NIWA
Taihoro Nukurangi

HIGH FREQUENCY WATER QUALITY MONITORING GUIDANCE - PROJECT OVERVIEW AND DATA STANDARDS

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McKergow, L., Wood, D., Hudson, N., Arnold, J., Woodward, B., Elley, G., Milne, J., MacDonald, I. Crawford, R. (2025) High frequency water quality monitoring guidance – Project overview and data standards. Envirolink Tool prepared by NIWA. NIWA Client Report 2025317HN. http://www.envirolink.govt.nz/

Front cover: Monitoring platform on Te Waihora/Lake Ellesmere, Canterbury [Hamish Carrad, Environment Canterbury].

Back cover: DO monitoring at Rees River, Otago [Emily Olson, ORC].

CONTENTS

BACKGROUND

Obtaining information about water quality dynamics over short time scales (such as diel cycles, or during a storm or rain event lasting a few days) using conventional discrete samples or field measurements, may be costly and logistically challenging to undertake frequently. Fortunately, high frequency water quality (HFWQ) sensors can be deployed on site to measure environmental indicators (e.g., nitrate, dissolved oxygen) and provide detailed insights into water quality dynamics at scales of interest (minutes to hours). HFWQ monitoring projects are most likely to succeed if they have (1) clearly defined objectives, (2) robust data collection systems, and (3) well thought-out methods for managing raw data and converting it into knowledge for making decisions.

PURPOSE AND SCOPE

This report provides an overview of the project and includes a large acknowledgements section. It also includes draft NEMS for nitrate, algal fluorescence and specific conductivity, which do not fit neatly in the main guidance reports.

RELATED RESOURCES

This report is designed to sit alongside the guidance reports produced during the project. The reports are standalone documents so that users can find their way directly to the resources of interest. The reports are cross referenced where appropriate.

1. HFWQ Use cases and system design guidance (McKergow 2025d)
2. HFWQ Resourcing guidance (McKergow and Hughes 2025)
3. Optical nitrate sensor selection (McKergow and Vincent 2025)
4. Water temperature sensor selection (McKergow 2025f)
5. Dissolved oxygen sensor selection (McKergow 2025b)
6. Electrical conductivity sensor selection (McKergow 2025c)
7. Optical scattering (turbidity and backscatter) sensor selection (McKergow 2025e)
8. Algal fluorescence sensor selection (McKergow 2025a)
9. HFWQ Automated anomaly detection (Wood 2025)

PROJECT OVERVIEW

The nine reports listed above are the outputs of a two-year Envirolink Tool project. The project fills some of the key technical gaps identified by regional council staff in a workshop help in 2022 (Milne et al. 2022).

The process

The nine reports are outputs from a common development process (Figure 1). Once the task plans were finalised the workgroup members were recruited via the Te Uru Kahika Special Interest Groups (SIGs). The workgroups and workshop participants contributed to the guidance through a pre-workshop survey and workshop. The workgroup members helped develop the case studies and undertook report review.

Figure 1. Project process for each report.

The team

A large team of experts have contributed to this project – sharing their expertise and knowledge, providing case studies and photos, and contributing to guidance reviews (Figure 2). The project has provided a space for sharing detailed knowledge and experience, and it delivers on the transfer of knowledge from experienced regional council staff to their council peers. Many regional council staff (25 staff from 12 regional councils) worked together with researchers from NIWA (8) and other research organisations (3) in the nine workgroups.

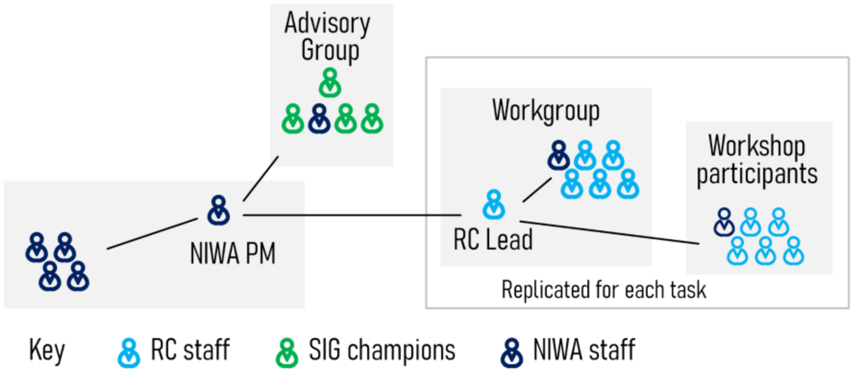

Figure 2. Simple diagram of project teams and relationships.

The project advisory group has overseen the work and engaged regularly with the SIGs. We are grateful for their considered advice and for the time they dedicated to guiding the NIWA project team through key challenges and maintaining ongoing involvement from regional council staff.

A workgroup was formed for each task and numerous people also participated in the workshops (see Acknowledgements below). We are grateful to the workgroup members who contributed to guidance review and continued to ask questions and share their detailed knowledge and experience.

We are grateful to those people who contributed case studies. The project includes 22 case studies; 15 by regional councils (Environment Canterbury, Environment Southland, Hawke's Bay Regional Council, Taranaki Regional Council, Otago Regional Council, and Waikato Regional Council) and 7 by NIWA. These case studies are valuable to illustrate the challenges HFWQ sensor users have had and how they have overcome them. A wider group of 30 people also contributed to the AAD Drivers and Barriers Survey that is summarised in a case study.

A small team of experienced and new users also contributed to guidance review (as external reviewers). Feedback from the new users was particularly helpful, and we are grateful for their contribution to the guidance. All of the reports were skilfully edited by Andrea Graves.

PROJECT ACKNOWLEDGEMENTS

Name	**Organisation**
Advisory Group	
Ed Brown (Project champion)	Waikato Regional Council (ED SIG)
Coral Grant (Project champion)	Auckland Council (SWIM SIG)
Tina Bayer	Environment Canterbury (Lakes Forum)
Chris Eager	Waikato Regional Council (C-SIG)
Neale Hudson (2023-2024)	NIWA
Ben Woodward (2024-2025)	NIWA
Nitrate	
Hamish Carrad	Environment Canterbury
Alex Vincent	NIWA
Darren May	Environment Southland
Emily Olson	Otago Regional Council
Phil Abraham	ESR
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Dissolved oxygen	
Hamish Carrad	Environment Canterbury
Emily Olson	Otago Regional Council
Ben Woodward	NIWA
Chris Eager	Waikato Regional Council
Sue Rosandich	Northland Regional Council
Alex Ring	Environment Canterbury
David Brown	Horizons Regional Council
Malcolm Burningham	Bay of Plenty Regional Council
Wayne Worth	Otago Regional Council
James Dare	Bay of Plenty Regional Council
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Janine Kamke	Auckland Council
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Alex Ring	Environment Canterbury
David Brown	Horizons Regional Council
Iain MacDonald	NIWA
Chris Eager	Waikato Regional Council
Ryan Evison	NIWA
Water temperature	
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David Brown	Horizons Regional Council
Emily Olson	Otago Regional Council
Claire Kotze	Waikato Regional Council
Stacey Fraser	Auckland Council
James Dare	Bay of Plenty Regional Council
Jonny Horrox	West Coast Regional Council
Automated anomaly detection	
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Jeff Cooke	Hawke’s Bay Regional Council
Preston Ferreira	Northland Regional Council
Chris McBride	Limnotrack
Sorren Hunter	Horizons Regional Council
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Glen Reeve	NIWA
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Coral Grant	Auckland Council
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Chris Eager	Waikato Regional Council
Editor	
Andrea Graves	

DRAFT DATA STANDARDS

Draft data standards for indicators which do not currently have NEMS are part of this Envirolink Tool project. These draft standards (Table 1, Table 2, Table 3) are immature but identify some of the key factors affecting data quality and challenges sensor users will encounter.

Table 1. Draft NEMS for continuous optical nitrate.

		Requirements for all data	Requirements for good data	Recommendations	Notes
Site selection	Location		• Representative of the target characteristics of the water body or location to be measured. • Not influenced by local turbidity or dissolved organics sources.	Horizontal (rivers) or vertical (lakes) cross-section survey recommended	
	Mixing considerations			Create a new site if change of location alters site factors (e.g., range or characteristics).	
Measurement	Units	Nitrate-N (mg/l)			
	Minimum resolution	0.1 mg/l *Resolution varies with pathlength and sensor.*	≥ 10 mm pathlength 0.01 mg/l ≤ 5 mm pathlength 0.1 mg/l		
	Method	Optical nitrate sensor deployed in-situ or ex-situ with pumped system.			
	Nitrate reference	Laboratory nitrate-N			
	Reference method	Method 4500-NO_3 I. Flow Injection Analysis, or Ion Chromatography APHA 4110 B			
	Reference accuracy	± 5%			Rogers et al. (2025), Davies-Colley et al. (2019)
Timing of measurements	Sampling method	A point sample stored as an instantaneous value. *Note: a representative average value of a burst of measurements may be used but must result in a point sample*			
	Resolution	1 second			
	Maximum recording interval (for continuous data)		15 minutes		Trade off with lens aging. Consistent with OOI (Palevsky et al. 2023).
	Accuracy		• Within ± 90 s of actual NZST, and • Clock drift <± 90 s over 30 days.		
Instrumentation	External data logger		• Stores data without compromising the accuracy, resolution and recording interval also required for QC 600.		
In-situ optical nitrate sensor	Pathlength	Selected pathlength: • Should be suitable for the expected nitrate concentration range. • Should be selected to minimise interferences (shorter pathlength) while retaining sensitivity and resolution.			
	Accuracy	Accuracy and resolution depend on: • instrument pathlength selected • algorithm used or developed • nitrate wavelengths measured, and • nitrate concentration. Real world accuracy also depends on: • matrix interferences, namely dissolved organic matter and suspended particulate matter • algorithm suitability.			
	Range		Measures the full range of nitrate values to the resolution required for QC 600. *Note: For all sensors operating in turbid waters the measurement range is less than the stated range.*		
	Resolution		2 dp		Depends on pathlength
	Firmware			• Sensor firmware updates should be monitored at least annually. *Note: If the sensor firmware is out of date the sensor may need to be returned to the manufacturer for firmware updates.*	
	Operation		Sensor is clean, and not obstructed or buried, or exposed to the air, or damaged or disturbed.		

		Requirements for all data	Requirements for good data	Recommendations	Notes
	Fouling management		Antifouling system should clean lenses at regular intervals to maintain clean lenses.	Recommend: • Antifouling system should clean lenses prior to each measurement to maintain clean lenses. • Robust low maintenance system	Allows for short-term swaps without wiper.
	Validation method	• Stable environment • At least 2 points, including fresh DI and nitrate standard(s) for range expected at site, or • As per manufacturer's specification.			
	Validation frequency	• Before deployment • When field sensor functional check fails, or • As per manufacturer's specification.			Will depend on sensor hardware and environment
	Baseline intensity method	Update baseline intensity with ultra-pure water value (lamp aging, internal lens coating for xenon lamps): • Subject to monitored sensor performance • To be completed by an experienced user only, stable dark environment, and guided by manufacturer's instructions and/or recommendations. *Note: This is seldom required.* *Note: Some sensors allow the user to store historic baseline intensity files.*			Xenon lamps get a coating on the inside of the lens
	Baseline intensity frequency	• When sensor fails validation after failing field sensor functional check • When a lens is replaced	For sensors with xenon lamps: • 12 months	Return nitrate sensors for routine manufacturer re-calibration as and when recommended by manufacturer.	
Algorithm	Proprietary algorithm method	An algorithm selected shall be suitable for the site and water matrix. • Should include "turbidity"/SPM correction for surface waters with varying "turbidity"/SPM. • Should include coloured dissolved organics (CDOM) correction for waters with background or varying CDOM. • Should include bromide and salinity correction for seawater.	Pre-deployment algorithm check: • Use discrete sample from site representative of target conditions and spike with nitrate. • Use sensor as a field meter during representative target conditions (such as a river in flood) and collect concurrent discrete sample for lab analysis of nitrate-N.		- Need instructions for suitability test spiking, see Pellerin et al. (2013).
	Proprietary algorithm frequency	• Before deployment	Algorithm shall be reviewed: • At least annually		
	Local adjustment method	Adjust algorithm for suspended particulate matter, dissolved organics and other interferents: • Guided by manufacturer's instructions and/or recommendations	Adjust manufacturer's algorithm: • Guided by manufacturer's instructions and/or recommendations, and • Using reference value pairs of discrete nitrate-N sample value and concurrent sensor nitrate value. • Minimum number of samples should be 20 across > 60 % of the range of measured conditions. Calculate nitrate values: • On-board the in-situ sensor (if possible), • On an external logger, or • Post-process.		- To meet statistical assumptions a minimum sample number would be reasonable. Effort required to collect samples beyond monthly field visits (e.g., high flow samples).
	Local adjustment frequency		Algorithm shall be reviewed: • At least annually		
	Site-specific algorithm method		Develop a new site-specific algorithm: • Minimum number of samples should be 20 across > 60 % of the range of measured nitrate conditions. • Should use valid sensor output (within absorbance limits) • Should use a corrected spectra • Use partial least squares regression or linear least squares optimisation to predict discrete nitrate-N from available wavelengths. • Calculate nitrate values: ○ On-board the in-situ sensor (if possible), ○ On an external logger, or ○ Post-process.		- See box above. - Check interferent absorbance value range is reasonable.

		Requirements for all data	Requirements for good data	Recommendations	Notes
	Site-specific algorithm frequency		When local adjustment fails to meet verification tolerance across the full range. *Note: Some manufacturer's offer support to develop site-specific algorithms.*		
Maintenance	In-situ sensor functional check method		• After cleaning sensor lenses, rinse and visually inspect lenses, and then immerse sensor window in fresh DI water • Ensure cleaned sensor meets manufacturer's criteria for nitrate, absorbances and/or raw counts. • Guided by manufacturer's instructions and/or recommendations.		Checking that lenses are spotless and sensor is not damaged.
	In-situ sensor functional check frequency		At least once every 60 days		
	In-situ functional check attempts		• When senor functional check fails after 3 attempts (each followed by thorough lens cleaning & re-check) refer to manufacturer's instructions.		
	Lens inspection	Visual inspection of clean lens condition • At least once a year, and • Subject to monitored sensor performance. • Use magnification to detect scratches, coatings, or abrasion.			
	Fouling management system	The impact of biofouling should be managed. • Use a proprietary or third-party mechanical wiper system. • Monitor the operation and performance of the mechanical wiper. *Note: Fouling may vary seasonally.*	The impact of fouling should be managed. • A proprietary or third-party fouling management system should be used. *Note: Optical nitrate sensors are sensitive to fouling. A robust antifouling system is required for unattended deployments.*	• Biofouling management plan recommended. • Fouling management system should clean lens prior to each measurement. • Mechanical wiper metadata is captured and stored to inform biofouling management plan.	
Verification	Method	Reference sample shall be taken: • at the same time as an in-situ sensor value (< 60 s difference) • as close to the in-situ sensor as safely possible.	• Samples should span at least 60 % of the nitrate range measured at the site. This may require additional sampling effort.	Autosamplers recommended for sites with variable water matrix.	Covers use of log value or initiating independent reading.
	Frequency	• At least once every 60 days. • Sampling should be conducted using NEMS Discrete WQ protocols.	Logged values for nitrate shall be verified • Immediately following sensor deployment • During every verification visit • At least once every 60 days • On retrieval at the end of any monitoring period	Additional verification samples may be useful during the first 3-6 months of a deployment to enable checking of the algorithm and sensor pathlength suitability.	Need 20+ samples for verification to be statistically valid, will take ~2 y to collect if relying on monthly
	Acceptance tolerance		• Use manufacturer's field accuracy specifications plus ± 5% (for the lab sample value), or • Use the manufacturer's stated accuracy to calculate a tolerance: ±2 × manufacturer's stated accuracy (for pure water standards) plus ± 5% (for the lab sample value).		- 1 x = ideal lab conditions, 2 x = more real world. Pellerin et al. (2013) recommend 3 x manufacturer's "accuracy". - Some manufacturers provide field specifications (Sea-Bird Scientific 2025).
Supplementary measurements	Raw counts, absorbances and/or quality codes	Continuous at site record of sensor metadata for each value of at minimum, • Proprietary quality code for each value which identifies a valid value was measured and calculated by the algorithm (e.g., a spectral quality index (SQI) or similar), and/or • Counts or absorbances for nitrate wavelength(s) and interferents (suspended particles, coloured dissolved matter). *Note: Nitrate wavelengths likely in the range 205–240 nm but may use the spectral shoulder ~260–270 nm.* *Note: Coloured dissolved organics wavelengths typically 254 nm, but some sensors may also use longer wavelengths (~275–360 nm)* *Note: Suspended particles wavelengths likely ~350–360 nm (for UV sensors) or ~600–700 nm (for UV-Vis sensors).*	A method for determining if a value is valid shall be used. This method should use: • A manufacturer's proprietary quality code for a good data, and/or • Analysis of absorbances using manufacturer supplied limits for good data.		

		Requirements for all data	Requirements for good data	Recommendations	Notes
		Note: Temporal variability in suspended particulate matter may be low in aquifers and spring fed streams. *Note: Absorbance values or spectra are required to develop and apply a site-specific nitrate algorithm if the manufacturer supplied algorithms are not suitable.*			
Additional supplementary measurements – saline waters	**Bromide**	Absorbance for bromide and nitrate ions are closely related and their wavelengths overlap. Correction for bromide ions is required to accurately compute nitrate concentrations. Bromide varies with temperature while nitrate does not.			Expand later if coastal water included
	Method	Calculated from water temperature sensor using well tested algorithms provided or recommended by the manufacturer.		Users are encouraged to review current literature for best practices.	OPUS (Nehir et al., 2021) different from SUNA (Sakamoto et al., 2009; Plant et al., 2024)
	Water temperature	Required for bromide and salinity corrections.			
	Method	• Temperature sensor built in, or integrated with, the in situ optical nitrate sensor, and • logged concurrently with nitrate.			
	Units	Degrees Celsius (°C)			
	Minimum resolution	0.02 °C			
	Sensor accuracy	Manufacturers stated accuracy of ± 0.5 °C or better.			
	Primary reference method	Certified traceable reference thermometer, as per NEMS Continuous Water Temperature.			
	Reference method	Independent, portable temperature sensor or field referenced thermometer. *Note: Sensor may be built-in to a multi-variable and/or hand-held instrument.*			
	Reference sensor validation method	Minimum 5-point check in water bath against two primary references, as per NEMS Continuous Water Temperature.			
	Practical Salinity	Required for salinity correction in seawater.			
	Units	Unitless			
	Minimum resolution	Conductivity: 1 µS/cm or better.			
	Sensor accuracy (reference & in-situ)	Manufacturer's stated accuracy for conductivity: 3 µS/cm or better.			
	Sensor calibration method	Set to value of standard solution for estuarine (1288 mS/m) or open coastal (5300 mS/m) waters as applicable.			
	Primary reference method	Standard conductivity solution(s).			
	Reference method	Portable, independent from in-situ sensors, combined conductivity, depth and water temperature (CTD) sensor.			
	Reference sensor validation method	Checked against the standard solution for estuarine (1288 mS/m) or open coastal (5300 mS/m) waters as applicable			
	Depth	Required for calculation of practical salinity for salinity correction			
	Method	Pressure transducer on combined conductivity, depth and water temperature sensor.			
Complementary measurements	Sensor metadata			Collect and store available sensor metadata data (raw counts, light & dark lamp values, sensor logs) output by the sensor.	
	Antifouling system metadata			Collect and store available antifouling system metadata (such as wiper park position, wiper use count; wiper peak current).	
	Water level			To identify dewatering events and track sensor depth or bed clearance due to changing water levels.	
	Archiving			If collected, complementary data shall be: • Identified • Available during data processing • Stored indefinitely	
Metadata	Scope	• Recorded for all sites and measurements. • Permanently archived and discoverable.			

		Requirements for all data	Requirements for good data	Recommendations	Notes
	Identification of Standards	• Standards and versions applied shall be tracked over time in time-stamped Stationarity Comments			
	Identification of data	All data shall be identified by a minimum of: • A unique site name and/or identifier • The variable's name and units, and • Date and time of the measurement or record.			
	Quality coding	• All data shall be quality coded using the NEMS *National Quality Code Schema*.			
	Site records	• All stations shall have a unique identifier. • A Station History (or site file) shall be established and maintained. • Remote telemetry station configuration changes shall be controlled and recorded. • All supplementary data shall be identified and described. • Significant site and station maintenance shall be recorded in the Station History. Records of those activities with bearing on data quality shall be retained indefinitely. • All photos and video retained as metadata shall be date-stamped, indexed to the site, and named and/or annotated with the orientation and subject.			
	Site visit records	• A record of every site visit shall be made, including routine cleaning and maintenance and verification details. • The records shall be accessible when data are processed and retained indefinitely as original data.			
	Instrument records	• All specification, configuration, servicing and replacement, calibration and validation records shall be accessible and retained indefinitely. • Reference spectrum (i.e., sensor dark and light counts in ultra-pure water) shall be recorded.		Dedicated instrument database or asset management system recommended.	
	Time series label	• Time series labels should include sensor model. *Note: Labels could be for time series, parameter or unit depending on database structure and limits.*		If sensor model is available in multiple pathlengths, consider adding pathlength to label.	
	Algorithms	• All algorithms for calculating nitrate, including sensor check algorithms shall be tracked and accessible.			
	Processing of data	• Incoming data shall be tracked, and records of quality checks maintained and available. • All supplementary data shall be available. • All changes from raw data shall be documented. • Automated facilities shall be controlled, documented, and regularly evaluated. • Time-series comments shall be timestamped at the start of the applicable record period or gap.			
	Derived values	Any derived values (local adjustments or new algorithms) shall be: • fully traceable back to the sensor or logger output • labelled, and kept separate from measured data, and • summarised in the time-series metadata.			
Stationarity	Change of sensor method or location			Recommended to co-locate new sensor type with existing for a period of overlap that captures typical range of measurement. Create a new site if: • Change of location alters site factors (e.g. range of characteristics), or Analysis of co-located data identifies significant difference following the change of sensor technology.	Might not just be sensor type.
Quality assurance	Field and office manual	• Monitoring agency shall develop SOP(s) or equivalent. • Staff shall be conversant with the SOP(s) and competent to perform required tasks.		• A site-specific fouling management plan shall be developed. • The plan shall be revised if the installed system is unable to maintain a clean lens.	

		Requirements for all data	Requirements for good data	Recommendations	Notes
	Data grading		• Monitoring agency shall develop SOP(s) or equivalent. • Staff shall be conversant with the SOP(s) and competent to perform required tasks. *Note: The manufacturer's quality code may apply to the raw sensor values (counts or counts converted to absorbances) or calculated nitrate values.* *Note: The manufacturer's quality code may be specific to an algorithm. Selecting a different algorithm may change the value's quality code.*		
	Station inspection			Visual inspection of structures and all on-site equipment recommended at least once every 12 months at long-term or permanent stations.	
	Field site audit			Independent check of deployment and field activities at permanent stations.	
Stationarity	Change of sensor location or method			Recommended to co-locate new sensor type with existing for a period of overlap that captures typical range of measurement. Create a new site if: • Change of location alters site factors (e.g. range of characteristics), or • Analysis of co-located data identifies significant difference following the change of sensor technology.	
Archiving	Original and final records	Store, retain indefinitely, and if electronic, back up regularly: • Original data • Final data • Supplementary measurements • All required metadata (including all calibration, validation, verification and editing information). • Additional time series and/or metadata used and/or generated during data processing.		If collected, complementary data shall be: • Identified, • available during data processing, and stored indefinitely.	

Table 2. Draft NEMS for continuous electrical conductivity.

		Requirements for all data	Requirements for good data	Recommendations	Notes
Risk Management	Scope			• Secure and safe access. • Hazards identified (initial and on-going) • Compliance with regulations as required.	
	Site access and security			• Adequate for all equipment and conditions. • Permissions, consents and engineered design, as required. • Signage and security devices as needed. • Long-term access agreement recommended.	
Site selection	Location		• Representative of the target characteristics of the water body or location to be measured. *Note: In most cases, the above will also require a well-mixed location.*		
	Mixing considerations			Horizontal (rivers) or vertical (lakes and estuaries) cross-section survey recommended.	
Measurement	Units	• Freshwater: µS/m at 25 °C • Coastal and estuarine water: mS/m at 25 °C *Note: 1 µS/cm is equivalent to 0.1 mS/m.*			
	Minimum resolution	• Freshwater: 0.1 µS/cm • Coastal & estuarine: 1 mS/m			Check coastal resolution
	Method	Electrical conductivity sensor deployed in-situ			
	Reference method	Calibrated, independent, and portable electrical conductivity & temperature sensor			
	Reference sensor accuracy	• Freshwater: ± 1 µS/cm, or ± 0.5% for full scale error • Coastal & estuarine: ± 5 mS/m, or ± 0.5% for full scale error			
Timing of measurements	Sampling method	A point sample stored as an instantaneous value. *Note: a representative average value of a burst of measurements may be used but must result in a point sample.*			
	Resolution	1 second			
	Maximum recording internal (for in-situ)		5 minutes (estuarine). 15 minutes (rivers, lakes and the open ocean)		
	Accuracy		• Within ± 90 s of actual NZST, and • Clock drift <± 90 s over 30 days.		
Instrumentation	External data logger		Stores data without compromising the accuracy, resolution and recording interval also required for QC 600.		
In-situ conductivity sensor	Accuracy		Manufacturer's stated accuracy of at least: • for freshwater: ± 1 µS/cm (or ± 0.5% for full-scale error), • for coastal waters: ± 5 mS/m (or ± 0.5% for full scale error)		
	Range		• Measures the full range of conductivity values to the accuracy and resolution required for QC600.		Not defined.
	Operation		• Sensor and shroud/casing are not obstructed, buried, exposed to the air, or damaged.		
	Calibration method	Some sensors should only be factory calibrated. If calibration to a standard is recommended: • Stable environment • Two-point calibration, or • Guided by manufacturer's instructions and/or recommendations			
	Reference		Standards • Freshwater: appropriate standard(s) for deployment environment. • Estuarine: 1288 mS/m • Coastal: 5300 mS/m		
	Calibration frequency		• When validation fails (unless replaced), and • At no stage less than the manufacturer's recommendations	Recommended: • Return conductivity sensor for routine manufacturer re-calibration as and when recommended by manufacturer, or when verification and validation failed.	

	Validation method	Using a standard solution of: • Coastal waters 5300 mS/m (53,000 µS/cm) • Estuarine: 1288 mS/m (12880 µS/cm) • Freshwater: appropriate standard for deployment environment. *Note: Standards below 1000 µS/cm can easily become contaminated.*			
	Validation frequency	• Before deployment	• When verification fails • On retrieval at the end of any monitoring period.		
	Validation acceptance criteria		Measurement within ± 5% of standard, or if low conductivity standards are used: • Standard ≤ 10 µS/cm: ± 25% • Standard >10 and ≤ 200 µS/cm: ± 15%		
Reference conductivity sensor	Validation frequency		Within the last 7 days	Recommended: • On day of and prior to intended use. • When troubleshooting a failed verification.	
	Validation acceptance criteria		Measurement within 5% of standard, or if low conductivity standards are used: • Standard ≤ 10 µS/cm: ± 25% • Standard >10 and ≤ 200 µS/cm: ± 15%		
	Instrumentation			Instruments with all sensors built-in to the reference conductivity sensor are preferred	
Maintenance	In-situ sensor			• Biofouling management plan recommended. • Wiper system recommended to reduce fouling. *Note: Fouling will change the conductivity cell dimensions and alter the calibration.*	
Verification	Method	• Reference measurements shall be made using independent reference sensor, as close to time and place of in-situ measurement as possible. • Calculate difference between reference measurement and concurrent logged value from in-situ sensor (ensuring the same form and units of measurement), and • Compare difference to verification tolerance (for each variable).		All variables recorded continuously at site should be verified together	
	Verification tolerance		• Specific conductivity: ± 5% of reference value • Water temperature: ± 5%		
	Frequency		Logged values for specific conductivity shall be verified • Immediately following sensor deployment • During every verification visit • At least once every 90 days for surface water • On retrieval at the end of any monitoring period	Recommended at least every 60 days.	
	Method			Recommended: • In still or saline waters, take side by side reference and in-situ sensor measurements in a well-mixed bucket containing water of interest. • Use electronic field forms to calculate verification tolerances that include proportion of reference reading.	
Supplementary measurements	**Water temperature**	Required for specific conductivity.			
	Method	• Temperature sensor built into, or integrated with, the in-situ conductivity sensor, and • Logged concurrently with conductivity		Instruments with all sensors built-in to in-situ conductivity sensor are preferred.	
	Units	Degrees Celsius (°C)			
	Minimum Resolution	0.02 °C			
	Sensor accuracy (reference and in-situ)	• Manufacturer's stated accuracy of ± 0.5 °C or better			
	Primary reference method	Certified traceable reference thermometer as per NEMS Water Temperature			

	Reference method	Independent portable temperature sensor or field reference thermometer *Note: Sensor may be built into a multi-parameter and/or handheld instrument.*			
	Reference sensor validation method	Minimum 5-point check in water bath against two primary references as per NEMS Water Temperature		As per NEMS Continuous Water Temperature V3.	
	Reference sensor validation			Recommended before validation of the conductivity sensor during pre-deployment checks.	
	Raw conductivity or engineering units			Recorded at the same frequency and time s.	Useful as a backup - temp sensor failure.
Complementary measurements	**Water level**			Can identify dewatering events and track sensor depth or bed clearance when not reasonably static due to changing water levels.	
	Archiving			If collected, complementary data shall be: • Identified, • available during data processing, and • stored indefinitely.	
Metadata	Scope	• Recorded for all sites and measurements. • Permanently archived and discoverable.			
	Identification of Standards	• Standards and versions applied shall be tracked over time in time-stamped Stationarity Comments			
	Identification of data	All data shall be identified by a minimum of: • A unique site name and/or identifier • The variable's name and units, and • Date and time of the measurement or record.			
	Quality coding	All data shall be quality coded using the NEMS *National Quality Code Schema*.			
	Site records	• All stations shall have a unique identifier • The Station History (or site file) shall be established or maintained. • Remote telemetry station configuration changes shall be controlled and recorded. • All supplementary data shall be identified and described. • Significant site and station maintenance shall be recorded in the Station History. • 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.			
	Site visit records	• A record of every site visit shall be made, including routine cleaning and maintenance and verification details. • The records shall be accessible when data are processed and retained indefinitely as original data.			
	Instrument records	• All specification, configuration, servicing and replacement, calibration and validation records shall be accessible and retained indefinitely. *Note: include timing method used if part of instrument specification.* • Logger software (documented code and version) shall be controlled and their history maintained and preserved. • Any algorithm used to obtain point samples from a measurement burst shall be described and justified.		Dedicated instrument database or asset management system recommended.	
	Change of method	Every method change shall be: • noted in the site visit records at the time, • added to the relevant history, and • summarised in a filed comment (and in a Stationarity Comment if significant change).			
	Processing of data	• Incoming data shall be tracked, and records of quality checks maintained and available.	.		

		• All supplementary data shall be available. • All changes from raw data shall be documented. • Automated facilities shall be controlled, documented and regularly evaluated. • Time-series comments shall be timestamped at the start of the applicable record period or gap			
	Derived values	Any derived values shall be: • fully traceable back to the sensor or logger output • labelled, or kept separate from measured data, and • summarised in the time series metadata.			
Quality assurance	Field and office manual	• Monitoring agency shall develop SOP(s) or equivalent. • Staff shall be conversant with the SOP(s) and competent to perform required tasks.			
	Telemetered sites			Recommended: • Daily check of data collection, at-site power status and sensor function • Use logs and alerts to help maintain data integrity.	
	Station inspection			Visual inspection of structures and all on-site equipment recommended at least once every 12 months at long-term or permanent stations.	
	Field site audit			Independent check of deployment and field activities at permanent stations.	
Stationarity	Change of sensor location or method			Recommended to co-locate new sensor type with existing for a period of overlap that captures typical range of measurement. Create a new site if: • Change of location alters site factors (e.g. range of characteristics), or • Analysis of co-located data identifies significant different following the change of sensor technology.	Change in sensor method (i.e., to or from inductive or capacitive) could make big changes.
Archiving	Original and final records	Store, retain indefinitely, and if electronic, back up regularly: • Original data • Final data • Supplementary measurements • All required metadata (including all calibration, validation, verification and editing information). • Additional time series and/or metadata used and/or generated during data processing.			

Table 3. Draft NEMS for continuous algal fluorescence.

		Requirements for all data	Requirements for good data	Recommendations	Notes
Risk Management	Scope			• Secure and safe access. • Hazards identified (initial and on-going) • Compliance with regulations as required.	
	Site access and security			• Adequate for all equipment and conditions. • Permissions, consents and engineered design, as required. • Signage and security devices as needed. • Long-term access agreement recommended.	
Site selection	Location		• Representative of the target characteristics of the water body or location to be measured. • Not influenced by local turbidity or dissolved organics sources. *Note: In most cases, the above will also require a well-mixed location.*		NERR EXO experiments
	Mixing considerations			Horizontal (rivers) or vertical (lakes and estuaries) cross-section survey recommended.	
Measurement	Units	• Raw (V, counts or engineering units), or • Relative fluorescence units (RFU) *Note: Fluorescence is a surrogate or proxy measure for algal biomass and community composition. "Calibration" of sensor units (RFU, counts) to an algal concentration (mg/l, cells/ml) is outside the scope of this data standard.*			
	Minimum resolution	• 0.01 RFU • 1 count (integer)			
	Method	Fluorescence sensor deployed in-situ			
	Reference method	Calibrated, independent, and portable algal fluorescence sensor.			
	Reference sensor accuracy	Same or better than in-situ sensor.			
Timing of measurements	Sampling method	A point sample stored as an instantaneous value. *Note: a representative average value of a burst of measurements may be used but must result in a point sample.*			
	Resolution	1 second			
	Maximum recording internal (in-situ)		5 minutes (estuarine). 15 minutes (rivers, lakes and the open ocean)		
	Accuracy		• Within ± 90 s of actual NZST, and • Clock drift <± 90 s over 30 days.		
Instrumentation	External data logger		Stores data without compromising the accuracy, resolution and recording interval also required for QC 600.		
In-situ fluorescence sensor checks	Accuracy		*Note: Manufacturer's stated accuracy is likely for ideal and undisclosed test conditions.*		
	Range	Measures the full range of pigment fluorescence values expected at the site. *Note: For fluorescence sensors operating in turbid waters the measurement range is less than the manufacturer's stated range.*			
	Resolution		*Note: Resolution will depend on the units output by the sensor (counts, V or RFU).*		
	Operation		• Sensor and shroud/casing are not obstructed, buried, exposed to the air, or damaged. • The in-situ sensor shall be protected from stray light.		
	Sensor checks	Note: The purpose of algal fluorescence sensor calibration and/or validation is to monitor sensor performance and maintain stationarity of record. *Note: Some sensors should only be factory calibrated and the user should validate the sensor. Other sensors require calibration by the user.*	•		

		Requirements for all data	Requirements for good data	Recommendations	Notes
	Calibration method	As guided by manufacturer's recommendations. If calibration to a secondary standard is recommended: • Conduct in a stable environment that: • Is clean, with clean equipment • Has a stable temperature • Has consistent light conditions • Is conducive to good work practice • Two-point calibration, or • Guided by manufacturer's instructions and/or recommendations • Secondary standard should be a fluorescent dye. *Note: There is no universal primary standard for algal fluorescence sensors because no standard can accurately represent the algal community and resulting fluorescence.* *Note: High calibration value will not be 100% RFU*. *Note: Consideration should be given to any change in light conditions (change from fluorescent to LED room lighting, changes in proximity to windows; changes in calibration vessel)*			
	Standards	• At least 2-point at zero and a secondary standard, or as per manufacturer's specification or recommendation. • Care is taken to ensure diluted standards are fresh (<24 hours old). • Include expiry date checks of the concentrate (as purchased) and concentrated stock solution. • Care is taken to mix standards. *Note: Rhodamine WT is a strong dye so use a dedicated rhodamine-only calibration vessel to avoid contaminating a zero standard.* *Note: Some manufacturers recommend omitting the zero point.* *Note: Rhodamine WT is often used as a secondary standard. Stationarity of Rhodamine WT supplier is recommended.* *Note: Calibration solution can degrade over time if exposed to light and repeated warming cycles.*	• Standards shall be temperature referenced.		
	Calibration frequency	As guided by manufacturer's recommendations.	As guided by manufacturer's recommendations. When manufacturer requires calibration: • When validation fails (unless replaced), and • At no stage less than the manufacturer's recommendations.	Recommended: • Return fluorescence sensors for routine manufacturer re-calibration as and when recommended by manufacturer, or when verification and validation failed.	
	Validation method	Conduct in a stable environment that: • Is clean, with clean equipment • Has a stable temperature • Has consistent light conditions • Is conducive to good work practice • Guided by manufacturer's instructions and/or recommendations, or • Two-point validation using a secondary standard of a fluorescent dye. • A solid-state standard(s) could be used to check for sensor drift. *Note: Solid state standards may not produce equivalent results to liquid secondary standards. A robust evaluation of solid state standard performance is recommended.* *Note: Solid state standards are best used under clean conditions and at a near constant temperature.* *Note: Solid state standards should also be temperature indexed.*			
	Validation frequency		• Prior to deployment • When verification fails • On retrieval at the end of any monitoring period.		

		Requirements for all data	Requirements for good data	Recommendations	Notes
	Validation acceptance criteria		Measurement within ± 5% of standard		
Reference fluorescence sensor	Validation frequency		Within the last 7 days	Recommended: • On day of and prior to intended use. • When troubleshooting a failed verification.	
	Validation acceptance criteria	±5%			interpret Foster et al. (2022) tm1d10.
	Instrumentation	• Use of the same sensor model as the in-situ sensor will simplify verification. • If the in-situ and reference sensors are different models a site-specific relationship between them will be required. • Note: Sensor optical design, including the excitation and emission wavelengths, are different between models.		Instruments with all sensors built-in to the reference fluorescence sensor are preferred	
Maintenance	Fouling management	The impact of biofouling should be managed. • Use a proprietary or third-party mechanical wiper system. • Monitor the operation and performance of the mechanical wiper. *Note: Fouling may vary seasonally.*	• Fouling management system maintains clean lens.	• Biofouling management plan recommended. • Fouling management system should clean lens prior to each measurement. • Mechanical wiper metadata is captured and stored to inform biofouling management plan.	
	Operation	• Sensor is clean, and not obstructed or buried, or exposed to the air, or damaged or disturbed.			
	Lens inspection	• Visual inspection of clean lens condition at least once a year, and • Subject to monitored sensor performance. • Use magnification to detect abrasion or chemical fouling.			
	Firmware	• Sensor firmware should be checked for updates at least annually.			
	Stray light	The impact of ambient light should be managed: • Shield the sensor using a housing and/or guard • Test the sensor manufacturer's method for reducing the impact of stray light (filters or background fluorescence) • Verify the sensor in low ambient light conditions and store only low ambient light data.			
Verification	Method	• All variables recorded continuously at site should be verified together. • Reference measurements shall be made using validated and/or calibrated reference sensor, as close to time and place of in-situ measurement as possible. • If the reference sensor is a different model, adjust the reference sensor value to an equivalent in-situ sensor value using a site-specific relationship. • Calculate difference between reference measurement (raw or adjusted) and concurrent logged value from in-situ sensor (ensuring conformity of units), and • Compare difference to verification tolerance.		All variables recorded continuously at site should be verified together	
	Verification tolerance		± 5% of reference value		
	Frequency		Logged values for fluorescence shall be verified • Immediately following sensor deployment • During every verification visit • At least once every 60 days • On retrieval at the end of any monitoring period	Recommended at least every 60 days.	
	Method			Recommended: • In still or saline waters, take side by side reference and in-situ sensor measurements in a well-mixed bucket containing water of interest. • Use electronic field forms to calculate verification tolerances that include proportion of reference reading.	

		Requirements for all data	Requirements for good data	Recommendations	Notes
Supplementary measurements	**Water temperature**			Required for calibration and may be used for temperature correction of in-situ sensor values.	
	Method			• Temperature sensor built into, or integrated with, the in-situ fluorescence sensor, and • Logged concurrently with fluorescence *Note: Instruments with all sensors built-in to in-situ fluorescence sensor are preferred.*	
	Units			Degrees Celsius (°C)	
	Minimum Resolution			0.02 °C	
	Sensor accuracy (reference and in-situ)			Manufacturer's stated accuracy of ± 0.5 °C or better	
	Primary reference method			Certified traceable reference thermometer as per NEMS Water Temperature	
	Reference method			Independent portable temperature sensor or field reference thermometer *Note: Sensor may be built into a multi-parameter and/or handheld instrument.*	
	Reference sensor validation method			As per NEMS Continuous Water Temperature V3.	
	Reference sensor validation			As per NEMS Continuous Water Temperature V3.	
Complementary measurements	**Turbidity**			May be used to develop site-specific turbidity corrections. Could also help inform data processing and analysis.	
	Method			Any suitable method for measuring turbidity or optical scattering: • Meeting a recognised standard (ISO 7027, EPA 180.1) • Not meeting a standard *Note: despite recognised standards turbidity and optical scattering sensors lack numerical comparability*	Wider than NEMS Turb V2, some backscatter or unknown optical geometry.
	Units			Any recognised turbidity unit, volts (V) or counts.	
	Minimum resolution			0.1 NTU/FNU 1 count	
	Reference method			• Sensor of the same model as the in-situ sensor, • Sensor of a different model with a known relationship between the in-situ sensor and reference sensor, or • Lab turbidity	Lab turb QC500 NEMS Turb V2
	Verification				
	Dissolved organic matter			May be used to: • develop site-specific dissolved organic matter corrections. • inform data processing.	
	Method			At a site, using any fDOM sensor with known • Light source peak wavelength, • Optical geometry, and Detector peak wavelength and/or bandpass filter.	
	Units			Relative fluorescence units (RFU), counts, volts (V) or raw engineering units	
	Minimum resolution			0.1 RFU 1 count	
	Reference method			Calibrated, independent, and portable fDOM sensor. • Sensor of the same model as the in-situ sensor, or • Sensor of a different model with a known relationship between the in-situ sensor and reference sensor.	Simpler to use the same model.
Metadata	Scope	• Recorded for all sites and measurements. • Permanently archived and discoverable.			
	Identification of Standards	• Standards and versions applied shall be tracked over time in time-stamped Stationarity Comments			
	Identification of data	All data shall be identified by a minimum of: • A unique site name and/or identifier			

		Requirements for all data	Requirements for good data	Recommendations	Notes
		• The variable's name and units, and • Date and time of the measurement or record.			
	Quality coding	All data shall be quality coded using the NEMS *National Quality Code Schema*.			
	Site records	• All stations shall have a unique identifier • The Station History (or site file) shall be established or maintained. • Remote telemetry station configuration changes shall be controlled and recorded. • All supplementary data shall be identified and described. • Significant site and station maintenance shall be recorded in the Station History. • 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.			
	Site visit records	• A record of every site visit shall be made, including routine cleaning and maintenance and verification details. • The records shall be accessible when data are processed and retained indefinitely as original data.			
	Instrument records	• All specification, configuration, servicing and replacement, calibration and validation records shall be accessible and retained indefinitely. *Note: include timing method used if part of instrument specification.* • Logger software (documented code and version) shall be controlled and their history maintained and preserved.			
	Instrument records	Any algorithm used to obtain point samples from a measurement burst shall be described and justified.			
	Change of method	Every method change shall be: • noted in the site visit records at the time, • added to the relevant history, and • summarised in a filed comment (and in a Stationarity Comment if significant change).			
	Processing of data	• Incoming data shall be tracked, and records of quality checks maintained and available. • All supplementary data shall be available. • All changes from raw data shall be documented. • Automated facilities shall be controlled, documented and regularly evaluated. • Time-series comments shall be timestamped at the start of the applicable record period or gap	.		
	Derived values	Any derived values shall be: • fully traceable back to the sensor or logger output • labelled, or kept separate from measured data, and • summarised in the time series metadata.			
	Instrument history			Dedicated instrument database or asset management system recommended.	
Quality assurance	Field and office manual	• Monitoring agency shall develop SOP(s) or equivalent. • Staff shall be conversant with the SOP(s) and competent to perform required tasks.			
	Telemetered sites			Recommended: • Daily check of data collection, at-site power status and sensor function • Use logs and alerts to help maintain data integrity.	
	Station inspection			Visual inspection of structures and all on-site equipment recommended at least once every 12 months at long-term or permanent stations.	

		Requirements for all data	Requirements for good data	Recommendations	Notes
	Field site audit			Independent check of deployment and field activities at permanent stations.	
Stationarity	Change of sensor location or method			Recommended to co-locate new sensor type with existing for a period of overlap that captures typical range of measurement. Create a new site if: • Change of location alters site factors (e.g. range of characteristics), or • Analysis of co-located data identifies significant difference following the change of sensor technology.	
Archiving	Original and final records	Store, retain indefinitely, and if electronic, back up regularly: • Original data • Final data • Supplementary measurements • All required metadata (including all calibration, validation, verification and editing information). • Additional time series and/or metadata used and/or generated during data processing.		If collected, complementary data shall be: • Identified, • available during data processing, and stored indefinitely.	

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