barometric correction – on site** (recommended, eligible for QC 600 when obtained as continuous measurements concurrent with DO)

$$DO\%_{(Local)} = DO\%_{(Ref.)} \times \frac{1013.25}{\text{barometer}}$$

where barometer = local barometric pressure reading (hPa)

For example: If DO%<sub>(Ref.)</sub> is 95.3% and the at-site barometric pressure reading is 982 hPa, then DO%<sub>(Local)</sub> = (1013.25/982) × 95.3 = 98.3%.

**2. Barometric correction – nearby site** (eligible for QC 600 if applied using a continuous record from a barometer within 30 km)

$$DO\%_{(Local)} = DO\%_{(Ref.)} \times \frac{1013.25}{\text{barometer} \times (1 - 2.25577 \times 10^{-5}h)^{5.25588}}$$

where:

- barometer = local barometric pressure reading (hPa) of the nearby barometer
- $h$  = height (m) above sea level (a.s.l.) of the monitoring site minus the height above sea level of the nearby barometer

*For example: If  $DO\%_{(Ref.)}$  is 95.3% at a monitoring site 900 m a.s.l. and the local barometric pressure reading is 982 hPa from a nearby barometer at 1,100 m a.s.l., then  $DO\%_{(Local)} = 95.3 \times 1013.25/982 \times [(1 - 2.25577 \times (10^{-5} \times 200))]^{5.25588}$*

$$\begin{aligned} &= 95.3 \times 1013.25/\{982 \times [1 - (-4.51154 \times 10^{-3})]^{5.25588}\} \\ &= 95.3 \times 1013.25/\{982 \times [1.00451]^{5.25588}\} \\ &= 95.3 \times 1013.25/\{982 \times 1.02393\} \\ &= 95.3 \times 1013.25/1005.50 \\ &= 96.0\% \end{aligned}$$

**3. Altitude only correction** (eligible for QC 500)

$$DO\%_{(Local)} = DO\%_{(Ref.)} \times \frac{1}{(1 - 2.25577 \times 10^{-5}h_{alt})^{5.25588}}$$

where  $h_{alt}$  = height (m) above sea level (a.s.l.) of the monitoring site

*For example: If  $DO\%_{(Ref.)}$  is 95.3% at a monitoring site 900 m a.s.l. then*

$$\begin{aligned} DO\%_{(Local)} &= 95.3 \times 1/[1 - (2.25577 \times 10^{-5} \times 900)]^{5.25588} \\ &= 95.3 \times 1/[1 - (0.02030)]^{5.25588} \\ &= 95.3 \times 1/[0.97970]^{5.25588} \\ &= 95.3 \times 1/0.89781 \\ &= 95.3 \times 1.11382 \\ &= 106.1\% \end{aligned}$$

The following example calculations illustrate the relationship between DO concentration, and uncorrected and corrected DO% saturation.

*A DO sensor is calibrated in a fully saturated solution when barometric pressure is 987 hPa. The sensor should read  $987/1013.25 \times 100 = 97.4\%$  (DO% uncorrected).*

*DO concentration of the fully saturated solution is 97.4% of the solubility of oxygen in water at standard atmospheric pressure for the current temperature and salinity of the solution. If salinity is zero and temperature is 15°C, then the DO concentration of the calibration solution is:*

$$10.084 \times 0.974 = 9.82 \text{ mg/L (from Table C2, Annex C).}$$

The sensor is then used to measure a fully saturated solution at a site at 880 m altitude. The barometric pressure reduces as a result of the altitude difference to:

$(1 - 2.25577 \times 10^{-5} \times 880)^{5.25588} \times 987 = 0.90 \times 987 = 888.3 \text{ hPa}$  (from the correction calculations (above) Table C1, Annex C).

The sensor will read  $888.3/1013.25 \times 100 = 87.7\%$  (DO% uncorrected) i.e.  $0.90 \times 97.4\%$ . DO concentration, if no salinity and temperature is 15°C, is  $10.084 \times 0.877 = 8.84 \text{ mg/L}$ .

If barometric pressure is measured at site, the uncorrected DO% saturation reading can be corrected so that 8.84 mg/L registers as 100% saturation, i.e.  $1013.25/888.3 \times 0.877 = 100\%$  (DO% corrected, also known as DO% local).

## DO saturation calculations

Equation relating equilibrium (saturation) dissolved oxygen concentration ( $C_s$ ) to water temperature ( $T$  in K = °C + 273.15) and salinity ( $S$ ) is given by APHA 23<sup>rd</sup> edition as follows:

$$\ln C_s = -139.34411 + \frac{1.575701 \times 10^5}{T} - \frac{6.642308 \times 10^7}{T^2} + \frac{1.243800 \times 10^{10}}{T^3} - \frac{8.621949 \times 10^{11}}{T^4} - S \left[ 1.7674 \times 10^{-2} - \frac{1.0754 \times 10^1}{T} + \frac{2.1407 \times 10^3}{T^2} \right]$$

where:  $\ln C_s$  is the natural logarithm (base  $e$ ) of  $C_s$ .

For example, when water temperature is 20°C ( $T=293.15 \text{ K}$ ) and salinity is 0 ppt,  $C_s$  is 9.09 mg/L; and at 20°C and a salinity of 30 ppt,  $C_s$  is 7.62 mg/L.

## DO conversion calculations

The following are conversion calculations:

$$DO_{mg/L} = \frac{DO\%}{100} \times [14.621 + (-0.4094 T) + (0.0087 T^2) + (-0.0001 T^3) + (0.0000002 T^4)]$$

$$DO\% = \frac{DO_{mg/L} \times 100}{[14.621 + (-0.4094 T) + (0.0087 T^2) + (-0.0001 T^3) + (0.0000002 T^4)]}$$

where  $T$  = water temperature (°C)

# Annex E – 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 DO sensor out of the water? Yes (*describe*) or No
  - Is the DO 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 DO values (% saturation and mg/L) and logger time (NZST)
  - Reference sensor DO value (% saturation and mg/L) and reference time (NZST)
  - Logged and reference sensor DO 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

