National Environmental Monitoring Standards

Water Level

Continuous Measurement of Water Levels for Environmental Monitoring Purposes

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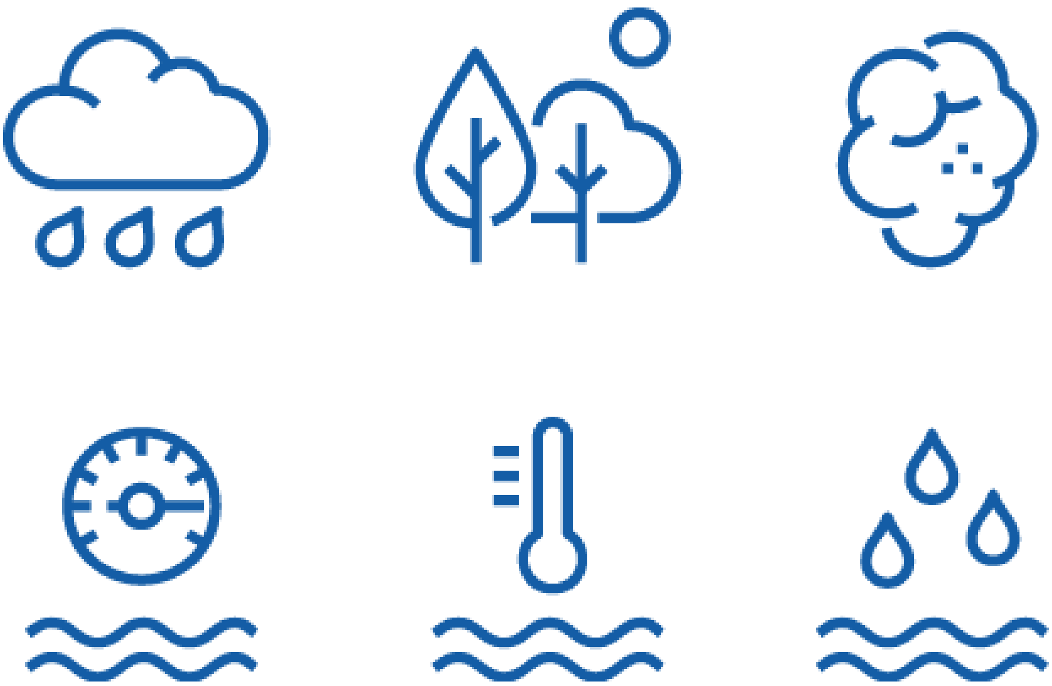

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Change register

Version Number	Revision Date	Section	Topic	Revision Summary
1.0	Jun 2013			Initial release.
2.0	Jul 2016			
3.0.0	Jul 2019			
3.1.0	Dec 2022			Draft only. Not released due to pending new document structure/format.
4.0.0	Oct 2024	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.		
4.0.1	Oct 2025	The Standard – Water Level		Requirement for 2 or 3 monthly site visits removed and replaced with alternate wording.
		7.5.3	Frequency	Wording changes to align with the above change to the Standard.
		Annex A – Visit Matrix		Wording changes to align with the above change to the Standard.
	Throughout this Standard			Minor wording changes to improve clarity.

Table of Contents

The National Environmental Monitoring Standards

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

Development

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

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

Implementation of the strategy is overseen by the NEMS Steering Group, which currently comprises Glenn Ellery (Chair), Jeff Watson (Technical Advisor), Phillip Downes, Rachel Herbert, Jon Marks, Charles Pearson, Jochen Schmidt, Michael Ede, Dan Elder, 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.

Review

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

Feedback

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

About this Standard

Introduction

Water level information is collected from a variety of water bodies and used for many purposes.

In rivers, a water level record is most often collected as a surrogate for a record of flow because of difficulty continuously measuring flow directly. When water levels are used for this purpose, a good understanding of the relationship between water level and flow, and the problems faced in maintaining that relationship, is required.

Water levels may also be analysed on their own (e.g. flood levels, tide) or used in conjunction with other variables, often those associated with water quality.

It is important to understand the range of uses to which the data can be put, and to ensure that data collected for one purpose can be used as widely as possible in the future. Key to compiling a useful long-term record of water level measurements (and derived flows) is the understanding of, and catering for, stationarity.

Formal water level recording started in New Zealand in the 1890's. Collecting water level information to calculate flow data for hydro-electricity development and flood protection works began in the late 1920's, and for irrigation investigations in the 1930's.

In 1949 the first Hydraulic Survey parties were established, and during the 1950's and 1960's many hydrological recording stations were built for a wide variety of purposes including flood control and soil conservation studies. The International Hydrological Decade (commencing 1964) saw a notable period of growth in data collection and analysis, with the emergence of both the first truly accurate recording instruments and computers to store and analyse the data.

Growth in the number of recording stations continued, and by 2010 the total number of surface water level recorders reached more than 1300, with an additional 470 being deployed for the purpose of measuring groundwater.

This version of this Standard is the culmination of a review in late 2022 by Graeme Horrell (Graeme Horrell Consultancy Ltd), Matthew Rowland (Greater Wellington Regional Council) and Paul Peters (Horizons Regional Council), subsequently updated and restructured by Marianne Watson (Hydronet Limited) to apply a new, more standardised format for NEMS Standards adopted in early 2024. Input from the newly formed NEMS Technical Oversight Group is also gratefully acknowledged.

Objective

The objective of this Standard is to ensure that water levels measured in aquifers, lakes, reservoirs, flowing channels, and the sea, 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 the deployment of in-situ instruments for the continuous recording of water level in aquifers, lakes, reservoirs, flowing channels, and the sea.

Exclusions

This Standard does not address piped networks and enclosed storages and does not apply to the monitoring of water levels for industrial applications.

Terms, definitions, and symbols

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

Normative references

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

- NEMS *Data Processing – Processing of Environmental Time-series Data*
- NEMS *Glossary – Terms, Definitions and Symbols*
- NEMS *Guidelines for Hydrological and Meteorological Structures*

- NEMS *Open Channel Flow Measurement – Measurement, Processing and Archiving of Open Channel Flow Data*
- NEMS *Safe Acquisition of Field Data in and Around Fresh Water – Code of Practice*
- NEMS *Site Surveys – Code of Practice*
- NZS 4411:2001 *Environmental Standard for Drilling of Soil and Rock*, and subsequent Standards.
- WorkSafe *Health and Safety Guidelines for Shallow Geothermal Wells*, and subsequent guidance. Accessible from www.worksafe.govt.nz/topic-and-industry/geothermal/health-and-safety-guidelines-for-shallow-geothermal-wells/.

The Standard – Water Level

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

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

Data that are collected, processed, and archived to meet requirements of the first three tables, in a verifiable and consistent manner, can be assigned the highest quality code (QC 600). When these requirements are not met, a lower quality code is assigned, deduced from the quality coding flow chart for water level 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 legislation, including relevant amendments, shall be complied with.
Stationarity		• Maintained wherever possible. • Documented in metadata if change occurs or is likely to occur. • If significant change (as defined in site requirements), create a new site.
Units of measurement		• Metric system. • SI units, unless stated otherwise (in the relevant Standard).
Timing of measurements	Time zone	Use New Zealand Standard Time (NZST), or Chatham Is. Standard Time (CHAST) as applicable. Do not use Daylight Time (NZDT or CHADT).
Metadata	Scope	• Recorded for all sites and measurements. • Permanently archived and discoverable.
	Identification of Standards	Standards and versions applied shall be tracked over time in time-stamped Stationarity Comments.
	Identification of data	All data shall be identified by a minimum of: • a unique site name and/or identifier • the variable's name and units (as defined in its relevant NEMS), and • date and time of the measurement or record.
	Quality coding	All data shall be quality coded using the NEMS *National Quality Code Schema*.
Archiving	Original and final records	Store, retain indefinitely, and if electronic, back up regularly:

		• Original data (as defined by the recording agency). • Final data (as verified). • Supplementary measurements. • All required metadata (including all calibration, validation, verification and editing information). • Additional time series and/or metadata used and/or generated during data processing.

Requirements for water level data irrespective of quality

Table 2 – Requirements for water level data irrespective of quality.

Measurement	Units (7.2.1)		Express units in: • metres (m), or • millimetres (mm).
	References (2.8)	Datum	All water level data shall be related to a known datum. *Note: NZVD2016 is preferred, but may be local (including MSL), or assumed.*
		Reference gauge(s)	• Independent of recorder. • Spirit levelled from benchmarks. • One per site nominated as primary reference.
Supplementary measurements	Barometric pressure (2.2.2.1 & 2.7.1)		Required for unvented pressure transducers.
Timing of measurements	Resolution (7.2.3.2)		1 s
	Sampling method (7.2.2)		Point sample stored as an instantaneous value. *Note: A representative value (e.g. average or minimum) of a burst of measurements may be used but must result in a point sample.*
Verification	Reference measurement (7.5.4.2 & 7.5.6)		• Nearest 1 mm with estimate of uncertainty. • If unreadable, survey the water level.

Metadata	Site records (1.7, 3.3.4.3, 3.4.1, 3.4.2 & 6.3)	• All stations shall have a unique identifier. • A Station History (or site file) shall be established and maintained, including a bore log at groundwater stations. • Remote telemetry station configuration changes shall be controlled and recorded. • All maintenance activities shall be logged. Records of those activities with bearing on data quality shall be retained indefinitely.
	Site visit records (7.2.8)	Record of every site visit shall be made and retained indefinitely as original data.
	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.)	Instrument records (2.9, 3.3.4, 4.6 & 5.5)	• All specification, configuration, calibration, and validation records shall be collated and retained indefinitely. *Note: Include timing method used if part of instrument specification.* • Logger software history (version and code) shall be maintained and preserved.
	Change of method (8.3)	Every method change shall be: • Noted in the site visit records at the time. • Added to the relevant history. • Summarised in a filed comment, and in a Stationarity Comment if significant change.
	Processing of data (3.3.4, 7.2.7 & 7.7)	• Incoming data shall be tracked, and records of quality checks maintained and available. • All changes from raw data shall be documented. • Automated facilities shall be controlled, documented, and regularly evaluated. • Time-series comments shall be timestamped at the start of the applicable record period or gap.
	Supplementary measurements (7.2.4)	All supplementary data shall be identified and described and stored indefinitely.

	Derived values	Statistics (10.2.1)	Shall be identified and labelled, catalogued in the metadata, kept separate from measured data, and used appropriately.
		Transformations (10.2.2)	Shall be fully traceable back to sensor output and summarised in the time-series metadata.

Additional requirements for water level 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 water level data irrespective of quality:

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

<table>
<tr><td rowspan="4">Accuracy</td><td rowspan="2">In-situ sensor
(7.2.3.1)</td><td>Rivers, lakes</td><td>The greater of:
• ± 3 mm, or
• ± 0.2% of effective stage.</td></tr>
<tr><td>Groundwater, sea</td><td>The greater of:
• ± 10 mm, or
• ± 0.2% of effective stage.</td></tr>
<tr><td colspan="2">Datum
(2.8.3 & 8.1.1)</td><td>Reduced level of recording zero demonstrated constant over time to ± 3 mm.</td></tr>
<tr><td colspan="2">Reference gauges(s)
(2.8.3 & 8.1.1)</td><td>Gauge zero = adopted recording zero ± 3 mm.</td></tr>
<tr><td colspan="3">Resolution (2.4.1, 3.3.3 & 7.2.3.1)</td><td>1 mm</td></tr>
<tr><td rowspan="5">Instrumentation</td><td rowspan="2">Sea level</td><td>Pressure transducer
(2.7.2.2)</td><td>Readings adjusted for density of sea water.</td></tr>
<tr><td>Gas bubbler
(1.6.6)</td><td>Suitable outlet bell fitted.</td></tr>
<tr><td colspan="2">Acoustic (sound path in water)
(2.2.3 & 2.7.4)</td><td>Readings adjusted for water temperature.</td></tr>
<tr><td colspan="2">Stilling well intake(s)
(3.1.2.5)</td><td>• Diameter achieves damping without lag.
• Fitted with correctly oriented static tube.</td></tr>
<tr><td colspan="2">Stilling well primary reference
(3.3.3.2)</td><td>Electric plumb bob installed.</td></tr>
<tr><td rowspan="2">Timing of measurements</td><td rowspan="2">Maximum recording interval</td><td>Rivers, lakes</td><td>5 min.</td></tr>
<tr><td>Groundwater</td><td>15 min.</td></tr>
</table>

Timing of measurements (cont.)	(7.2.2)	Sea	1 min.
	Sampling method	Sea (7.2.2)	1-minute average or median of a 1 Hz minimum burst of measurements.
	Accuracy (7.2.3.2)	Rivers, lakes, groundwater	• Within ± 90 s of actual NZST, and • Clock drift less than ± 90 s over a month.
		Sea	• Within ± 20 s of actual NZST, and • Clock drift less than ± 20 s over a month.
Calibration	In-situ sensor (4.4)	Frequency	When sensor validation has failed OR As a minimum, either: • Annually for pressure transducers, or • As specified by the manufacturer.
		Method	• Controlled, indoor environment, and • Follow manufacturer or service agent instructions.
	Reference gauge(s) (4.2 & 4.3)	Frequency	On installation
		Method	Spirit level survey using a minimum of three established benchmarks with misclose ≤ 3 mm.
	Portable calibrator (4.5.1)	Frequency	Annual.
		Method	Tested at an accredited facility.
Validation	In-situ sensor (5.4)	Frequency	• Pre-deployment. • When two consecutive verifications fail.
		Method	• Portable calibrator for pressure transducers.
	Reference gauge(s) (5.2 & 5.3)	Frequency	• When disturbance or damage is evident OR • As a minimum, biennially.
		Method	Spirit level survey using a minimum of three established benchmarks with misclose ≤ 3 mm.

Verification (7.5)	Recording installation	Frequency	• 3 monthly for sites that have telemetered dual independent sensors, and the sensors show less than +/-3mm deviation at all times, or else 2 monthly. • 2 monthly for sites that do not meet the above requirement • Monthly for 'troublesome[1]' sites.
		Method	Difference between logged value and primary (and/or reliable) reference within tolerance. *Note: Disagreement between EPB and ESG indicates silted stilling well and/or intake(s).*
Verification (7.5) (cont.)	Recording installation (cont.)	Primary reference	Uncertainty of reading ≤ verification tolerance.
		Tolerance	The accuracy required (as stated above) for the actual water level at the time of verification.
Supplementary measurements (7.2.4)	Salinity (or conductivity) (2.7.2.1)		Required for pressure transducers in estuarine environments.
	Water temperature (2.2.3 & 2.7.4)		Required for submersible acoustic sensors without on-board temperature compensation. *Note: May use a reference bar instead.*

[1] 'Issues the can cause a site to be considered *'Troublesome' are described in Section 7.5.3*

Other requirements, guidelines, and recommendations

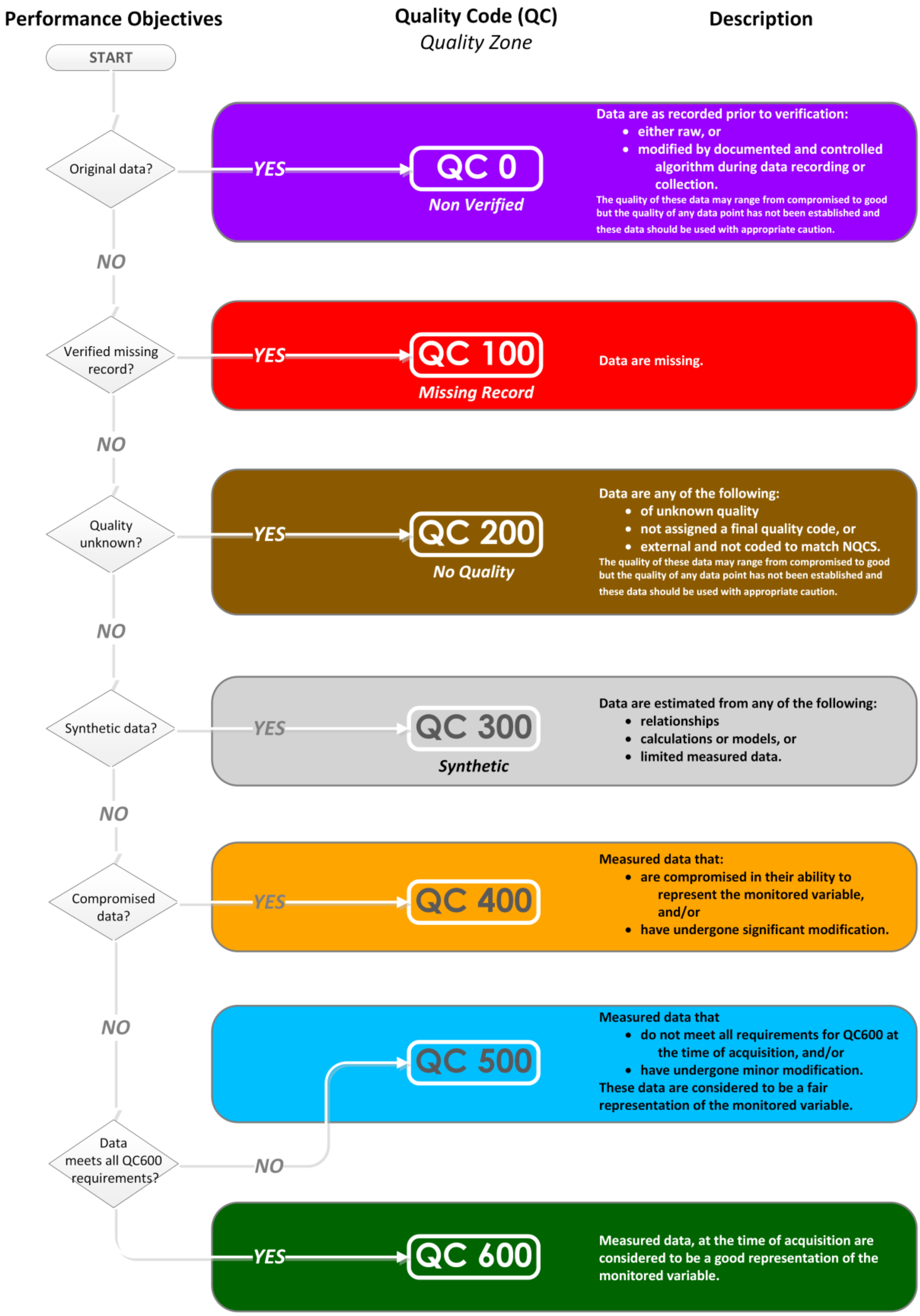
The following table summarises other requirements and guidelines (e.g. for quality assurance or lower quality codes), and additional recommended practices that are either not relevant to or not required for QC 600 but if implemented will enhance work practices and data quality.

Table 4 – Other requirements, guidelines, and recommendations.

Risk management	Scope (1.2)		• Secure and safe access. • Hazards identified (initial and on-going),
	Site access and security (1.2.1, 3.1.1 & 3.1.2)		• Permission required for all access. • Long-term access agreement recommended. • Signage and security systems required.
Site selection	As surrogate for flow	Rivers, lakes (1.3 & 1.4)	• Suitable gauging reach and flow controls. • Locate recorder in gauging reach if possible. *Note: Impact of these aspects on quality code of flow data is assessed via NEMS* Rating Curves.
Station design, construction, and installation (3.1.2, 3.2 & 3.3)			Conforms to requirements and guidance.
Measurement	Range	Rivers (1.3.4 & 1.3.5)	Recommended up to 200-yr ARI flood level and allow for long-term bed movement. *Note: Recommend restricting gravel extraction.*
		Sea (1.6.4)	Allow for storm surge, wave run-up, sea level rise and tsunami.
		Stilling wells (3.1.2.5)	Lowest intake shall be: • ≥ 150 mm below lowest possible water level. • ≥ 300 mm above bottom of stilling well.
	Vertical datum (2.8.1)		Use NZVD 2016 unless impracticable.
	Missing data (7.7.3)		• Operational target of < 5 days total missing from one year of any two consecutive years. • Backup sensor and logger recommended.
	Barometric pressure	Groundwater, sea	Recommended to aid interpretation and assist with verification and analysis of water levels.

Complementary measurements (2.7 & 7.2.5)	Wind speed & direction	Sea (1.6.2)	
Verification (7.5)	Recording installation	Frequency	Recheck agreement within 7 days if primary reference reading uncertainty > verification tolerance.
Audit	Field site audit (8.1.2)		Agencies shall document and implement a standard methodology for audit and review.

Quality coding of water level 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 water level data.

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

Water level 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 site. By selecting the best available site and, for rivers and lakes, choosing the best available control feature(s) or installing the best possible control structure, data quality will be maximised, and work minimised over the period of the record.

Figure 1 – Water level station at Lake Hauroko, Fiordland.
Photographer: NIWA.

1.1 Sources of information

Use the following sources of information, where available or reasonably obtainable, to help decide the most appropriate stretch of river or shoreline in which to locate the site:

- topographical maps
- aerial photographs and plans, including historical aerial photography
- local advice on access, stability, and history
- land ownership

- consent information about local water takes and discharges
- cross-sections, long-sections, bathymetry, and/or LiDAR
- borehole information such as well (drilling) logs, pumping infrastructure and operational characteristics (for groundwater)
- the 200-year average recurrence interval (ARI) flood level (for rivers, lakes, reservoirs, and estuaries) (see Annex H), and
- historic and current information about other extreme water levels (high and low), e.g. tides and wave heights (sea level and estuaries), and lake seiche.

1.2 Risk management

1.2.1 Site access

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

A long-term 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 recording agency's organisational hazard management processes.

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

1.3 Site factors – river stations

1.3.1 Monitoring purpose

River stations are most often installed to monitor water levels as a surrogate for recording river flow. When operated for this purpose the site must be associated with a suitable gauging reach (see section 1.3.2) and the hydraulic properties of the recording reach must be considered (see sections 1.3.7 and 1.3.8).

1.3.2 Location

If flow is to be derived by rating curves from the recorded water levels, the water level recording site shall preferably be located in a long, straight reach that is also suitable for discharge measurement (i.e. gauging) (see NEMS *Open Channel Flow Measurement*).

If some or all gauging must be undertaken in a different reach, account for conceivable inflows or outflows between the water level recording installation and the gauging location(s).

Note: High flows may need to be gauged from a bridge or cableway some distance from the recorder (and wading gauging section). In highly mobile rivers, gauging location may differ with each measurement. The further the distance between recorder and gauging sections the more uncertainty is introduced to the stage-discharge rating due to possible inflows and outflows and time of travel. Inflows and outflows may arise from surface tributary inflows or diversions, gains from or losses to groundwater, or discharges to water or water takes, and may be seasonal or intermittent.

1.3.3 Access and legal requirements

Consider the following, in addition to section 1.2.1:

- the ability to position machinery and materials during construction
- provision of safe access to the water's edge for reading of staff gauges and to carry out discharge measurements
- potential environmental effects, and
- resource consent requirements.

1.3.4 Range of measurement

The site should preferably contain all flood flow without overtopping, at least up to the estimated 200-year ARI flood (see Annex H).

The installation should be able to record the 200-year ARI flood without:

- a float hitting the floor of the recorder structure
- a counterweight hitting the bottom of a stilling well
- a pressure transducer over-ranging, or
- a radar becoming immersed.

Ensure a generous allowance for anticipated future riverbed degradation or aggradation (analyse available cross-sections for trends over time if available), and whenever possible include an allowance for extra-large floods.

1.3.5 Installation

Consider the following when selecting a suitable stilling well location or sensor site:

- how to ensure public safety and site security, during construction and ongoing operation of the station
- availability or provision of a solid structure on which to build a stilling well or mount a sensor
  - Substrate needs to be solid or be engineered to provide a durable and solid foundation.
  - Mounting sensors on bridges requires permission from the relevant road controlling authority.
- constructability and durability, including protection from flood damage
- maintenance of the datum, including the installation of:
  - suitable benchmarks, and
  - reference gauges (e.g. external staff gauge or similar)
- an adequate power supply (e.g. solar, mains, or other power sources)
- adequate communication for telemetry
- the ability to deploy a sensor or intake that will cover the full range of anticipated water levels with allowances (see section 1.3.4)
- the likelihood of degradation or aggradation to the extent that water levels cannot be measured

- whether sedimentation will occur in or around a stilling well, intake or sensor, and
- having input into the relevant Regional Plan to prevent gravel abstraction in the vicinity of a flow recording station (500 m upstream and 1000 m downstream is recommended).

These considerations may result in a trade-off between durability and cost.

1.3.6 Hydraulic properties

Rivers have hydraulic properties that should be considered, including:

- availability of a recorder cross-section with minimal turbulence throughout the flow range, and
- if flow is to be derived from water level:
  - the presence and location of suitable flow control(s), and
  - the possibility of backwater effects (see section 1.3.7).

1.3.7 Flow controls

A flow (hydraulic) control is one or more physical features, natural or artificial, in a cross-section (section control) or river reach (channel control) that govern the level of the water.

The nature of the control(s) determine the relationship between stage height and discharge at the water level measurement location. Therefore, controls must be considered when selecting a water level site that is intended to provide a continuous record of flow.

As stage varies through its full range, different controls may become active. In almost all cases the relevant controls will be downstream of the water level recorder. Most commonly the low flow control is a section control, while higher flows are subject to channel control.

Suitability of a control can be described by two physical attributes that should be assessed when selecting a site. They are:

- stability, and
- sensitivity.

The nature, configuration, and vegetal cover of the streambed and banks influence the stability and sensitivity, which in turn affect the relationship between stage height and discharge.

With a stable control, the stage–discharge rating for a site may hold for a number of years, but if unstable the rating may alter several times per year. An existing natural or artificial control can be modified to improve its sensitivity or stability.

See also Annex E – Hydraulics of flow measurement in open channels, and Annex F – Structures, of NEMS *Rating Curves*.

1.3.7.1 Stable features

Where practicable, one or more of the following features that are relatively resistant to erosion shall be present as a control:

- exposed bedrock
- armoured rapids
- sharp bends
- waterfalls
- a constriction in the channel between non-erodible banks
- large boulders (that are unlikely to move), and/or
- man-made substitute, e.g. a weir, grade control, or bridge.

Many of these features provide a downstream steepening of the slope of the water surface, which suggests that the feature is relatively resistant to erosion. Such features may be considered permanent or semi-permanent.

Unless a control is composed entirely of bedrock, its stability is extremely difficult to determine visually.

Although a control is stable (i.e. not subject to erosion), it may be altered by debris or bed material deposited on it or immediately upstream. This may alter the rating, not just at the time of the initial movement (usually a flood), but over a period afterwards as gravel and debris continues to build up behind the obstructions.

1.3.7.2 Unstable features

Where practicable, the following features shall be avoided:

- diverging reaches
- sand bars
- gravel bars, and
- dunes.

Riverbed changes that are caused by high velocities can alter controls. The finer the material, the more likely it is to shift. Silt, sand and fine gravel move easily during floods, and may even do so in periods of moderate to low flows.

Dunes of fine material indicate active bed material movement. In very active riverbeds, aggradation may occur during lower flows and be followed by a short period of degradation during a flood.

1.3.7.3 Vegetal growth

Where practicable, a control that is likely to be affected by vegetal growth on the riverbed and/or banks shall be avoided, or its effects mitigated by weed control measures.

Vegetal growth on the bed and banks can cause gradual and usually seasonal rating changes. Algal growth on weirs can cause small but significant rating changes. The normal remedy is to either:

- visit frequently and clear weed before the change becomes significant, e.g. scrub a weir with a brush or rake weed from the bed, or
- frequently file rating changes that transition over long periods.

Neither tends to be satisfactory, so reaches with significant weed are best avoided.

1.3.7.4 Human interference

Where practicable, a control that is likely to be affected by human activity shall be avoided.

Activities that may be encountered that will likely alter the stage-discharge rating include:

- major earthworks for bridge construction or river protection
- minor earthworks for gravel control and/or water abstraction
- gravel extraction nearby, either upstream or downstream
- use of a ford (stock or vehicles), and
- river users building weirs to enhance a swimming hole.

1.3.7.5 Sensitivity

Sensitivity of a control refers to the relative change in stage height for a corresponding change in discharge.

Control sensitivity may have a large effect on uncertainty of the derived discharges, especially at low flows and in small streams. The stage height measured at the recorder should be sensitive to changes in discharge in the river. High sensitivity improves resolution of the stage–discharge rating, thus improving accuracy of the flow record.

Sensitivity is usually considered during site selection, and further assessed during station design.

The shape of a control's cross-section governs sensitivity. This can be explained with reference to a simple V-notch weir.

- A very shallow angled V-notch (almost flat) produces a small change in stage height for a considerable change in flow and would be considered insensitive.
- A more acute angled V-notch (say 90°) constricts the flow, producing a greater change in stage height for the same change in flow and thus is more sensitive.
- A control with a narrow cross-section in a natural river provides greater sensitivity than a wide, shallow cross-section.

The degree of sensitivity of the control(s) is indicated by the slope and shape of the rating curve, as depicted in Figure 2.

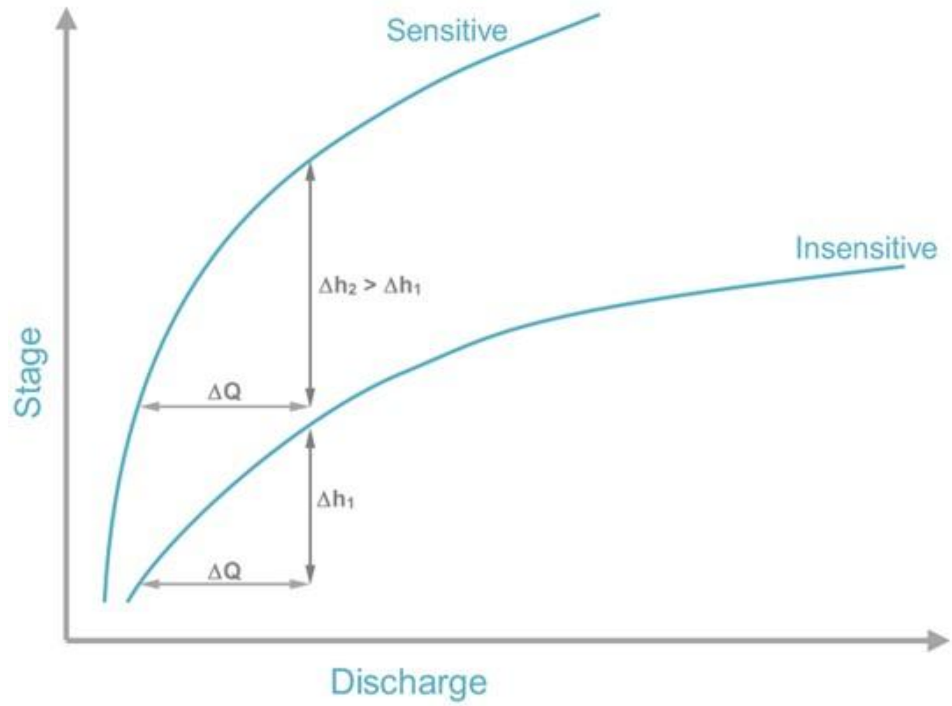


Figure 2 – Stage–discharge rating shapes for sensitive and insensitive controls.

Source: NEMS *Rating Curves.*

The uncertainty in determining flow for a given water level measurement resolution generally increases as flow decreases, especially in small basins (< 50 km^2) with small flows. This can be mitigated by installing a more sensitive control and/or improving water level measurement resolution. However, with very small flows, gains from installing a weir or flume often do not result in increased accuracy sufficient to offset decreased sensitivity due to the small range of stage that occurs (Freestone, 1983).

Refer to NEMS *Rating Curves* for more information about sensitivity of a rating curve.

1.3.7.6 Natural controls

Satisfactory natural controls are often difficult to find; influenced by local topography, geology, and the frequency and range of flows.

Gorges cut through bedrock invariably provide a better control for a site than riverbeds on alluvial plains and should be preferred whenever possible.

1.3.7.7 Artificial controls

Purpose-built artificial controls can provide a stable rating, albeit at some cost of construction. They can be classified as either:

- pre-calibrated structures, or
- bed controls.

Pre-calibrated structures are weirs or flumes that when built accurately to standard designs have a theoretically derived rating that may or may not hold true in practice, depending on a variety of factors including:

- approach velocities
- exit conditions
- flood-deposited debris
- sediment load and deposition, and
- weed and algae growth.

For guidance on use of thin-plate weirs, see ISO 1438:2008 *Hydrometry – Open channel flow measurement using thin-plate weirs*.

1.3.7.8 Siting artificial controls

Siting an artificial control structure requires careful consideration and a balancing of conflicting requirements. The structure should:

- give a sensitive rating, yet present minimum obstruction to the flow for:
  - stability
  - passage of debris
  - sediment
  - fish passage, and
  - avoiding erosion and scouring downstream.
- have sufficient fall between the upstream water level and the tail water.

Sufficient fall ensures the structure continues to operate as the control at higher flows. If the structure is 'drowned out', a different feature downstream may start acting as the control. However, fall should be minimised:

- to prevent washout by the force of the flow, and
- avoid or reduce the tendency for a deep scour hole to develop downstream.

1.3.7.9 Backwater effects

Even when a suitable control exists for a site, downstream effects can sometimes overwhelm that control causing backwater that affects the rating.

If backwater does occur, simple stage-discharge rating techniques are insufficient to derive flows with acceptable accuracy. Instruments that continuously measure water level and river velocity or water surface slope are needed along with modified rating techniques (see NEMS *Rating Curves*).

As a general guide, when a rapid or control structure exists downstream of the recorder, a backwater effect should not propagate up through it provided the rapid or structure is not drowned out at higher flows or by a downstream effect.

Examples of possible downstream effects to be avoided or mitigated are:

- tidal levels moving upstream towards a site
- a large tributary inflow entering just downstream of the recorder

- civil works in the riverbed, or a natural blockage (e.g. bank collapse)
- high water level in a higher order river preventing outflow at their confluence
- excessive weed growth in the downstream channel
- closure of gates or barriers

Note: A stream or river that has a low gradient is especially vulnerable to this problem and sites located near the coast may become tidal as sea level rises. In low gradients a backwater effect can propagate upstream for several kilometres.

1.3.8 Other considerations

Rivers have highly variable flows (viz. floods) and many have highly mobile riverbeds. Take extra care to ensure monitoring equipment can be kept operational, stable, and secure for the full range of measurement over the lifetime of the station.

1.4 Site factors – lake and reservoir stations

1.4.1 Monitoring purpose

Recording the water level of a lake may only be required for knowledge of the storage within the lake (as with a reservoir situation), but more significantly these data can provide a record of lake inflow and, for an uncontrolled lake, outflow.

1.4.2 Location

When outflow is required, the site should be located near to the outlet, but away from any drawdown.

Choose locations that are sheltered from waves to avoid surging at the sensor, erosion, and physical damage. In reservoirs, waves can cause an unmeasured loss of water over a dam that may, at times, be significant.

1.4.3 Access and legal requirements

Consider the following, in addition to section 1.2.1:

- the ability to position machinery and materials during construction

- provision of safe access to the water's edge for reading of staff gauges and to carry out measurements
- potential environmental effects, and
- resource consent requirements.

1.4.4 Range of measurement

Often lakes have broad, shallow edges. Consider how to ensure very low lake levels can be measured. Long intakes or sensor cables may be required.

1.4.5 Installation

Consider the following when selecting a suitable stilling well location or sensor site:

- how to ensure public safety and site security, during construction and ongoing operation of the station
- availability or provision of a solid structure on which to build a stilling well or mount a sensor
  - Substrate needs to be solid or be engineered to provide a durable and solid foundation.
  - Mounting sensors on existing structures should only be attempted with their custodian's permission.
- constructability and durability, including protection from flood or wave damage
- maintenance of the datum, including the installation of:
  - suitable benchmarks, and
  - reference gauges (e.g. external staff gauge or similar)
- an adequate power supply (e.g. solar, mains, or other power sources)
- adequate communication for telemetry
- the ability to deploy a sensor or intake that will cover the full range of anticipated water levels
- whether sedimentation will occur in or around a stilling well, intake or sensor
- influence of any saltwater-freshwater interface

- depth of measurement with respect to possible stratification, and
- navigation hazard to watercraft that may result from the installation.

These considerations may result in a trade-off between durability and cost.

1.4.6 Flow controls

The sensitivity of the stage–discharge relationship will depend upon the section control at the outlet, and possibly on the channel control downstream. In alluvial formations, lake outlets tend to be shallow and wide, and hence insensitive.

Weed growth can also be an issue at lake outlets, creating a possibly unstable and variable control.

For more information about the nature of flow controls, see section 1.3.7.

1.4.7 Other considerations

Operating a lake or reservoir water level recorder properly requires consideration of wind effects, seiche and rating curve uncertainties.

If an unregulated lake has a stable threshold across its outlet, the outflow can be gauged and rated against lake level or derived from the lake storage (stage-volume) curve.

The lake storage curve can be derived from:

- LiDAR data that has been flown when the lake is at a low level, supplemented with bathymetric survey, or
- bathymetric LiDAR of the topography down to the lowest possible water level that might be recorded.

1.5 Site factors – groundwater stations

1.5.1 Monitoring purpose

If monitoring is long term, it may be desirable to construct a stand-alone observation bore rather than access a bore that is in active use.

Note: New bore costs are often no more than the cost of a river level recording site and will provide better data with lower operating costs. For example, water hammer caused by large pumps starting and stopping can damage pressure transducers.

1.5.2 Location

Often there is no choice of location at which to monitor groundwater levels, e.g. when accessing an existing bore.

If constructing a stand-alone observation bore, consider:

- a location that is likely to be representative of the groundwater level of the aquifer being monitored, and
- the proximity of abstraction or reinjection wells or localised surface discharge that may affect groundwater levels.

1.5.3 Access and legal requirements

Consider the following, in addition to section 1.2.1:

- the ability to position machinery and materials during construction
- safe access to instruments, e.g. for reading a positive head staff gauge
- potential environmental effects, and
- resource consent requirements.

1.5.4 Range of measurement

Monitoring of groundwater levels may be in terms of positive (artesian) or negative head; these require different approaches for measurement.

Negative head usually requires the installation of underground sensing equipment, often in a narrow bore casing, and some distance below the ground.

Artesian head requires pressure sensors or venting to atmosphere, e.g. in a stilling well.

Groundwater level in some bores may vary seasonally between negative and positive head.

1.5.5 Installation

Consider the following when intending to install a groundwater level station:

- how to ensure public safety and site security, during construction and ongoing operation of the station

- constructability and durability, including protection of the well head
- the ability to deploy a sensor that will cover the full range of groundwater movement (including artesian) to the desired accuracy
- required elevation of mountings and instruments to ensure accurate use of pressure gauges and measurement of artesian head
- the highest anticipated rate of change of groundwater level

  Note: Gas purge (bubbler) systems do not adequately measure rapidly changing water levels in pumped bores.

- construction or modification of the bore head to allow equipment access
  - Allow for independent reference depth readings to be taken by plumb bob, dipping probe, or similar, or via a pressure fitting if artesian and not open to atmosphere.
  - Where possible, install a dipper tube for manual measurements, particularly if the well is equipped with a pump. This will ensure long-term data gathering without interference with the pump hose and cables.
- maintenance of the datum, including the installation of:
  - suitable benchmarks, and
  - reference gauges (e.g. external staff gauge or similar).
- an adequate power supply (e.g. solar, mains, or other power sources)
- adequate communication for telemetry
- influence of any saltwater-freshwater interface
- depth of measurement with respect to possible stratification, and
- climatic factors, such as water freezing in the well head and heat expansion of water in riser tubes.

Refer also to NZS 4411:2001 *Environmental Standard for Drilling of Soil and Rock*, and WorkSafe Health and Safety *Guidelines for Shallow Geothermal Wells*, and any subsequent standards and guidelines, as applicable.

1.6 Site factors – sea level stations

1.6.1 Monitoring purpose

1.6.2 Location

Consider the following when selecting a suitable location:

- resource consent requirements
- the need for supplementary measurements (e.g. conductivity when located in an estuary)
- the usefulness of complementary measurements, and where best to obtain them, (e.g. wind-speed and direction, atmospheric pressure, and visual observations))
- protection from waves, as much as is reasonably practicable

  Note: Large waves carry an enormous amount of energy, and can make the use of an external reference impossible.

- tidal range attenuation

  Note: If the sea level gauge is situated inside an estuary or lagoon, and the estuary or lagoon outlet is small in relation to the estuary or lagoon size, then the sea level recorded inside the estuary or lagoon may be attenuated. This occurs because the estuary or lagoon mean water level lags behind the tide level outside the outlet. The greatest lag occurs at about half-tide or just before and is usually indicated by a visible current at the outlet. If this current is > 0.1 m/s (approximately), then the estuary or lagoon is probably not suitable for a sea level gauge.

  Note: In harbours, the tidal range will usually increase, not attenuate, with increasing distance from the entrance.

- tidal dynamics, when measuring in a harbour.
  - A small, deep, wide-mouthed harbour without a river flowing into it should be a good option.

  Note: If changes to a harbour occur e.g. from silting or development, these may give a false impression of changing tide levels.

1.6.3 Access and legal requirements

Consider the following, in addition to section 1.2.1:

- the ability to position machinery and materials during construction
- safe access to instruments in the majority of sea conditions
- timing of access to allow sensors to be installed significantly below lowest spring tide level
- potential environmental effects, and
- resource consent requirements.

1.6.4 Range of measurement

The station should be capable of recording the full range of levels, i.e. the combination of:

- the greatest tidal range at the location
- the extra rise or fall due to barometric pressure changes (e.g. storm surge)

  Note: This could be as much as ± 800 mm.

- anticipated wave action, including:
  - wind-driven wave run-up, and
  - large wave troughs at spring low tides that may expose a sensor and/or sensor orifice (which should be below the water surface at all times).
- likely sea level rise, and
- potential tsunami.

1.6.5 Installation

Consider the following when intending to install a sea level station:

- how to ensure public safety and site security, including potential for vandalism, during construction and ongoing operation of the station
- availability or provision of a solid structure on which to mount both sensors and logger housing
  - Where relevant, consider the type of rock. If it is easily weathered then it will not be suitable in the long term, whereas hard rock provides a much more secure substrate.

    - Rock crevices give some protection to pressure transducers and gas bubblers, but they also magnify surging and are not desirable in this respect.
- locating the instrument housing above maximum levels expected from wave run-up, storm surge, and tsunami
- where, and how, to install benchmarks and reference gauges that will ensure datum is maintained (see section 2.8)
- use of sacrificial anodes to prevent corrosion
- measures to minimise biofouling
- tidal influence with respect to variations in salinity and water quality
- an adequate power supply (e.g. solar, mains, or other power sources), including whether there will be sufficient sunlight for solar charging
- adequate communication for telemetry, and
- navigation hazard to watercraft that may result from the installation, e.g. from piles being driven and/or any protection required for the structure and/or sensor.

1.6.6 Other considerations

The type of sea level gauge will often be determined by what can be installed.

Although a stilling well with a float and counterweight-driven encoder is perhaps the most reliable and accurate instrument in freshwater, salt incrustation, corrosion, and/or biofouling can become a problem in the marine environment., The dynamics of an open-coast marine site will also often make this option untenable.

Other choices of instrument include radar, immersed pressure transducer, and dry pressure transducer with a gas-bubbler system.

Of these, the gas-bubbler is the most versatile in terms of where it can be placed, followed by the immersed pressure transducer.

However, gas-bubbler systems may under-register water level if there are waves, due to gas feed not keeping up with sudden rapid rates of rise. Using a large outlet bell and a high bubble rate can overcome this problem.

Note: Without a larger diameter bell (in relation to bell length) the recorded sea level will be significantly under read (Pattinson, 2012) perhaps by as much as 1 m when waves are large.

To achieve QC 600, gas-bubbler systems installed at sea level stations shall be fitted with a suitable outlet bell to counteract wave effects.

When using pressure sensors, correction for density of seawater is needed (see section 2.7.2.2).

1.7 Required records

The following site metadata shall be recorded:

- site identifier (see section 3.4.1) and past and present aliases
- monitoring purpose
- 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.
- 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
- flood levels (historic, current, and the 200-yr ARI estimate)
- preliminary design details
- location, description, and assessment of flow controls
- requirement for, and method(s) of obtaining supplementary data, and

- relevant water abstraction and/or discharge data.

For groundwater the following shall also be recorded:

- location of the bore components and their reduced levels, preferably in terms of NZVD 2016 datum (see section 2.8.1)
- a geological well log that includes the following:
  - the driller's name, drilling date, and method
  - depths, type, and diameter(s) of casings
  - screening type and depth
  - well use, e.g. production or monitoring, and
  - where available and/or practicable, hydraulic properties at the time of construction, e.g. storativity and transmissivity.

2 Method and Equipment Selection

In this section

This section contains information about devices for measuring and recording water levels to guide their selection. It covers:

- instruments for continuous monitoring of water level that:
  - have direct contact with the water, or
  - take an indirect (non-contact) measurement of water level.
- recording equipment, and
- reference methods.

Additional guidance may be found in ISO 4373:2022 *Hydrometry – Water level measuring devices*.

2.1 Method principles

Each of the direct or indirect methods has differing accuracies, reliability, and operational requirements. In choosing a method to achieve the best quality data, consider appropriateness to the site along with cost. When considering cost, evaluate initial cost of installation against likely operational costs over the lifetime of the site.

Note: Methods with higher initial cost may significantly reduce long term operational costs.

Selecting a suitable device can be complex. Consider whether it is:

- fit for purpose (i.e. meets the desired quality under this Standard and fulfils client requirements),
- capable of meeting future anticipated data needs, and
- compatible (i.e. easily interfaces with existing hardware and uses common industry output protocols).

2.1.1 Direct contact with water

Devices that have direct contact with water include:

- float-driven shaft encoders
- submersible pressure transducers

- acoustic instruments with sound path in water, and
- gas purge sensors.

2.1.2 Indirect (non-contact) measurement

Devices that measure water level indirectly, without the device making contact with the water, include:

- acoustic instruments with sound path in air
- laser instruments, and
- radar instruments.

Acoustic instruments with sound path in air (e.g. 'down-looking' ultrasonics) are no longer acceptable under this Standard due to the inaccuracies introduced by air temperature variations along the sound path.

2.1.3 Damping

To derive an accurate record of flows using measured water levels as surrogate and simple stage-discharge rating techniques, static water levels are needed. Because of wind and wave action, some form of damping of the water surface is usually required.

Damping may be achieved by physical or electronic methods.

- The usual physical method is a stilling well (see section 3.1.2.5).
- The most common electronic method is a 'smoothing' algorithm implemented on the data logger (see section 7.2.7) .

Notwithstanding the difficulties of installing a stilling well in many locations, the use of a stilling well is not confined to float and counterweight systems. Other sensor types can be installed in stilling wells. However, do not install them near, or on the bottom of the well because they will almost certainly be buried by silt accumulation. The stilling well and intakes will also require regular maintenance for silting (see section 6.1.1).

For electronic methods, the data logger must have sufficient capability to scan connected sensors and run the additional algorithm without missing a recording interval, and capacity to store all the data generated. The 'smoothing' algorithm must be carefully chosen to avoid inducing bias and/or hysteresis in the data. Common algorithms, implemented over fixed or moving intervals, include:

- a central statistic, e.g. median, average, or mode (if noise is random), or

- tracking the minimum or maximum (if noise is biased).

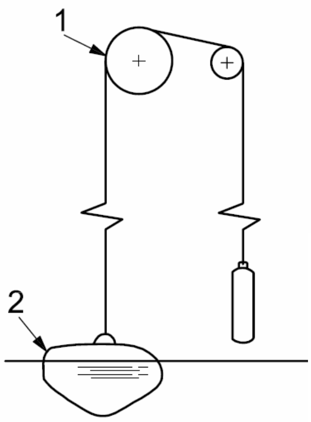
2.2 Instruments and (or) sensors

2.2.1 Principles of operation – shaft encoders

A shaft encoder:

- is an electro-mechanical device
- requires a stilling well (see section 3.1.2.5)
- consists of a pulley rotated by a float and counterweight system
- converts pulley rotation to millimetres of rise and fall, and
- records the stage, or relative rise or fall from a start point.

Used on its own, a shaft encoder can provide a direct readout of stage height without requiring an external energy source.



Key: 1 driven pulley

2 float

Figure 3 – Float and counterweight configuration.

Source: ISO 4373 (2008) Hydrometry – Water Level Measuring Devices.

2.2.1.1 Accuracy and resolution

Shaft encoders are precise measuring devices that usually have a resolution of ± 1 mm, but with some models this can be ± 0.1 mm. Resolution is uniform throughout the range.

As a mechanical device it is subject to small errors from changes in temperature, and from hysteresis and friction.

2.2.1.2 Compatibility

Most encoders are now electronic, linked to a separate data logger, and require constant power to operate.

2.2.2 Principles of operation – pressure transducers

Pressure transducers convert the pressure acting on a sensing element into an electrical signal. The signal varies in proportion to the pressure.

The pressure transducer measures the pressure head of the system but in most cases reports an equivalent head of water. It is important to understand this relationship and the effects it has on different measuring situations. The relationship is:

$$h = \frac{P}{(\rho \times g)}$$

where: h = head of water

P = pressure

g = gravitational acceleration, and

ρ = density (of the water).

The conventional values used in deriving the equivalent head of water are:

g = 9.80665 m/s^2

ρ = 1000 kg/m^3 (for water) derived at 4 °C

The density of water is affected by temperature, salinity, and sediment concentration, which in turn affects the relationship between pressure and head (depth) of water.

For example: Pressure sensors may not produce consistent measurements in estuarine environments and brackish water.

In most situations the error involved is small and proportional to the head of water over the sensor.

There are two main categories of pressure transducer used in the measurement of water level:

- submersible (wet transducer), and
- gas purge (bubbler) systems.

2.2.2.1 Submersible pressure transducers

Submersible pressure transducers are mounted directly in the water. They may be:

- vented (i.e. open to atmosphere) via their cable, or
- non-vented (i.e. sealed).

Vented transducers measure the water (gauge) pressure. Vent tubes must be kept open, clear, and dry, or measurements will be affected by barometric changes, and possibly temperature variations if moisture is present in the tube. A desiccant is used to ensure the air in the vent tube stays dry.

Non-vented transducers are available and have their advantages. However, their measurements include the effect of barometric pressure, and therefore require barometric compensation (see section 2.7.1).

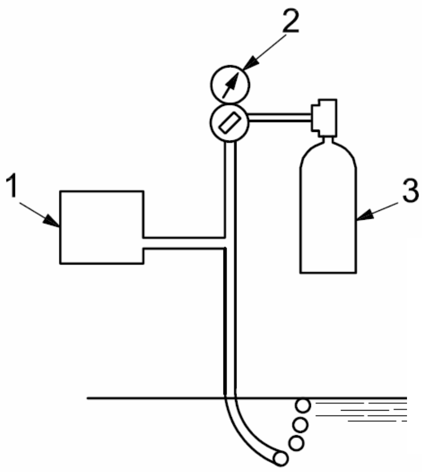
When measuring groundwater levels, there may not be sufficient space to install a submersible pressure transducer, or the risks of not being able to retrieve it may be high. In this case, gas purge sensors are frequently used (see section 2.2.2.2).

2.2.2.2 Gas purge (bubbler) systems

Gas purge sensors systems employ a pressure transducer but differ from submersibles by having the transducer located above and away from the water, normally within the recorder housing.

The transducer senses the head (depth) of water at an underwater orifice that is connected to the transducer by small diameter tubing. The instrument maintains sufficient gas pressure in the tubing for a small feed of gas to bubble out through the orifice. The backpressure in the tubing measured by the transducer is proportional to the water pressure over the orifice and hence the water level.

Note: In some situations, there are considerable advantages in having only small diameter tubing exposed to the stream rather than an expensive transducer. There is, however, additional cost associated with the use of the gas purge system.



Key: 1 pressure sensor

2 regulator

3 compressed gas

Figure 4 – Gas purge system.

Source: ISO 4373 (2008) Hydrometry – Water Level Measuring Devices.

2.2.2.3 Accuracy

Manufacturers of pressure transducers state sensor accuracy in differing formats and can include linearity and temperature errors. The total error should be considered when selecting a pressure transducer.

Accuracy may be in terms of full-scale error (% FS), which states error as a percentage of maximum sensor range, or as a percentage of measured value, which gives a proportional error over sensor range and better accuracy the lower the measured value.

For example: A sensor with a range of 10 mH2O and accuracy of 0.1% FS has an error of ± 10 mm anywhere over its 10-m range whereas a sensor of the same range with accuracy of 0.1% of measured value has an error of ± 10 mm at full range but only ± 5 mm at half range (see Table 5).

Table 5 – Examples of pressure transducer accuracy specifications.

For a transducer with range 0 – 10 m					
	Measured value (effective stage) (m)	1	3	5	10
Method	Accuracy specification	Accuracy (± mm)			
% of reading	0.1% of reading	1	3	5	10
% FS	0.1% of full scale	10	10	10	10
% of reading with % FS ‘floor’	0 – 3 m 0.03% FS 3 – 10 m 0.1% of reading	3	3	5	10

Specifying accuracy as full-scale error is conservative. A sensor could be capable of better accuracy over part of its range. The calibration relationship provides the necessary information to assess this. It can be requested on purchase or determined and scaled with a traceably calibrated portable calibrator (see section 4.5.1).

Deciding if a sensor meets the accuracy requirements for QC 600 under this Standard (see Table 3 and section 7.2.3.1) requires consideration of:

- the sensor's accuracy specification
- its intended use (water body to be measured and desired accuracy), and
- the operating range of the sensor.

For example: A 0.1% FS 10-m range sensor has error of ± 10 mm.

- *If used for groundwater level or sea level it meets the QC 600 accuracy requirement because its error, anywhere within its range, is no more than ± 10 mm.*
- *If used for lake level it will only meet the QC 600 accuracy requirement when operating between 5 m and 10 m effective stage, because ± 0.2% of 5 m effective stage is ± 10 mm, increasing to ± 20 mm at 10 m effective stage.*
- *If operating at less than 5 m effective stage, the sensor's error of ± 10 mm falls outside both parts of the QC 600 accuracy requirement (i.e. ± 0.2% of effective stage and ± 3 mm).*
- *For a 0.1% FS sensor to be certain of meeting ± 3 mm its range must be no more than 3 m. Similarly for a 0.2% FS sensor to be certain of meeting ± 3 mm its range must be no more than 1.5 m.*

See Annex I – Pressure Transducer Accuracy for additional examples.

For non-vented submersible pressure transducers, even if barometric pressure is measured in conjunction with water level, barometric compensation rarely produces results that can meet the accuracy requirements for QC 600 under this Standard.

2.2.2.4 Compatibility

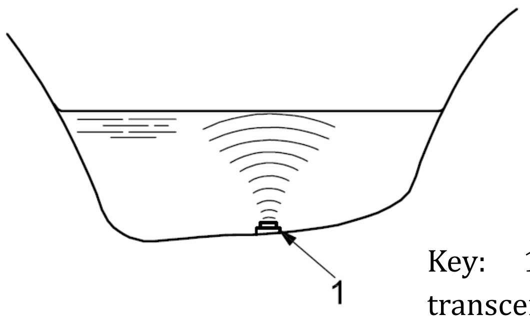
Submersible pressure transducers can be used in a range of applications from surface water and lakes to deep groundwater and can be used with well-head adaptors to measure artesian groundwater systems.

2.2.3 Principles of operation – acoustic transceiver (submersible)

The submersible (i.e. sound path in water) acoustic transceiver:

- consists of an acoustic transmitter/receiver
- measures the time elapsed between transmission of the pulse and reception of the echo from the water/air interface and converts this time to distance.

The transducer is used as transmitter and receiver so there is usually a minimum time after transmitting before receiving is possible, which results in a requirement for a minimum depth of water (refer to the manufacturer's specifications).



Key: 1 transceiver

Figure 5 – Acoustic water level sensin

Source: ISO 4373 (2008) Hydrometry – Wa

The velocity of sound in water is strongly proportional to water temperature and a technique for compensating for this effect is required for the data to achieve QC 600. Either the water temperature shall be measured directly, or a reference bar shall be located at a known distance above the transceiver.

Because the transceiver is fully submerged it:

- does not intrude visually
- is less susceptible to vandalism, and
- experiences less temperature variation.

2.2.3.1 Accuracy

Accuracies better than the QC 600 requirements of this Standard (see Table 3 and section 7.2.3.1) can be achieved. Ensure when choosing a sensor that the required level of accuracy can be met. An example specification is:

Range: 0.3 m to 22 m, ± 3.0 mm accuracy, -40°C to +80°C operation.

2.2.4 Principles of operation – non-contact instruments

Non-contact instruments are placed above the water (i.e. they are downward looking) and emit a signal that is reflected back to the sensor from the water surface; a process known as echolocation. The value returned is the relative position of the water surface in the area covered by the beam.

- Acoustic sensors emit a beam of sound.
- Laser sensors emit a beam of light.
- Radar sensors emit microwaves.

2.2.4.1 Acoustic sensors

Non-contact acoustic sensors operate very similarly to submersible acoustic sensors (see section 2.2.3) except that there is no minimum water depth, and the sound path is through air not water. As such they are very susceptible to temperature variations in the air column. Because of this their overall accuracy is insufficient for NEMS (see section 2.2.4.4).

2.2.4.2 Radar

Radar sensors transmit a spread beam, measuring a circular area on the water surface (i.e. a footprint) with diameter given by:

$$\text{Ø} = 2 \times D \times \tan\frac{\theta}{2}$$

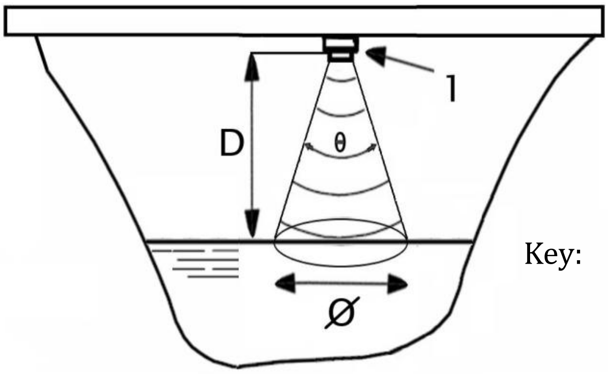
where: Ø = footprint diameter

D = distance to water, and

θ = radar beam angle.

Sensor footprint therefore varies with stage (see Figure 6).

For example: For a beam angle of 10°, at distance 5m the footprint diameter is 0.87m, at distance 10m (i.e. lower stage) the footprint diameter is 1.75m, and at distance 20m the footprint diameter is 3.5m.



Key: 1 transceiver

θ beam angle

D distance to water

Ø footprint diameter

Figure 6 – Radar water level sensing configuration.

Illustration: Marianne Watson.

Radar sensors can be one of two types:

- pulse, or
- FMCW (frequency modulated continuous wave).

Pulse radar use the time-of-flight principle, with time expansion applied to enable measurement of the time delay for the instrument to receive the echo. Distance to water is then calculated as:

½ the time delay × speed of light.

Pulse technology is now more commonly used, with Doppler, for surface velocity radars.

FMCW emits a continuous frequency modulated signal where the frequency increases over time to create signal sweep. The echo received has a slightly different frequency to the signal transmitted at that moment. The difference is proportional to the echo delay, which is proportional to the distance to water that is then converted to a water level.

FMCW uses the frequency domain rather than amplitude modulated or time-difference domains and therefore provides for more accurate signal conversion and greater measurement accuracy and sensitivity, similar to the advantages of FM radio over AM (Emerson, 2023).

Radar sensors emit harmless radiation, have no moving parts, and are relatively low maintenance. In general, they are unaffected by temperature and pressure, and weather conditions other than ice and wind. They solve traditional problems with submersed sensors (e.g. corrosion, fouling, installation and secure underwater mounting challenges) and are useful at sites prone to heavy silting, high velocities, debris, shallow depths, and ephemeral or intermittent flow, but they present another set of issues.

They are adversely affected by surface foam and waves, and vibration of their mounting (see Section ?). Pulse technology is more susceptible to surface turbulence, can be insensitive close to the sensor, and can be affected by extremes of ambient temperature.

2.2.4.3 Lasers

Laser sensors are emerging technology for hydrometric monitoring. They operate similarly to radar except that they transmit a narrow beam of light, usually either visible or infrared. The narrow beam is less affected by false echoes in confined applications e.g. in wells and bores.

Some laser sensors are fitted with diffuser filters to deliberately spread the beam so that, together with averaging algorithms, they measure static level despite a turbulent surface. These variants are a better choice for open water.

In clear water the laser may penetrate, increasing the time delay and biasing water level measurements low. In confined applications this can be mitigated by installing an inert floating target e.g. a polystyrene or plastic 'biscuit'.

As with radar, combined velocity and level sensors are available, but the level sensor may be acoustic rather than laser.

The potential for public access and possibility of eye damage should be considered. Most water level instruments utilise eye-safe lasers, but they may still present a hazard if viewed using optical devices e.g. binoculars and cameras.

2.2.4.4 Accuracy

Radar sensors have a typical absolute accuracy of ± 3 mm for 15-m to 30-m range, with FMCW variants regarded as generally more accurate than pulse instruments.

Radar and laser instruments exhibit similar typical measurement uncertainty to stilling well float and counterweight systems but are capable of a greater operating range (ISO 4373:2022). However, in terms of their ability to measure static water level, radar and laser instruments will record more noise if there is no mitigation of surface turbulence.

Non-contact acoustic sensors with their sound path in air have poor accuracy when installed in the natural environment and are not to be used (see section 2.1.2).

2.3 Site characteristics

Every water level site is unique.

When selecting the appropriate sensor, consider the site characteristics in conjunction with the following factors:

- measurement range
- seasonal conditions
- environmental conditions, and
- power budget assessment.

2.3.1 Measurement range

Prior to installation, determine the maximum and minimum measuring range at the site (see sections 1.3.4, 1.4.4, 1.5.4, or 1.6.4 for rivers, lakes, groundwater, and sea level respectively). This will ensure the installation and sensor covers the likely full range and hence avoids data loss.

2.3.2 Seasonal conditions

Examples of seasonal conditions that can influence or damage the sensor include:

- heat
- weed and algal blooms
- frost and ice
- recreational activity
- sediment flushes
- floods
- flood debris build up, and
- current and foreseeable tidal range and storm surge.

2.3.3 Environmental conditions

Examples of environmental conditions that can influence the performance of the sensor and affect the usefulness of the monitoring installation include:

- wind
- waves
- bank stability
- movement of bed materials

- river works
- water turbulence, and
- migrating channels.

2.3.4 Power budget

Calculate the power budget and maximum demand of the sensor(s), logger(s) and telemetry system combination, to ensure that sufficient charge and battery capacity are installed.

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 isolated sites, also consider backup systems and equipment (with separate backup data logger batteries).

2.4 Recording equipment

Chart and punched tape recorders shall not be used.

2.4.1 Electronic data loggers

There are many electronic data loggers on the world market with a large range of price and capability. Generally, they all can:

- interface to several different types of sensors
- vary the recording interval, and
- output the data in various electronic formats to computers.

For QC 600, any electronic data logger utilised must be able to store data at the preferred 1 mm resolution. Where a data logger includes the sensing device, the resolution and uncertainty requirements shall relate to the stored value.

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

- ability to interface to relevant sensors
- 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 samples)
- 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 7.2.3.2), and
- scan rate, i.e. the frequency at which a data logger can measure and process signals.

2.5 Sampling equipment

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

2.6 Ancillary equipment

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

2.7 Interferences

2.7.1 Barometric pressure

If using a non-vented submersible pressure transducer, compensation for barometric pressure is required to remove the effect of barometric pressure from the instrument's absolute pressure readings.

Supplementary measurements of barometric pressure are therefore needed, either at the same site, or from nearby.

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

Barometric pressure data may also be collected as complementary data to assist with verification and analysis of groundwater and sea levels.

2.7.2 Density of water

2.7.2.1 Salinity

Salinity affects the density of water. In estuaries, salinity can vary greatly depending on tide, weather, freshwater inflow, and other factors. Salinity is therefore required as a supplementary measurement if using a pressure transducer in an estuarine environment.

2.7.2.2 Seawater

Correction for density of seawater is needed for QC 600 to be assigned when using pressure sensors (immersed or dry) to measure sea levels. The correction is a factor of 0.976, or 2.4% and therefore becomes larger as water depth over the gas line outlet or pressure transducer element increases (see Table 6). Subtract the density effect from apparent water depth (head) over the outlet or element to obtain true water depth over the outlet or element.

Table 6 – Correction for density of seawater.

Water depth (m)	Density effect (mm)
1	24
2	48
3	72
4	96
5	120

2.7.3 Groundwater aeration

Special measuring techniques are required for groundwaters to avoid errors caused by surface aeration within a well.

It may be necessary to vent a well to the atmosphere via a tube or open bore case to prevent build-up of gas pressure in the well.

2.7.4 Temperature

If using an acoustic sensor, compensation for temperature variations along the sound path is required for the data to achieve QC 600. Sound path in air instruments are excluded from this Standard because of the errors involved (see section 2.1.2).

Supplementary measurements of water temperature, or a reference bar, are needed for 'sound path in water' instruments (see section 2.2.3).

Temperature compensation is almost always performed within an acoustic instrument, but if not, must be applied during data processing, which means the water temperature data or reference bar readings must also be retrieved and stored.

2.8 Reference methods

2.8.1 Datum

In almost all cases, stage is required from records of water level i.e. water levels referenced to a known and fixed vertical datum. The vertical datum may be in terms of:

- New Zealand Vertical Datum
- a local datum, or
- an assumed datum.

The vertical datum must be:

- maintained by benchmarks (see section 2.8.2), and
- preserved for the life of the station, or
- traceable and documented in the metadata, if changed.

Refer to NEMS *Site Surveys* for additional information about the various datums and the means of converting between them.

2.8.1.1 New Zealand Vertical Datum

New Zealand Vertical Datum (NZVD) is a geocentric datum compatible with GPS that replaces previously established datums such as mean sea level (MSL). NZVD 2016 replaces earlier versions of NZVD.

Use NZVD 2016 as datum for water level stations unless it is not reasonably practicable to do so.

Note: Use of the data in groundwater modelling, hydraulic modelling, and management of reservoirs is easier if all is referenced to NZVD 2016.

2.8.1.2 Local datum

Local datum may be:

- mean sea level (MSL), or
- a datum established by an organisation such as a local authority.

Prior to NZVD, mean sea level (MSL) was the established datum for New Zealand. However, MSL datum varies regionally, and offsets occur between them that also vary with site location i.e. the various MSL datums are not parallel planes.

Conversion between MSL and NZVD is not straight-forward. Refer to NEMS *Site Surveys* and the Land Information New Zealand (LINZ) website.

Local authority datums are usually only used within the authority's jurisdiction. They may or may not be tied by survey to an MSL datum via an established benchmark.

2.8.1.3 Assumed datum

An assumed datum may be used instead of an established datum when:

- it is not reasonably practicable to use an established datum, and
- stage height is being measured to determine flow and the actual elevation of the water surface is not required.

Confer an assumed level to the most immovable of the site's benchmarks, then level all else to it.

Choose an assumed level for the initial benchmark that is:

- a round number, with only one or two significant figures
- large enough that negative elevations are avoided anywhere on site, and
- dissimilar to actual elevation (in MSL or NZVD 2016) to avoid confusion.

For example: 100.000 metres.

2.8.1.4 Recording zero

The recording zero of a station shall be:

- tied by spirit level survey to the chosen datum for the site
- set to a sensible number (e.g. nearest whole metre) below the lowest level to which the water surface is likely to fall
  - taking into account possible degradation at the site that may lower water levels in future, and
  - avoiding negative stage values over the life of the station.

2.8.2 Benchmarks

A minimum of three suitable, permanent benchmarks shall be:

- installed and maintained at each site, or
- located in the vicinity, and
- established preferably to NZVD 2016 datum (see section 2.8.1).

Where practicable, benchmarks shall be stainless steel pins anchored in an immovable firm concrete or rock base.

Establish the level of one benchmark by GPS survey (preferably the most immovable), then establish the reduced level of all other benchmarks by spirit level surveying.

Note: GPS survey vertical accuracy is inadequate for levelling between benchmarks and/or reference instruments.

Benchmarks shall be regularly checked for movement.

Note: Three benchmarks are essential to resolve the cause of any discrepancy in levels that may occur over time by the movement of one or more parts of the installation.

Refer to NEMS *Site Surveys* for benchmark installation and survey requirements and guidance.

2.8.3 Reference instruments

Reference gauges may be one or more of:

- vertical staff gauge
- sloping staff gauge
- electric plumb bob
- electronic water level indicator, e.g. a groundwater 'dipping' probe
- electronic distance meter, e.g. a handheld laser or range finder device.

Available electronic devices vary in their accuracy and resolution. To be used as a reference instrument, the device shall be capable of 1 mm resolution and the measurement accuracy required under this Standard for the waterbody in which they are used (see 'The Standard – Water Level' and Section 7.2.3.1).

Set the effective zero of each reference gauge to the recording zero adopted for the site.

Regularly survey all reference instruments by spirit levelling from established benchmarks to ensure recording zero and datum are maintained. As a minimum, this is included in the biennial station inspection (see Annex D). For QC 600 to be assigned, any variance shall be no more than ± 3 mm.

2.8.3.1 Staff gauges

A staff gauge is:

- a non-recording graduated device, similar to an oversized ruler
- mounted either vertically or inclined, and
- permanently installed.

A staff gauge provides an:

- inexpensive, simple, absolute, robust method of measuring water level
- independent manual check on automatically recorded water levels
- easy direct check on the performance of non-contact and pressure sensors, and whether they have moved, and
- indication of silting of intakes and/or stilling wells (by comparison with an internal water level reading).

The vertical staff gauge is the most common form. It normally consists of a series of 1-metre plastic plates, graduated at 10 mm and 100 mm (10 cm) intervals, (see Figure 7) and fixed to a secure mount, e.g. a concrete wall, or a treated timber board secured to a driven pile.

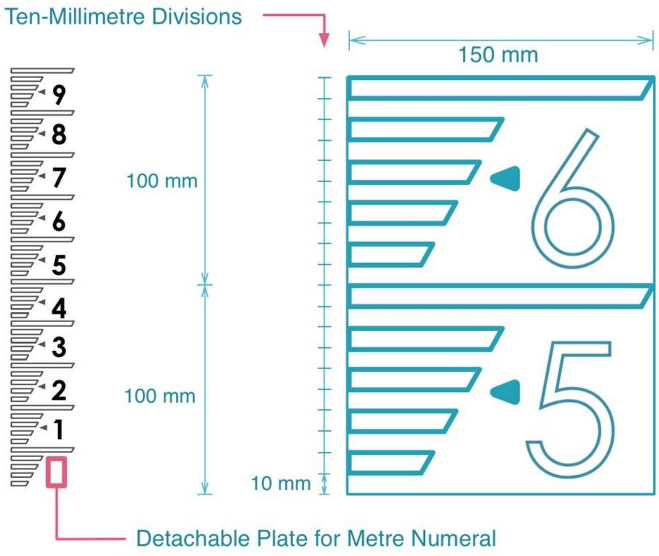


Figure 7 – Staff gauge plates.

Illustration: Chris Heath.

Sloping staff gauges can be used where:

- there are no suitable anchorages for vertical staff gauges
- vertical staff gauges are too prone to be damaged by high velocities and debris, or
- a better resolution is required.

Note: A sloping gauge achieves better resolution than a vertical staff gauge because distance up the slope is greater than corresponding vertical height.

Remote readings are possible via telemetered images from a camera trained on the gauge board, however depending on their relative position, sighting distance, and stage range, the readings may be affected by camera angle, image distortion, and parallax or reflection errors.

2.8.3.2 Electric plumb bob

The electric plumb bob (EPB) is a non-recording gauge normally used to measure water level in a stilling well or borehole. It gives an independent check on the internal water level in the well and therefore provides a check on the recorder.

An EPB can provide:

- an accurate indication of water level in situations where access and visibility are impaired, and
- acceptable accuracy when the distance to the water surface is of the order of tens of metres.

An EPB consists of a plumb bob connected to a graduated steel tape, wound onto a brass reel (Figure 8). This forms part of a low voltage electrical circuit that is completed when the plumb bob is wound down to, and touches, the water surface. The contact is registered on a milliammeter, or buzzer/light. The plumb bob is raised or lowered so that it is only just touching the water surface, and a reading is then taken from the tape graduations at the read-point.

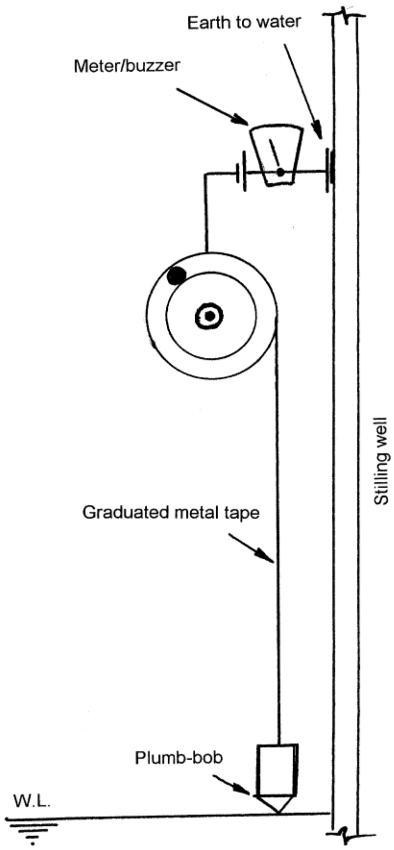


Figure 8 – Electric plumb bob schematic diagram.

Source: ISO 4373 (2008) Hydrometry – Water Level Measuring Devices.

Because EPBs rely on a low voltage electrical circuit they require a good earth and may not work in waters of very low conductivity.

In groundwater applications, electronic water level indicators (dipping probes) are used. These consist of a spool of dual conductor wire with a probe attached to the outer end. When the probe is lowered and contacts the water, the circuit is closed and the meter light and/or buzzer signals the contact. Depth to water below an established fixed reference point is then read from the tape.

2.8.3.3 Sea level references

Reading sea level from traditional external references is difficult and often worthless due to surge and wave action, even within a sheltered port area. If the sea level gauge is effectively in the open ocean, no permanent external reference is possible.

If the gauge is in a sheltered environment, independent reference may be possible using one or more of the following methods:

- an electric plumb-bob in a stilling well
- a laser system returning the average of a set of high frequency readings
- the average of a series of manual readings, or
- manual interpretation of a video of a staff gauge.

2.8.4 Primary reference

The primary reference gauge is the means by which the in-situ instrument is referenced to the site's recording zero.

At least one primary reference gauge shall be installed at each site.

At sites equipped with stilling wells, the electric plumb bob (EPB) shall be the primary reference, due to their superior achievable accuracy. However, because EPBs in stilling wells are affected by the same potential silting problems as the water level recorder, each EPB reading should be paired with an external staff gauge reading to confirm the installation is functioning correctly (or is otherwise possibly silted).

At all other surface water level stations, the primary reference shall be:

- the external staff gauge, or
- a suitably installed and operated distance meter (e.g. if the in-situ sensor is non-contact mounted over open water).

2.9 Required records

Relevant site characteristics (see section 2.3) shall be included in 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 covers planning, constructing, installing, and commissioning a water level recording station.

3.1 Station planning

The design, deployment and installation of water level recording systems shall comply with the relevant clauses of the:

- New Zealand Building Code and Regulations
- Health and Safety at Work Act (2015) and associated Regulations, and
- NEMS *Guidelines for Hydrological and Meteorological Structures.*

3.1.1 Access

Safe and convenient access to recording stations is crucial for reliable measurements and continuity of record.

Permission shall be obtained for access over and installation of equipment on any land. or bed or banks of a river or lake, or structure, whether private, local authority, iwi, corporate, or government owned.

Consider all requirements and recommendations of section 1.2.1, and of section 1.3.3, 1 4.3, 1 5.3 or 1.6.3 as applicable to the water body being measured.

Begin construction work on a site with work on the access itself, including foot tracks and steps to the work site.

3.1.2 Design

3.1.2.1 Site survey

A site survey for the purposes of design should precede any construction work for a water level recording site.

The survey shall be carried out in accordance with NEMS *Site Surveys*.

For a river site, the survey shall include:

- cross-sections upstream and downstream of the proposed site:
  - at least two and preferably three, and

- up to at least 200-year ARI flood level (see section 1.3.4), and

- documentation in a form that enables the survey to be repeated in the future.

3.1.2.2 Signage

Signage shall be installed to warn of any hazards.

A sign that briefly explains who operates the station, their contact details and the station's purpose is recommended.

3.1.2.3 Security

Protect installations where practicable from interference and damage, including from animals and surrounding vegetation (e.g. overhanging trees or tree roots).

Where relevant, security gates or alternate security systems shall be installed:

- for the safety of anyone who visits the vicinity, and
- to protect the station from vandalism.

3.1.2.4 Design flood level

A water level recording station should be capable of measuring extreme floods, especially if established for flood warning or flood design.

Consistent with USGS practice, stations should be designed and built so that structures and/or sensors are high enough to enable a 200-year average recurrence interval (ARI) flood event to be measured.

Refer to Annex H – Estimating stage height for the 200-year ARI flood, for the procedure to estimate the design flood level for proposed river level stations.

3.1.2.5 Stilling wells

Stilling wells are used to:

- protect sensors, e.g. the float and counterweight, and
- damp the water level fluctuations present in open water that are caused by wind, waves, and turbulence.

Provided the stilling well is functioning properly, water levels within the stilling well accurately represent the static level of the open water.

Figures 8 and 9 show one design that consists of a number of sections, each section being 600 mm in diameter and 1200 mm in length. A steel recorder housing bolts to the flange of the top section.

The stilling well shall be of sufficient height and depth to allow the float to freely travel up and down the full range of water levels.

A means of access (e.g. inspection hatch) to the well and intakes for desilting and other maintenance shall be provided.

A convenient flushing system should be designed, incorporating a means of closing off the static pipe at the stilling well end.

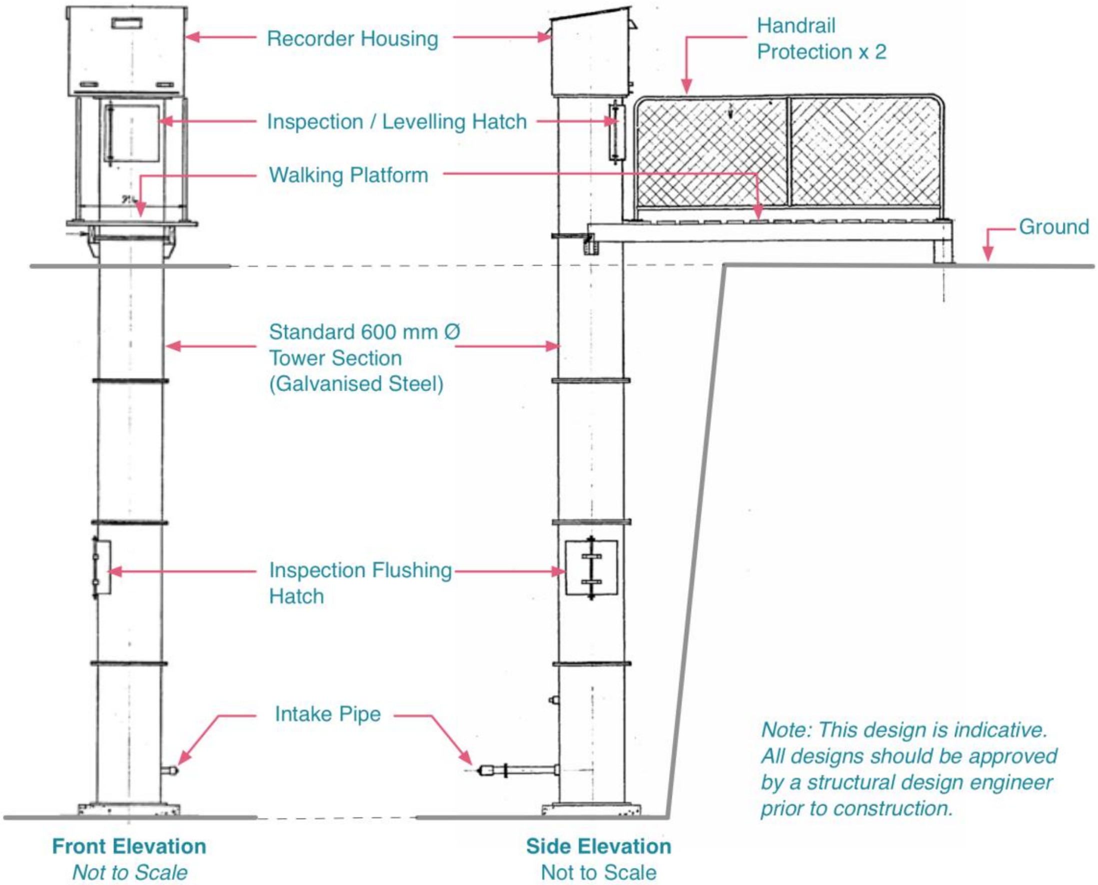


Figure 9 – Typical stilling well and housing setup.

Source: NIWA Field Manual.

Figure 10 – Stilling well with multiple sections and housing.
Photograph: Horizons Regional Council.

The well shall be connected to open water by one or more appropriately sized and positioned intake pipes.

The level(s) at which intake pipes are fitted is a crucial decision likely to impact considerably on usefulness of the structure over time. The lowest intake pipe shall be:

- at least 150 mm below the lowest anticipated water level, and considerably lower if degradation of the bed is possible, and
- at least 300 mm and preferably 1 m above the bottom of the stilling well, to avoid blockage by sediment.

Provision should also be made during design and construction for capped sockets to be fitted so that additional intake pipes can be added if required at a later date.

The cross-sectional area of an intake pipe should be large enough relative to the diameter of the well to follow rapid changes in the external (open) water level without significant lag, but not overly large so as to result in surging in the stilling well. Use a nominal ratio of 1:12 between intake pipe and stilling well diameters, although it will be greatly influenced by the number of intakes and their length.

Where velocity past the open water end of the intake is at times high (i.e. above 1.5 m/s), drawdown of the water level in the stilling well may occur. To reduce this drawdown, attach a capped and perforated static tube to the intake, oriented parallel to the direction of flow (± 10°) (see Figures 10 and 11).

For more information, see Annex G – Intake Pipe Dimensions.

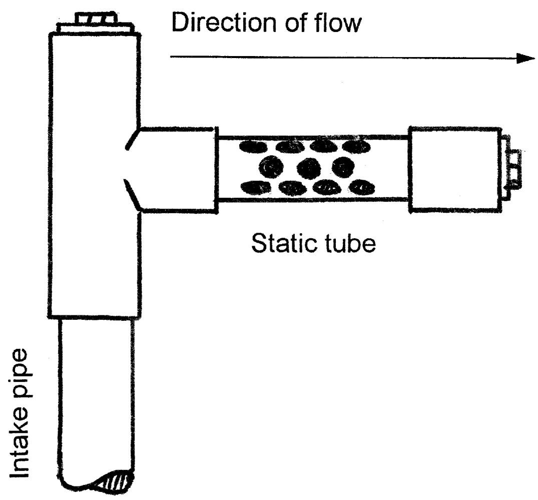


Figure 11 – Typical static tube setup.

Source: NIWA Field Manual.

Figure 12 – Example of intake and static pipe.

Photographer: Evan Baddock.

3.1.2.6 New bores

If constructing a new bore for groundwater monitoring purposes, ensure:

- the bore/well is suitably constructed. Refer to NZS 4411:2001 *Environmental Standard for Drilling of Soil and Rock*.
- the bore will cover the full range of water levels expected, including artesian levels, and is deep enough to allow for siltation
- the diameter of the bore allows a suitable sensor to be installed alongside any other equipment likely to be deployed
- the bore head allows equipment access for independent reference depth readings, and
- there is sufficient access to the water table, i.e. a straight pipe at least 30 mm diameter leading from the top of the bore casing to below the water table.

Avoid placing screens at multiple levels if possible; doing so can enable connection between otherwise separate aquifers.

3.1.2.7 Recorder housings

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 Construction

3.2.1 Materials

All materials used in installations shall:

- conform to:
  - the New Zealand Building Code and Regulations, and
  - NEMS *Guidelines for Hydrological and Meteorological Structures*
- be of adequate strength, thickness, and durability for the purpose.

  Note: Extended durability is desirable because sites may be repurposed after their initial use, or temporary installations may become permanent.

Generally:

- Use timber treated to an appropriate specification or better to prevent rot.

  Note: A minimum of H4 treated is recommended for use in all hydrological structures. Use H5 where ground contact occurs and within marine environments.

- Hot dip galvanise all exposed and structural steelwork or use stainless steel.
- Use galvanised or stainless-steel wire ropes and nuts and bolts.

For sea level sites and coastal locations, use:

- grade 316 stainless steel components, and
- an epoxy that sets under water.

To minimise visual impact on the surrounding environment, all structures and housings may need to be painted. However, bare galvanising is often acceptable, particularly once weathered.

3.2.1.1 Stilling wells

Many of the early stilling wells were made of concrete.

Today, stilling wells are generally made of:

- spiral-welded steel pipe, or
- standard rolled steel sections 1200 mm in length (see Figure 9).

Other materials and designs may be as good or better in certain situations. However, the stilling well should be made of a material that has a low coefficient of thermal expansion. Alternatives include:

- concrete pipes
- plastic pipes (PVC, PE, HDPE, or PP)
- fibreglass pipes, and
- corrugated culvert pipes.

Note: All plastic pipe expands, some less than others. Fibreglass expands much less.

In salt water, stilling wells made of high-density plastic composites with low coefficient of expansion may be a viable alternative to installing a steel tower and sacrificial anode.

3.2.1.2 Fasteners

Rock bolts can be a useful method of fastening equipment to bedrock, large rocks, or concrete structures.

These can range from masonry fasteners driven into holes in concrete to substantial bolts grouted into holes drilled in bedrock by a compressor-powered drill.

3.2.2 Methods

Where used, concrete footings shall be built in accordance with the New Zealand Building Code to ensure the stability of hydrological structures.

Cleaning and preparation of any foundation is essential.

3.2.2.1 Stilling wells

The stilling well shall:

- be vertical within practicable limits
- not allow the float and counterweight systems to come in contact with the walls
- only allow water to enter and leave through the intakes, i.e. all construction joints of the stilling well and intake pipes shall be watertight, and
- be firmly founded so that subsidence will not occur.

Foundations that sit directly on bedrock are preferable. Otherwise, a substantial concrete mass poured into hard alluvium is required, or driven piles.

Generally, stilling wells require concrete foundations to:

- key them to bedrock, or
- form the broad and substantial footing in alluvium, to prevent subsidence or movement.

Intake pipes shall be laid:

- on firm material that will not subside, and
- at a constant gradient; normally horizontal.

Note: If an intake slopes down from the stilling well toward open water it is the elevation of its invert at the stilling well end that determines when it ceases to function as the open (external) water level recedes.

3.2.2.2 Weirs

Generally, weirs require deep cut-off walls and a substantial downstream apron to prevent:

- leakage, and
- downstream scour and overturning of the structure.

3.2.2.3 Groundwater

Generally, groundwater sites are mounted on a sturdy steel bore pipe.

If this is not the case, ensure that the datum will remain stable and structural strength is adequate by using suitable construction methods and materials.

Allow for easy access to recording equipment.

3.2.2.4 Sea level

Schedule construction for around the trough of a king tide for ease of access.

Use battery-powered tools (when working around salt water).

Install a sacrificial anode (also known as a galvanic cathode protection system) on steel structures. Inspect the anode at least annually and replace when significant galvanic corrosion of it has occurred.

Note: A sacrificial anode involves the use of a more active metal, in terms of electrochecmical potential, to protect a structure made of less active metal from corrosion. The anode is consumed in the process, hence 'sacrificial'.

3.3 Installation and commissioning

3.3.1 Sensors

Pressure sensors (submersible and gas bubbler), acoustic sensors, and non-contact sensors can be installed relatively simply, without a stilling well, and hence at significantly lower cost. However, they are then susceptible to the effects of wind and waves, so some form of damping may need to be considered (see section 2.1.3).

3.3.1.1 Submersible pressure transducers

For negative head in a used groundwater well, run the pressure transducer inside polythene (or other tubing) so that it can be removed without fouling on pump cables and other obstructions inside the bore.

It is not normally possible to set the sensor at the recording zero, so an offset (i.e. the difference between the elevation of the transducer element and the recording zero) is usually needed (see section 3.3.4.1).

3.3.1.2 Gas purge systems

These systems must be installed correctly, with:

- a gas tube length appropriate to the system being deployed
- dual lines to minimise system lag and friction effects (over-reading) if a long gas line is necessary
- no dips in the gas line that may fill with water if gas pressure is lost
- sufficient bubble rate to ensure maximum rate of rise is followed
- a suitable orifice system that enables measurement of fast rates of rise and therefore also prevents under-reading in surging waters, and
- an offset added to measured values if it is not possible to position the orifice at recording zero (see section 3.3.4.1)

In bores, the gas line should be attached to a weighted stainless-steel cable marked at the reference point (usually the well head) so that it can be reinstalled to the same level if the gas line ever needs to be removed.

Note: A gas line is unlikely to be straight when it goes down a well unless it is secured to a weighted cable. Securing it in this way also eliminates the possibility of orifice drift caused by it floating or the tubing slowly uncoiling over time.

3.3.1.3 Acoustic transceiver (submersible)

The transceiver shall be:

- installed in a straight section of channel, avoiding any curves and abrupt changes in elevation
- mounted securely so the instrument is unable to move and is level, and
- mounted where:

   - the instrument can measure the full range of water levels and velocity, including allowing for minimum depth limitations, and

   - there is no risk of sound reflection from channel edges at higher water levels,

Note: An upwards-facing transducer is prone to sediment settling on it, particularly if it is placed on or near the bed in an attempt to overcome the minimum depth limitation.

3.3.1.4 Non-contact instruments

The instrument shall be mounted:

- in air where it is accessible for maintenance but protected from vandals, insects, birds and other animals

- securely so the instrument is unable to move and is level (the water level sensing beam must be perpendicular to the water surface)

- clear of the highest anticipated water level, plus any required air gap

  Note: Some non-contact instruments will tolerate immersion but will not measure a water level higher than their reference plane. The instrument reference plane may be different for different sensor types and not necessarily be the physical end of the antenna (VEGA, 2021).

- in a manner that:

  - does not obstruct other water and riparian activities or bridge traffic (vehicle and pedestrian)

  - avoids moisture ingress e.g. via cable glands, and

  - ensures datum is always known, and preferably does not change.

The instrument may be mounted on:

- an arm extending over the water surface, or

- a bridge span beyond interference from abutments, piers, and other structural features.

The arm shall be rigid, and long enough to ensure that the conical beam does not strike channel walls. Interference to the radar beam from wall protrusions can be blanked out. A rotatable arm is recommended for ease of access for maintenance. Vibration due to wind can be an issue so a sheltered location is preferred.

Bridges deflect and vibrate under traffic load so the instrument should be mounted as close to a pier as possible to minimise movement while avoiding interference from the structure.

Other considerations for a bridge installation are:

- the hydraulic impact of the bridge (i.e. scour and deposition of bed material and debris under the sensor, and drawdown and heading-up of water)
- use the upstream side in preference, which is less likely to be affected by surface disturbance and drawdown due to the piers
- avoid large metal surfaces near the sensor beam (e.g. ladders, struts, casings, and other structural elements)
- beware of water draining from the structure that may interfere with the sensor beam
- access may require abseiling and working at heights and/or temporary traffic management
- Road Controlling Authority (RCA), and NZ Transport Agency (NZTA/Waka Kotahi) if a state highway, permissions are required before attaching anything to a road bridge or culvert, and likewise from KiwiRail for rail bridges and culverts.

Suspension bridges are unsuitable due to their greater deflection and temperature effects.

Note: Suspension bridges rise and fall with temperature-induced expansion and contraction of the suspension cables and because they are flexible, move unevenly and to a greater extent under load than other bridge designs.

Independently validate the instrument tilt angle on installation.

The sensor signal may be polarized; the direction of which influences false echoes. Bear this in mind when mounting or moving the sensor.

Some brands and models may be 4-wire and/or require 24 Volt supply to adequately power the instrument.

The level sensor may be an instrument combination with a surface velocity sensor in which case installation must take account of the requirements for both. Refer to the Australian *National Industry Guidelines for hydrometric* *monitoring – Part 11: Application of surface velocity methods for velocity and open channel discharge measurements.* (NI GL 100.11-2021) for guidance on installing surface velocity instruments.

3.3.2 Housings

The recorder housing shall be installed above maximum possible water level.

All equipment within the housing shall be installed in a secure and orderly manner. Wires, cables, and pulleys must not interfere with operation and servicing.

3.3.2.1 Walk-in types

A 'walk-in' housing may be:

- a small shed, or
- the top of a large diameter concrete stilling well that is mounted:
  - above a stilling well, or
  - separately on the ground nearby.

3.3.2.2 Chest height types

A 'chest height' recorder housing may be a smaller design mounted:

- at chest height on the recorder stilling well (see Figure 13), or
- in a suitably protected location, if the sensor is connected only by cable or tubing (which is protected from the elements and interference).

Figure 13 – Typical stilling well housing design.
Photographer: Evan Baddock.

3.3.3 References

All reference gauges shall be:

- referenced to benchmarks
- correctly aligned to recording zero
- of robust and stable construction
- readable to 1 mm resolution, and
- cover the full range of anticipated stage.

3.3.3.1 Staff gauges

Staff gauges shall be installed so that:

- the staff gauge mounts are immovable and not prone to settling

- the method of fastening the timber to the mount is positive (i.e. friction should not be relied on to prevent slippage)
- the zero of each gauge is at the recording zero
- the gauges are adjacent to, and/or on the same river cross-section as the intake pipes, sensor orifice, or beam area (as much as is practicable)

  Note: Having the bottom staff gauge as close as possible to the intake pipe, gas line orifice, or radar beam area is particularly important at low water levels to ensure the staff gauge is measuring the same water surface as the sensor.

- where a series of stepped gauges are required to measure the full range of water levels, there is a minimum of 15 cm overlap between the top of one gauge and the bottom of the next
- the water level is easily and accurately read at any time, and
- the gauges are protected from high velocities, or
- if high velocities are unavoidable, the gauges are:
  - short (i.e. install more of them), or
  - fastened to a concrete face.

Sloping staff gauges shall be set at a known angle on a secure mount, e.g. a plank or concrete pad (see Figure 14). 30˚ is recommended, as staff gauge plates are available for this angle (and for 45°).

If standard vertical plates are used at 30˚, slope distance is twice the vertical height, so values read from the sloping staff gauge can be halved to obtain the actual water level.

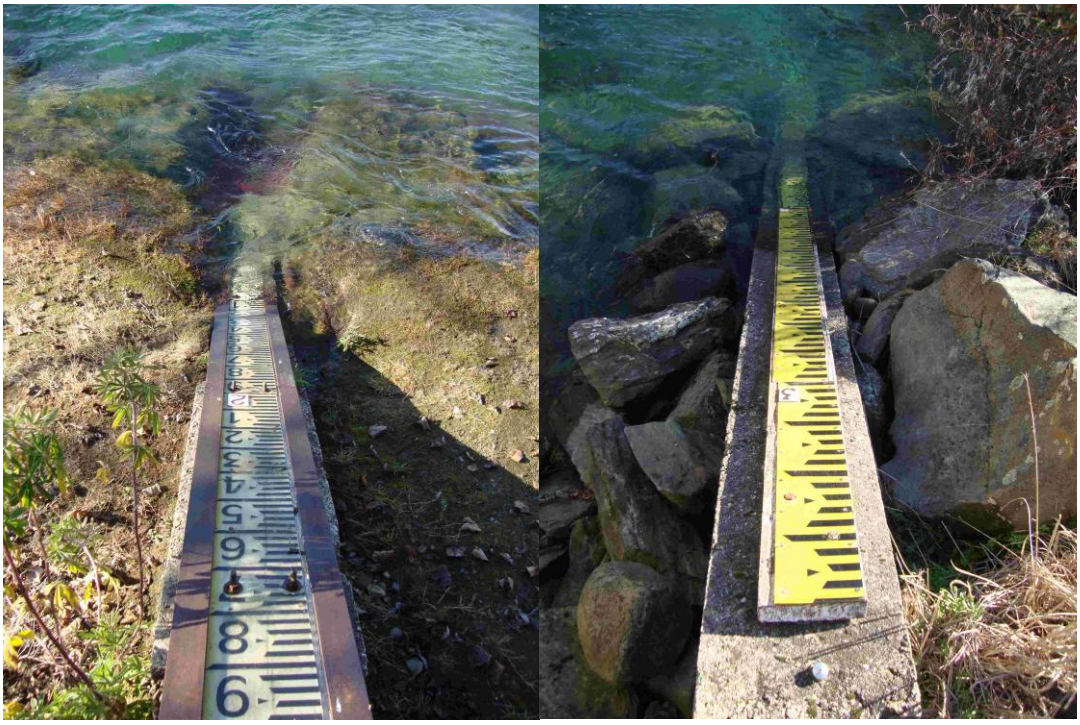


Figure 14 – 30° sloping staff gauge examples.

Photographer: Evan Baddock.

3.3.3.2 Electric plumb bobs

For a stilling well site to qualify for QC 600, an EPB shall be installed as the primary reference instrument.

EPBs shall be mounted in a manner that prevents vertical movement. Any vertical movement will shift the gauge zero with respect to the recording zero.

Fixed pointers shall be installed to ensure that readings can be taken to 1 mm precision.

For further guidance on the installation and set-up of an EPB, see Annex B – Installing an Electric Plumb Bob.

3.3.4 Configurations

3.3.4.1 Instruments

Sensor output (raw signal) may require additional scaling (i.e. a multiplier) to record the water level measurements in their correct engineering units; most importantly for voltage and milliamp outputs but can be important for digital signals too.

Pressure transducer systems usually require an offset to be derived and applied to convert measured values from effective stage (head over the orifice or element) to stage in terms of the recording zero.

- The offset must be recorded in the field notes at the time of installation.
- The offset is usually added to measured values on the data logger but may be added later during data collection or data processing.
- The orifice or sensor mount should preferably be surveyed to provide the offset, and for re-instatement when necessary, but may be set to a stable and correctly installed primary reference gauge.
- The transducer and offset must be checked for stability over time. If drift or movement occurs a change in offset may subsequently be required.

3.3.4.2 Data loggers

Data logger program code shall be controlled and documented. Program 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 program in the site visit record, with a minimum of:

- the program 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.

3.3.4.3 Telemetry

Remote station configurations may be changed via telemetry.

- New sampling programs (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.

If the above methods are used, ensure that the configuration changes are controlled and documented in a manner equivalent to making the change when on site.

Note: An 'office' logbook, or electronic field sheet 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.

3.3.5 Structures

3.3.5.1 Stilling wells

A rotational motion can be set up during floods, mainly in large diameter stilling wells, causing wrapping of the float and counterweight around each other. If this occurs:

- weld an eye to the side of the float, and
- run a taut wire from the underside of the floor to the base of the tower and through the eye, to prevent sideways movement of the float.

3.3.5.2 Calibrated structures

The installation of a weir or flume can, in theory, enable flow measurements to be reduced to the simple measurement of stage, and the insertion of this value into the formula for that design.

However, for the theoretical formula to apply, the structure must be installed strictly to design. In almost all cases in the natural environment this is not possible, and the structure will require some calibration initially, and over time, by gauging.

- The water level recorder and staff gauge shall be located a distance at least three times the maximum head away from a weir to avoid drawdown caused by flow over the crest.
- The approach channel should be straight with a uniform cross-section and be free of obstructions (e.g. boulders).
- Flow in the approach channel should be uniform.
- The velocity distribution should approximate that found in smooth-sided and straight channels.
- Baffles and flow straighteners can be used to simulate ideal velocity distribution, but their location with respect to the weir should be no closer than approximately 10 times the width of the nappe at maximum head.

For more information, see Annex F – Structures, of NEMS *Rating Curves*.

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 recording agency to allocate and catalogue their station identifiers.

The *Index to hydrological recording sites in New Zealand* (Walter, 2000) can be used to allocate site numbers.

Note: Historically, New Zealand used a national system of site numbers for water level stations that was based on river numbers. NIWA, some regional and unitary councils, and various companies use, or have used, this system. NIWA last published an index to stations identified under this system in the year 2000 (Walter, 2000).

3.4.2 Station History

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

- site identifier and/or name
- location
- intended purpose (e.g. measuring low flows and/or floods)

- ownership of land
- installation(s) (e.g. structures)
- equipment types
- variable(s) measured, and kinds of data collected, including backup water level and supplementary and/or complementary variables
- method of data collection (e.g. telemetered and/or manually collected)
- start (and end) date(s) of site and records
- datum for the site
- recording zero
- benchmarks and their reduced levels, date established, and status
- references and reduced levels, including as applicable:
  - staff gauge zero, for each staff gauge installed (external, and internal where installed)
  - internal (electric) plumb bob zero
  - reference point for the distance meter or groundwater dipping probe (e.g. the mounting point when measuring from a bridge to check a radar instrument, or top of casing when dipping a bore)
- reduced levels of sensor(s), including as applicable:
  - orifice level for gas purge systems
  - element level of submersible pressure transducers
  - transducer level of submersible acoustic sensors
  - radar sensing point for radar devices
  - the invert of all intake pipes, at the stilling well end of the pipe
  - the level of all static tube connections (intake pipes may not be horizontal)
  - the underside of recorder house floor/stilling well ceiling,

- minimum of three, preferably five, cross-sections (e.g. recorder, control, standard gauging section, and top and bottom of the slope-area reach), and a long-section
- stage for zero flow, i.e. the lowest elevation of the control or reach, below which the river stops flowing (cease to flow, CTF).
- depth below surface of sensors suspended from buoys or platforms.
- estimated 200-year (ARI) flood level and method used to estimate (if a river or lake level station), and
- history of changes to the above over time.

Use a form to collate this information. See Annex C – Hydrological Station History Form.

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 (biennial and any additional)
- 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 sets out the calibration requirements of reference devices and sensors for the data collected from them to achieve QC 600.

4.1 Purpose

Calibration ensures an instrument is serviceable and will perform to specification.

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 references

4.2.1 Staff gauges

4.2.1.1 When to calibrate

All staff gauges shall be installed with their gauge zero set at recording zero for the site and re-established to the same level if repaired or replaced.

4.2.1.2 Method

Staff gauges shall be levelled in by spirit level survey using a minimum of three permanent benchmarks.

4.2.1.3 Acceptance criteria

Precision of survey readings shall be 1 mm. Survey closure error shall be as for 3rd-order levelling. See NEMS *Site Surveys*.

Staff gauge plates are assumed to be supplied from their manufacturer correctly calibrated.

4.2.2 Electric plumb bob

4.2.2.1 Factors to consider

Electric plumb bobs (EPBs) are the primary reference at stilling well sites.

4.2.2.2 When to calibrate

All EPBs shall be installed with their gauge zero set at recording zero for the site and re-established to the same level if repaired or replaced.

4.2.2.3 Method

EPBs shall be levelled in by spirit level survey using a minimum of three permanent benchmarks.

4.2.2.4 Acceptance criteria

Precision of survey readings shall be 1 mm. Survey closure error shall be as for 3rd-order levelling. See NEMS *Site Surveys*.

EPB tapes are assumed to be supplied from their manufacturer correctly calibrated however the EPB must also be correctly installed (see Annex B).

4.2.3 Distance meters

4.2.3.1 Factors to consider

Portable distance meters must have an immovable mounting or reference point established at site.

4.2.3.2 When to calibrate

All meter mounting or reference points shall be installed to a known elevation above recording zero, and re-established, preferably to the same level, if repaired or replaced.

4.2.3.3 Method

The mounting or reference point shall be levelled in by spirit level survey using a minimum of three permanent benchmarks.

4.2.3.4 Acceptance criteria

Precision of survey staff shall be 1 mm. Survey closure error shall be as for 3rd-order levelling. See NEMS *Site Surveys*.

Devices are assumed to be supplied from their manufacturer correctly calibrated.

4.3 Reference instruments

Any one of the possible primary references may be installed as an additional reference at a water level site. Refer to section 4.2 (calibration requirements are the same).

A portable calibrator may be used as the reference to calibrate pressure transducers. See section 4.5.1 for the calibration requirements of the portable calibrator.

4.4 In-situ sensors

4.4.1 Factors to consider

Calibration shall be undertaken by a recognised service provider who can comply with the manufacturer's specifications, or if undertaken in house, a high level of care and attention to calibration methods is required.

4.4.2 When to calibrate

A sensor shall be calibrated:

- when instrument validation has failed
- when field validation is not possible
- at least annually for pressure transducers, and
- otherwise, at the frequency recommended by the manufacturer.

Note: Most calibration failures will result in drift over time. The risk of drift affecting logged data is best reduced by making sufficienlty frequent routine verification checks.

4.4.3 Method

Sensors shall be calibrated in a:

- controlled laboratory environment (preferred), or
- suitable office or workshop.

The methodology shall be as recommended by the manufacturer or servicing agency.

A calibration may involve the physical adjustment of the device, but if so, the device shall be checked again after adjustment to ensure it is now serviceable.

4.4.4 Acceptance criteria

Sensors shall be calibrated to the manufacturer's specifications.

4.5 Equipment used for instrument servicing and calibration

4.5.1 Portable calibrators

A range of portable calibrators is available, and these provide a cost-effective means of managing deployed pressure transducers.

The portable calibrator consists of three main components and may be incorporated into a single unit or be modular depending on the manufacturer and model. The key components are:

- a high accuracy pressure element to provide the reference
- a pump for applying the pressure, and
- a display unit with sensor inputs.

4.5.1.1 Factors to consider

A portable calibrator should be selected that has:

- a suitable accuracy and measuring range, and
- the required inputs to test all deployed sensors.

4.5.1.2 When to calibrate

The portable calibrator shall be tested annually.

4.5.1.3 Method

The portable calibrator shall be tested at an accredited facility.

4.5.1.4 Acceptance criteria

Devices shall be calibrated to the manufacturer's specifications.

4.6 Required records

A record is required of every calibration. As a minimum, a calibration record shall include the:

- instrument make, model, and serial number

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

Ensure any newly purchased instrument is delivered with a calibration certificate that:

- is less than 12 months old
- shows its relationship to a traceable reference, and
- details the sensor's accuracy.

Calibration records and/or certificates, and instrument relocation details, shall be stored with the instrument history (see section 2.9).

If an instrument requires repair, pre-and post-repair calibration results shall be requested and obtained from the service agent if the calibration was not undertaken in-house.

Note: Pre-repair calibration results can be used to adjust compromised logged data.

Calibration dates and outcomes shall be noted in the time-series metadata by way of filed comments (see section 9.5).

5 Equipment Validation

In this section

This section sets out requirements for validation of reference devices and sensors for the data collected from them to achieve QC 600.

5.1 Purpose

Validation tests whether an instrument or device is performing to specification and its calibration is still valid.

5.2 Primary references

5.2.1 Staff gauges

5.2.1.1 When to validate

Staff gauges shall be validated:

- as soon as possible after disturbance and/or damage is noted
- as part of each biennial site inspection (see Annex D), and
- if two consecutive verification checks fall outside tolerance (see section 7.5.5).

5.2.1.2 Method

Check by spirit level survey using a minimum of three permanent benchmarks.

5.2.1.3 Acceptance criteria

Precision of survey readings shall be 1 mm. Survey closure error shall be as for 3rd-order levelling. See NEMS *Site Surveys*.

Validation fails if the gauge zero is more than 3mm different from the recording zero.

5.2.2 Electric plumb bob

5.2.2.1 Factors to consider

Electric plumb bobs (EPBs) are the primary reference at stilling well sites.

5.2.2.2 When to validate

All EPBs shall be validated:

- as soon as possible after disturbance and/or damage is noted
- as part of each biennial site inspection (see Annex D), and
- if two consecutive verification checks fall outside tolerance (see section 7.5.5).

5.2.2.3 Method

Check by spirit level survey using a minimum of three permanent benchmarks.

5.2.2.4 Acceptance criteria

Precision of survey readings shall be 1 mm. Survey closure error shall be as for 3rd-order levelling. See NEMS *Site Surveys*.

Validation fails if the gauge zero is more than 3mm different from the recording zero.

5.2.3 Distance meters

5.2.3.1 When to validate

Distance meter mounting and/or reference point shall be validated:

- as soon as possible after disturbance and/or damage is noted
- as part of each biennial site inspection (see Annex D), and
- if two consecutive verification checks fall outside tolerance (see section 7.5.5).

5.2.3.2 Method

Check by spirit level survey using a minimum of three permanent benchmarks.

5.2.3.3 Acceptance criteria

Precision of survey readings shall be 1 mm. Survey closure error shall be as for 3rd-order levelling. See NEMS *Site Surveys*.

Validation fails if the effective gauge zero is more than 3mm different from the recording zero.

5.3 Reference instruments

Any one of the possible primary references may be installed as an additional reference at a water level site. Refer to section 5.2 (validation requirements are the same).

A portable calibrator may be used as the reference to validate pressure transducers.

5.4 In-situ sensors

5.4.1 Factors to consider

Pressure sensors, including those used in bubbler systems, can be susceptible to calibration drift and may require additional validation between routine annual calibrations.

Note: Bubbler systems may also appear to drift when there is insufficient gas supply.

Other sensor types are not susceptible to calibration drift but may appear to drift for other reasons, such as:

- acoustic and optical or laser sensors, because of environmental conditions in the wave path
- analog sensors, because of electrical instability, and
- radar and float and counterweight systems, because of physical issues, e.g. unstable installation, leaking float or float-tape riding the pulley.

Validation is often a field check. For some sensors, validation may not be practicable but on-board instrument diagnostics are available that monitor causes of potential drift.

Where field validation is not possible, or instrument diagnostics are unavailable, proceed directly to a calibration process, potentially by replacing a questionable sensor with another freshly calibrated sensor.

5.4.2 When to validate

A sensor shall be validated:

- pre-deployment
- following observed fault or major discrepancy at any site inspection, indicating that it requires checking

- if the data collected between site inspections contains evidence that the instrument requires checking, and
- when any two consecutive verifications fail, i.e. the difference between recorded water level and readings from one or more reference gauges is outside the specified tolerance for that station and sensor combination (see section 7.5.5).

5.4.3 Method

Where practicable, the validation method shall:

- obtain a series of readings against a traceably calibrated reference through the full range of the instrument
- include an open-air reading (for pressure transducers), and
- be consistent with the instrument manufacturer's instructions.

Where the above is not practicable, if on-board instrument diagnostics are available and routinely evaluated, at least coincident with verification visits (see section 7.5.3), these may substitute for sensor validation.

Wherever possible, position and tilt angle of non-contact instruments should be continually monitored to confirm the instrument is secure and datum is preserved.

Where applicable, validation shall also ensure the correct multipliers and offsets are being applied to obtain correct measurement values from raw signal (see sections 3.3.4 and 10.1.3).

If the sensor is removed, return it preferably to the exact location as it was prior to validation, or at least to the same recording zero.

5.4.4 Acceptance criteria

Sensors pass if they conform to their stated manufacturer's accuracy and pass manufacturer's recommended performance tests.

Calibrate the sensor or replace it with a freshly calibrated instrument if validation fails or cannot be performed.

5.4.5 Pressure transducers

5.4.5.1 Factors to consider

When validating the performance of a pressure transducer, a direct pressure comparison (e.g. using a portable calibrator, see section 4.5.1) is preferable because it checks the sensor independent of gravity and density variations that arise with water level measurements, i.e. independent of the relationship between head and pressure (see section 2.2.2).

5.4.5.2 Method

Test the sensor independent of any output modifications (e.g. resistors) or measurement conversions (i.e. multipliers and offsets) and over its full range, including zero-point.

Collect enough data to detect drift and/or non-linearity. Apply cycles of increasing and decreasing test pressure to detect any hysteresis (lag) in the sensor.

Ensure there are no leaks in the testing system and the test environment is stable.

5.5 Required records

A record is required of every validation. As a minimum, a validation record shall include the:

- site and variable identifiers
- instrument serial number
- name of the person performing the validation
- date and time of the validation
- location and environment (e.g. at site)
- method
- reference(s) used
- test values and corresponding instrument readings, and
- outcome (i.e. serviceable, repaired, or replaced)

Validation results may be included with site visit records (see section 7.2.8) or the instrument history (see section 2.9). Instrument relocation details shall be stored in the instrument history.

Date and outcome of all validations, 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).

6 Maintenance

In this section

This section covers general and routine maintenance for sites, stations, and equipment.

6.1 Site and station maintenance

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.

Note: A well-maintained station gives the impression of a professional undertaking.

Stations should be built and maintained with the objective of achieving at least the operational target for reduced missing record (see section 7.7.3).

To maintain a station and the site in good order, the following tasks shall be carried out on a regular basis:

- clean and tidy the recorder housing
- lubricate hinges and locks. Use graphite powder on locks, but:
  - keep the powder away from electronic and electrical components and aluminium surfaces that may become wet, and
  - use sparingly or it may bind the locks.
- clean, and repair as needed or replace, signage relating to hazards, and
- maintain access tracks in a safe condition, including clearing vegetation.

For more information, see Annex E – Schedule of Station Visits.

6.1.1 Stilling well silting management

Sites with known sediment problems shall be carefully checked at each visit, and if there are any indications of a siltation problem, the structure must be flushed as soon as possible.

The following may be indications of a blocked or partially blocked intake and/or stilling well:

- disagreement between the electric plumb-bob and external staff gauge
- a slow response to changes in external water levels
- features apparent on the recorded hydrograph, such as:
  - uncharacteristically flat or stepped recessions, or
  - rounded peaks.

For more information on flushing techniques for cleaning silt from stilling wells, and methods for checking the amount of silt in a stilling well or intake pipes, see Annex F – Desilting Stilling Wells

6.2 Equipment maintenance

6.2.1 Routine servicing

At-site routine servicing and maintenance tasks are included in the recommended schedule of station visits (see Annex E).

For recommended frequency of site visits see section 7.5.3.

Ensure updates to firmware, software, and/or configuration are timely and recorded,

6.3 Required records

All maintenance activities shall be logged.

- Record routine maintenance in the site visit records (see section 7.2.8).
- Update the instrument history (see section 2.9) when instruments are serviced, repaired, reconfigured, or replaced.

- Update the Station History (see section 3.4.2) when significant site and/or station maintenance is undertaken.

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 water level 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 portable reference instruments (e.g. laser distance meter, groundwater dipping probe, or portable pressure calibrator) to use the same reference point at each visit, thus maintaining datum.

Instruments for continuous monitoring of water levels are permanently installed and there is no additional set up required at each visit. Refer to section 7.5 for checks of the installed equipment.

For on-site set-up and checks of survey instruments refer to NEMS *Site Surveys*.

7.2 Measurement

7.2.1 Units of measurement

Units of measurement for recorded water levels shall be:

- metres, or
- millimetres (if integers are preferred).

7.2.2 Timing of measurements

All data shall be recorded in New Zealand Standard Time.

Preferred recording intervals (i.e. for the data to achieve QC 600) are:

- every 1 minute for sea level
- every 5 minutes for surface water level, and
- every 15 minutes for groundwater level.

Some recording sites may require data to be recorded at a lesser interval to enable rapid fluctuations to be accurately captured.

For example: Streams that respond very rapidly to rainfall, or are affected by human activities upstream of the recording site (e.g. a site downstream of hydroelectric dams), and groundwater levels in, or adjacent to, a pumped well.

Water level 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 statistic obtained from a burst of measurements within the interval (to mitigate noise, see section 2.1.3).
    - In the case of sea levels, the 1-minute average or median of a 1 Hz minimum burst of measurements is required for QC 600.

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*).

Note: Historically, for many years, most digital recording of water levels used a 15-minute recording interval. Prior to that, analogue charts resulted in data being filed at a range of recording intervals, and not necessariliy a fixed interval. Irregular timesteps were also a consequence of data compression applied historically.

7.2.3 Required accuracy, precision, and resolution

7.2.3.1 Water levels

For QC 600, resolution of all water level data shall be 1 mm.

For rivers and lakes, this Standard follows the United Stated Geological Survey (USGS) approach to defining required accuracy, which is, for QC 600:

- ± 3 mm up to an effective stage of 2 m, and
- ± 0.2% of effective stage at 2 m effective stage and above (i.e. at 2 m, required accuracy is 2 m x 0.002 = ± 4 mm).

For non-contact sensors mounted over water, e.g. radar and laser, by definition effective stage is always zero (see NEMS *Glossary*), therefore a proxy shall be used.

- Effective stage for these sensors, for the purpose of defining required accuracy, is the difference between stage measured and the anticipated minimum stage likely to be recorded over the life of the station.

- The anticipated minimum stage adopted for this purpose shall be:
  - decided at or before site installation, and
  - recorded in the site and time-series metadata (i.e. the Station history or file and the Site/Initial Comment).

The accuracy requirement is therefore constant at lower water levels but lessens proportionally as levels rise, making allowance for:

- water level sensors that cannot maintain accuracy over their full range
- diminished accuracy of staff gauge readings and sensors as velocity and surge increase, and
- physical distance between staff gauge and effective sensor location, which often increases as stage increases, and frequently results in different water levels occurring at the staff gauge and sensor location.

Note: Rating curve accuracy contributes to overall uncertainty of the flow record for open channel flow sites and may be significantly impacted by uncertainty of the rating in ungauged parts of the stage range e.g. high flows or extreme low flows.

For groundwater and sea levels, required accuracy for QC 600 is:

- ± 10 mm up to an effective stage of 5.5 m, and
- ± 0.2% of effective stage at 5.5 m effective stage and above (i.e. at 5.5 m, required accuracy is 5.5 m x 0.002 = ± 11 mm.

Note: The accuracy required for measuring water levels in rivers and lakes is frequently impractical for measuring water level in boreholes due to the physical restrictions and much larger ranges often encountered.

7.2.3.2 Time

Time resolution for all water level data 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 sea levels, for the data to achieve QC 600:

- no data point shall be recorded with a timestamp more than ± 20 seconds from the actual time (in New Zealand Standard Time (NZST)) that the value measured occurred.
  - Timing devices used for sea level recording shall not drift by more than ± 20 seconds over a month.
  - Timing devices when checked and/or reset shall be accurate to within ± 20 seconds of actual NZST.

For river, lake, and groundwater levels, for the data to achieve QC 600:

- no data point shall be recorded with a timestamp more than ± 90 seconds from the actual time (in New Zealand Standard Time (NZST)) that the value measured occurred.
  - Timing devices used for sea level recording shall not drift by more than ± 90 seconds over a month.
  - Timing devices when checked and/or reset shall be accurate to within ± 90 seconds of actual NZST.

7.2.4 Supplementary measurements

Supplementary measurements are required if using:

- an unvented pressure transducer (see section 2.7.1)
- a pressure transducer in a saline environment (see section 2.7.2), or
- an acoustic sensor (see section 2.7.4).

All supplementary measurements shall be:

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

7.2.5 Complementary measurement

If measuring groundwater or sea levels, barometric pressure may be collected as a complementary variable (see section 2.7) to aid interpretation of the water level data.

If collected, barometric pressure measurements shall be:

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

7.2.6 Required calculations

The following calculations may be required, as applicable to the site and instrument choice:

- conversion from raw sensor signal to water level measurement units (see sections 3.3.4 and 10.1.3)
- compensation for:
  - barometric pressure (see section 2.7.1)
  - salinity (see section 2.7.2), or
  - water temperature (see section 2.7.4).

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

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

7.2.7 On-board processing

Modern data loggers are capable of more than storing data from sensors. They can also apply programs and perform some processing of the data, for storage or for output to other devices, e.g. flow rates for gate settings.

On-board processing may be used:

- for quality control
- to convert raw signal to measurement units (see section 7.2.6)
- to implement electronic damping (see section 2.1.3)
- to apply compensations (see section 7.2.6), or
- to create useful derived data, e.g. sub-interval averages, medians, and standard deviations.

Algorithms used to implement electronic damping shall be justified. All algorithms applied must be documented, tested, and controlled.

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

7.2.8 Site visit records

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

A site visit record shall include:

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

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

- the verification record(s) (see section 7.5.6)
- record of validations (see section 5.5)
- results of recorder 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 sections 3.3.4 and 8.3)
- status of power supply and communications
- discharge measurement and control condition observations, if water level is being recorded as a surrogate for flow
- general remarks about the site, station and/or activities, and
- photographs and/or video of the site environs, installation and/or instrumentation, and flow controls, as applicable.

7.3 Sample collection

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

7.4 Laboratory processing

This section is not relevant to the measurement of water levels 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 instrument issues (e.g. drift), equipment problems (e.g. power supply), configuration errors, fouling, or physical damage or displacement that compromises the accuracy of water level measurements or prevents them entirely.

7.5.2 Factors to consider

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

- the nature of the installation and instrumentation
- whether telemetry and site visit checks are carried out, and
- the presence of backup instruments.

7.5.2.1 Pressure sensors

The relationship between head and pressure (see section 2.2.2) needs to be considered when comparing a pressure transducer against a body of water. In most situations the error involved is small and proportional to the head of water over the sensor.

However, for groundwater systems and deep lakes, the ability to effectively verify a measurement system depends on gravity and density of the water, and especially the temperature of the water, which determines its density.

For artesian groundwater systems, exposing the inspection tubes to radiant heating can add to the temperature effect. Purging the tube prior to inspection, or direct comparison to another pressure reference, is required in these systems.

If using another pressure reference, the system can and should also be verified against external references to monitor the overall site performance.

7.5.3 Frequency

There is no minimum site inspection and instrumentation verification frequency requirement for water level data because each site's characteristics are unique.

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, both in level and time.

Visit stations according to the need for:

- instrument checks and calibration
- clearing of weed and biological growth on and around the installations
- frequency or evidence of changes to controls
- 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.

Frequency required to assign QC 600 is at most three months for sites that have telemetered dual <u>independent</u> sensors, and the data show less than +/-3mm deviation at all times.

For sites that do not meet the above requirement, site visits should take place at most every two months. Sites and visit frequency should be further reduced to monthly for 'troublesome' sites, e.g. those sites with:

- unstable beds,
- high sediment loads, or are prone
- to debris or algae accumulation, or are,
- susceptible to damage.

Reference readings obtained remotely (see section 2.8.3.1) do not count toward verification frequency for the purposes of assigning a quality code.

7.5.4 Method(s)

Values from the in-situ water level instrument are routinely compared to simultaneous, usually manual, readings from one or more independent reference gauges.

Verification checks need to be carried out during visits to the station. For a schedule of station visit checks, see Annex E – Schedule for Station Visits.

7.5.4.1 Proximity to time of logged value

Verification checks are most useful and accurate when the reference reading and corresponding in-situ instrument measurement are simultaneous.

However, read the reference gauge(s) before the logger value, to prevent unintentional bias in the reference reading(s).

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 stage is changing rapidly, data is noisy, or if the logger only displays a value without an associated time.

Note: If the reference is situated a long way from the logger, it may be useful to have two people on site to synchronise the readings. Bear in mind too, that some data loggers do not update their display at every scan.

If the logger does not continually update its display with each scan, complete the verification check as close to a logged value timestamp as possible, and fill out the verification record at that time.

7.5.4.2 Uncertainty

Reference levels shall be read and noted to 1 mm resolution but always accompanied by an uncertainty, e.g. 756 mm ± 5 mm.

Note: It can be difficult to obtain external reference readings (e.g. from a staff gauge) in the field with a true accuracy better than ± 3 mm. Floods cause surges and standing waves that can introduce considerable inaccuracy.

For an electric plumb bob, the uncertainty is assumed to be ± 1 mm unless otherwise noted.

The observations collected and their uncertainty carry a lot of meaning when the data are processed and are expected to be carried out with utmost diligence.

7.5.4.3 Sea level

Tidal recording agencies, e.g. LINZ, install an accurate GPS receiver on a float next to the tide gauge for a full tidal cycle, then compare those readings with the tide gauge to obtain a correction that is applied back to the last tide gauge instrument calibration or replacement. However, such corrections take time and are expensive and are therefore rarely carried out. As a consequence, there is no ongoing verification of the tide gauge.

An alternative is to install an independent secondary sensor for ongoing verification of the primary sensor.

7.5.5 Assessment

7.5.5.1 Method(s)

Calculate the difference between logged water level and the concurrent reading from the primary reference gauge at the time of the check. If the difference exceeds the QC 600 verification tolerance, verification has failed.

At stilling well sites, also note the difference between the primary EPB reading and the simultaneous staff gauge reading. A difference of more than a few millimetres indicates the intake and/or well may be silted (see section 6.1.1).

7.5.5.2 Acceptance criteria

For QC 600, verification tolerance is the accuracy required, as stated in Section 7.2.3.1, of the actual water level at the time of verification.

If uncertainty in the reference reading exceeds the verification tolerance:

- maximum possible quality code is QC 500, and
- repeat the check within seven days (may be performed remotely, e.g. via telemetered camera).

  Note: The expectation is that conditions causing the excessive uncertainty in the reference reading (e.g. a flood or high wind) will have settled to enable a subsequent more reliable check before too much time has elapsed should there be a recording problem.

For time-keeping criteria see section 7.2.3.2.

7.5.5.3 Evaluation

If verification fails, in the first instance clean the sensor then recheck.

- For stilling wells ‘cleaning’ includes flushing intakes and/or removing silt from the tower.
- For immersed sensors, including gas-bubbler orifices, ‘cleaning’ includes removing debris and sediment accumulation from the sensor or orifice.

If the sensor is removed for cleaning, return it preferably to its exact prior location but at least to the same recording zero.

If cleaning does not resolve the differences, validate the reference(s) and in-situ instruments, or replace the instrument(s).

7.5.5.4 Resetting a logger after a fault

After a fault, reset the logger to the correct time and the value from the primary reference, provided that is confirmed reliable.

If reset when water level is varying, verification is needed soon after, during a period of relatively stable water level, to confirm the data logger was set correctly, or to adjust again if necessary.

Particular care is necessary when measuring groundwater level where pumping occurs.

7.5.6 Required records

As a minimum, a verification record for a water level recording station shall include:

- the site identifier (i.e. name and/or number)
- variable identifier(s) if more than one instrument (e.g. backup)
- the name of the observer
- conditions at the time of the check(s)
- the actual date and time of the check(s) (in NZST)
- the apparent date and time on the logger
- primary and other reference readings:
  - clearly identified as to which instrument
  - with uncertainties, and
  - where a primary reference gauge is unreadable for whatever reason (e.g. the staff gauge is damaged) the water level shall be surveyed.
- concurrent instantaneous logger and/or sensor value(s)
- results of visual inspections, and
- notes about anything that might affect:
  - instrument performance, or
  - the ability to operate the station properly or safely.

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

7.6 Data retrieval

The retrieval of water level data varies according to the type of recorder used and the urgency of acquiring the data. Most is collected through various telemetry systems. Data may also 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.

Most water level data are transmitted, received, decoded, and entered into local databases through various telemetry systems, such as over radio, cell phone, internet connections, and satellite systems.

It is good field practice to routinely, manually download the data logger at telemetered sites (see section 7.6.2).

7.6.2 Manual downloads

Manual download of data may be:

- direct to a mobile device or laptop computer, or
- by extracting a data card from the data logger and downloading from the card to a computer.

Protect the data from loss or damage, including while in transit.

7.6.3 Original time-series data

Original time-series data is defined as non verified in the NEMS *National Quality Code Schema*. It is the time-series data taken into the formal verification and editing processes that are performed by a skilled person and the subject of NEMS *Data Processing*. As such, original time-series data must be preserved indefinitely in case data processing errors are found in future.

Because of the increasing use of automated quality control and pre-processing of data, the original time-series data may not be the raw measurements. For this reason, and the wide variety of systems employed, what constitutes the original version of each time series must be defined by the recording agency (see NEMS *Data Processing*).

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 are able to 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

The purpose of these checks is 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.

7.7.1 Telemetered systems

A telemetry system offers the opportunity to remotely monitor many functions of a recorder station.

It is possible to detect very quickly:

- instrument failures
- electrical problems
- substantial or probable changes in the hydraulic control, and
- sedimentation problems, e.g. orifice burial or silting of the stilling well.

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 repair faulty equipment (by identifying the fault before departing).

7.7.2 Manual downloads

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

7.7.3 Missing record

The goal is no missing record. Recommended operational target is less than five days in total missing from alternate years (i.e. in only one year of two consecutive years).

Having a backup sensor and logger at a station is highly recommended to reduce the possibility of missing record.

Use of record from secondary (backup) instruments does not count toward the missing record total, provided the backup instrument is calibrated and 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 includes quality assurance tools intended to prevent problems occurring, and guidance for method changes that may disrupt stationarity and management of quality assurance records.

8.1 Quality assurance tools

8.1.1 Biennial station inspection

A full station inspection shall be carried out at least once every two years. This inspection is a thorough check of the station that includes:

- validating the site references (by survey)
- gathering the information to update station and instrument histories
- a comprehensive check of all instruments
- checking the integrity of all structures and ancillary equipment, and
- following up on issues identified from the previous inspection.

A checklist for these inspections is included at Annex D – Biennial Station Inspection.

8.1.2 Field site audit

All agencies shall document and implement a standard methodology for field site audit and review. The audit shall be undertaken by a suitably experienced and preferably independent person.

The purpose of the audit is to ensure:

- equipment calibration and data logging methods are fit for purpose
- data quality objectives can be achieved, and
- data collected can be verified and archived with as little processing and subsequent editing as possible.

Refer to NEMS *Data Processing* for requirements and guidance relating to the processing, editing, and quality assurance of the data.

8.2 Managing method changes

Significant change to methods can disrupt stationarity of the record. Examples include a change of:

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

Except for groundwater, where a different borehole is likely involved, relocating a site by a few metres can usually be regarded as the same site.

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

- measurement range
- inflows and outflows
- hydraulic characteristics, and/or
- control features.

8.3 Required records

Quality assurance records for a water level recording station include the following:

- all site survey data and level reductions
- all completed biennial station inspection forms, and
- the terms of reference and results of any audits.

Site survey data and completed biennial station inspection forms are original records.

- Survey data may be captured on paper or electronically and stored in a dedicated facility, or in the site folder or file.
- Reduced levels and completed forms should be stored with the Station History (see section 3.4.2) and be accessible when data are verified and processed.

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.

9 Metadata

In this section

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

9.1 Site details

Site metadata includes the following site details:

- the site identifier (see section 3.4.1)
- all records required from site selection (see section 1.7) 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:
  - calibrations (see section 4.6)
  - validations (see section 5.5), and
  - instrument servicing and maintenance (see section 6.3)
- assessment of the maximum quality code for water level measurements that the site and station is 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 the verification checks if undertaken during the visit, and
- form part of the site metadata.

9.3 Other details

Site metadata may also include, as applicable:

- confidentiality agreements
- intellectual property, and
- any other restrictions related to data access.

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 water level data. In other words, Tables 1 and 2 set out the minimum requirements for any water level data to be considered as having been "produced under NEMS".

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

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

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

All completed quality coding matrices shall be:

- annotated with the site identifier
- signed and dated by the person completing the assessment

- available when the data are processed (see NEMS *Data Processing*), and
- retained indefinitely as part of the site metadata.

9.4.1 Considerations

In most cases, water level 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.

Backup data and the results of required calculations (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.

9.5 Comments

Comments may be one or more of:

- remarks noted in the field
- annotation and explanation during data processing, and

- filed comments timestamped and stored with the time-series data.

Field remarks and comments noted during data processing may be informal. They are mostly intended for use by the recording 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 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 records

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 and field sheets 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
- validation records
- site surveys, and
- biennial site inspections.

10.1.2 Photos and video

Photos and video must be curated to avoid overwhelming storage with unnecessary and/or unidentifiable content. All photos and video retained as metadata must 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 recorder, etc.).

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

10.1.3 Raw data

Raw data is defined in NEMS *Glossary*.

For water level measurement, raw data may be converted from raw sensor signal to conventional (engineering) units, e.g. mA to mm (see sections 3.3.4 and 7.2.6) but are otherwise unaltered when captured.

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

10.1.4 Logged data

Data recorded in various formats must be deciphered and 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
- overlapping data from 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

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.

  Note: Data averaging can induce hysteresis and phase shift of the data.

10.2.2 Transformations

Transformations may be applied to:

- raw sensor signal before data are captured as raw water levels in the required measurement units (see section 7.2.7)
- raw water level values prior to transfer to the data processing system as original data (e.g. for damping or interference compensation) (see sections 7.2.7 and 7.6.3)
- obtain derived data during data capture and/or data collection (see sections 7.2.7 and 10.2.1)
- original data during data processing (see NEMS *Data Processing*), and
- data after they are processed, if collected as a surrogate for flow, (see NEMS *Rating Curves*).

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
- supplementary and/or complementary data used in the production of the final verified and archived time series (see sections 7.2.4 and 7.2.5).

10.3.1 Electronic records

Electronic records required to be retained indefinitely shall be:

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

Retrievable in perpetuity requires:

- a storage facility that is:
  - known (i.e. whereabouts and custodian)
  - secure, and
  - accessible.
- records be stored in a format that is either:

  - universally readable (e.g. text)
  - migrated as systems change, or
  - stored with the software to open and read them.

10.3.2 Paper records

Paper records required to be retained indefinitely shall be:

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

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Annex A Quality Coding Matrices

Quality coding matrices determine an initial quality code for the data based on site factors and field visit actions, observations, and verification checks.

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

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

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

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

    Note: QC 200 may not be available if there is no sensible concept of "poorer than" the relevant QC 400 performance requirement.
  - Action may be required instead, either immediately or subsequently, to resolve the performance issue and/or recheck.

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

- Initial quality code cannot be higher than QC 500 if any one QC 600 performance threshold is not achieved, by definition of Table 3 of the Standard.

- Data are considered to be of 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.

Site matrix

Criteria	QC 600	QC 500	QC 400	QC 200
All sites				
Stilling well intakes (3.1.2.5)	Suitably sized intake(s) with correctly oriented static tube(s). ☐	☐	No static tube(s) and/or poorly sized intake(s) with lag and/or noise apparent. ☐	
Stilling well primary reference (3.3.3.2)	EPB installed. ☐	☐		
Reference gauge zero (4.2)	Installed using at least three established benchmarks. ☐	☐	Installed from a single established benchmark. ☐	
	Installed to recording zero ± 3 mm and survey misclose ≤ 3 mm.		Action required: Reinstall if not within ± 3mm. Resurvey if survey misclose > 3 mm.	
Recording resolution (2.4.1, 7.2.3.1)	1 mm ☐	☐	From 3 mm to 5 mm. ☐	☐
Biennial station inspection (8.1.1)	Within last 2 years, and recording zero was correct (to ± 3 mm). ☐	☐	Overdue by 6 to 12 mths. ☐ *Incorrect recording zero may be addressed during data processing.*	☐
Supplementary measurements – acoustic sensors (7.2.4)	Water temperature or a reference bar is measured. Compensation is or can be applied. ☐		Water temperature compensation is not, and cannot be applied. ☐	
Supplementary measurements – pressure transducers (7.2.4)	If estuarine environment, salinity or conductivity is measured. Water density adjustments are, or can be applied. ☐		Water density adjustments are not, and cannot be applied. ☐	
Supplementary measurements – unvented pressure transducers	Local barometric pressure is measured. Compensation is or can be applied. ☐	☐	Barometric compensation is possible using barometric pressure data from 5 km to 30 km away. ☐	☐

(7.2.4)				

Criteria	QC 600	QC 500	QC 400	QC 200
Rivers and lakes				
Sensor accuracy (7.2.3.1)	At least (or better than) the greater of: • ± 3 mm, or • ± 0.2% of effective stage. ☐	☐	From the greater of: • ± 10 mm to ± 15 mm, or • ± 0.2% to ± 0.5 % of effective stage. ☐	☐
Recording interval (7.2.2)	5 minutes ☐	☐	Greater than 15 but no more than 30 minutes. ☐	☐
Groundwater				
Sensor accuracy (7.2.3.1)	At least (or better than) the greater of: • ± 10 mm, or • ± 0.2% of effective stage ☐	☐	From the greater of: • ± 20 mm to ± 50 mm, or • ± 0.2% to ± 0.5 % of effective stage. ☐	☐
Recording interval (7.2.2)	15 minutes ☐	☐	Greater than 30 but no more than 60 minutes. ☐	☐
Sea				
Gas bubbler (1.6.6)	Suitable outlet bell fitted. ☐		Unsuitable, or no outlet bell. ☐	
Sensor accuracy (7.2.3.1)	At least (or better than) the greater of: • ± 10 mm, or • ± 0.2% of effective stage ☐	☐	From the greater of: • ± 20 mm to ± 50 mm, or • ± 0.2% to ± 0.5 % of effective stage. ☐	☐
Recording interval (7.2.2)	1 minute ☐	☐	Greater than 2 minutes but no more than 5 minutes. ☐	☐
Sampling method (7.2.2)	1-min. average or median of ≥ 1 Hz measurement burst (i.e. 60 samples per minute) ☐	☐	2-min. to 5-min. interval average or median OR ≤ 10 samples per minute. ☐	☐
Supplementary measurements – pressure transducers (7.2.4)	Data are adjusted for density of sea water. ☐		Water density adjustments are not, or cannot be applied. ☐	

Visit matrix

Criteria	QC 600	QC 500	QC 400	QC 200
All sites				
Verification – timing (7.5)	Site visits within 3 months for sites that have telemetered dual independent sensors, and the sensors show less than +/-3mm deviation at all times. Or, Site visits within 2 months for sites that do not meet the above criteria. Or, Site visits every month for 'troublesome[1]' sites.	Site visit between 3 and 4 months where dual independent sensors show less than +/-3mm deviation at all times. Or Site visits between 2 and 4 months for sites that do not meet the above criteria. Or Site visits every month for 'troublesome[1]' sites.	4 months or more since last site visit, or 2 months or more for "troublesome[1]" sites.	
Verification – primary reference reading (7.5.5.2)	Uncertainty of reading ≤ verification tolerance.		Action required: Recheck within 7 days. *(Assessed when processed).*	
			Reference damaged or disturbed and water level not surveyed (to ± 3 mm).	
Verification – recorder (7.5)	Logged value is within verification tolerance of primary reference reading.		Action required: clean and/or clear sensor and recheck.	
			Recheck is not within verification tolerance of primary reference OR Not cleaned and rechecked.	

			Action required: validate instrument(s) after two failed verifications.	
Stilling well silting (6.1.1)	• EPB and ESG agree ☐ within uncertainty, and • no silt or lag apparent.		*Possibility and extent of silting and further effect on quality code to be assessed during data processing.*	☐
Sensor operation (3.1.2 & 3.3)	Not obstructed. ☐		*Extent of obstruction and further effect on quality code to be assessed during data processing.*	☐
Sensor calibration (4.4)	Is current OR Not required. ☐	☐	Overdue by half to one ☐ required calibration interval OR Failed. *(in place of validation).*	☐
Sensor validation (5.4)	Passed OR Not required. ☐		Failed. *Not applicable* ☐ *to pre-deployment check (should not be deployed).*	

[1] 'Issues the can cause a site to be considered *'Troublesome' are described in Section 7.5.3*

Criteria	QC 600	QC 500	QC 400	QC 200
Rivers and lakes				
Clock drift (7.2.3.2)	Less than ± 90 s per month, if any.		From ± 180 s and up to 5 minutes per month. ±	
Groundwater				
Clock drift (7.2.3.2)	Less than ± 90 s per month, if any.		From ± 180 s and up to 15 minutes per month. ±	
Sea				
Clock drift (7.2.3.2)	Less than ± 20 s per month, if any.		From ± 40 s and up to ± 60 s per month.	

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

Annex B Installing an Electric Plumb Bob

Although a simple device, installing an electric plumb bob requires some thought and care.

Components

An electric plumb bob (EPB) comprises:

- a mounting bracket
- a reel assembly with stainless steel measuring tape and indicator mark
- a weighted probe (the plumb bob)
- a power source (a 1.5V battery is enough if the circuit is well earthed)
- a milliammeter
- a switch

Operation

The probe is lowered so that its tip touches the water surface, completing an electrical circuit that is registered by the milliammeter. Corresponding stage is then read from the tape at the indicator mark, providing an independent check of water level in the well.

To install

1. **Mount the reel assembly.**

   Mount the reel assembly over the stilling well where it will not interfere with other instruments and the plumb bob when lowered will not touch the float tape, pipes, other fittings, or the side of the well.

   It should also be in a position that can be easily reached and where the ammeter and indicator mark can be easily read.

   Note: Good options are to screw it to a piece of 150 x 25 mm timber that has been bolted across the back wall of the housing or mount it on a steel angle bracket that has been bolted to the floor of the housing.

2. **Attach the battery.**

   Attach the battery with the positive side to the milliammeter via the switch, and the negative side connected to a good earth.

   Note: If a steel stilling well, earth to the well or the bolts connecting the housing floor to it. If a concrete, fibreglass, or plastic stilling well, attach to a *metal ladder, pipe or purpose-built earth (e.g. a weighted length of copper wire) in contact with the water.*

3. **Fix the measuring tape to the reel.**

   Ensure sufficient tape to reach to the further of 0.5m below the invert of the lowest intake pipe (capped or open) or the bottom of the well.

   Note: This should enable you to measure the lowest anticipated water level.

   Attach the tape to the inside of the reel with the zero end at the reel.

   Note: Adding a length of previously discarded tape, strong plastic-coated wire marked every 10 cm, or similar, to the zero end of the tape, sufficient to reach the bottom of the well enables sounding of the level of sediment that may accumulate in the well. Join the two pieces with a suitable small bolt or other fixture that will not corrode or degrade in a damp environment.

4. **Temporarily fix the plumb bob to the other end of the tape.**

   Ensure the plumb bob's adjusting screw is at its approximate mid-point.

5. **Check the electric plumb bob circuit is working.**

   Lower the plumb bob to water, switch the ammeter on and note its response. If not working, check the earth, battery, and all circuit wiring connections.

6. **Set up a surveyor's level.**

   Set up in a position where there is direct sight to a convenient and recently checked benchmark and the plumb bob can be sighted through a hatch or inside the recorder housing.

   Note: If not possible to directly sight a benchmark, install a peg at a suitable location as a temporary benchmark, surveyed in to the usual benchmarks with a zero close.

7. **Take readings with the level.**

   Take a backsight onto the benchmark, and an intermediate sight onto the well or river water level.

   Calculate the reduced levels (RL's) of the height of instrument (HI) and the water surface using normal survey practice.

8. **Convert the reduced levels to stage height equivalent.**

   Subtract the recording zero (noted in the Station History) from the HI and water surface RL's.

9. **Take an electric plumb bob reading.**

With the tip of the plumb bob visible at the cross hairs of the level, read the tape as usual at the indicator mark.

Note: One person observes through the level while another person operates the electric plumb bob.

10. Adjust the plumb bob tape length.

Subtract the stage height equivalent of the HI from the electric plumb bob reading. This is the length of tape that must be cut off.

Using the graduations on the tape, measure back this length from the free end and cut or snap off the tape, then securely reattach the plumb bob to the shortened tape.

11. Fine-tune the plumb bob length.

Observe the plumb bob through the level and use the plumb bob's adjusting screw to align its tip exactly with the level cross hairs.

12. Tighten the plumb bob lock nut firmly.

To check

Use the EPB to obtain a water level reading then compare that reading with a reading from the staff gauge (if installed) and/or the levelled water surface stage equivalent values, accounting for any observed change in stage during the installation.

Troubleshooting

Table B 1 – Troubleshooting electric plumb bob faults.

Problem	Possible Cause	Resolution
No power.	Flat battery.	Check the battery and replace if needed.
No power.	Loose or corroded wires.	Check wiring. Reconnect wires if loose or disconnected. Replace wiring if corroded.
EPB not working.	Corroded earth connection. *Note: Leaving the battery connected may hasten corrosion of the earth despite the operating switch being left off.*	To test, disconnect the earth then very briefly touch it across the EPB tape with the operating switch closed. **Caution:** *This puts a potentially damaging current through the milliammeter.* If the test is successful, clean all connections.

		If difficult to get a good earth, install a weighted length of copper wire down the well to directly contact the water. If the ammeter needle deflects in the wrong direction, reverse the battery polarity.
Poor EPB reading.	Corrosion on the plumb bob tip.	Scrape or sand any corrosion off the plumb bob.
Low EPB reading.	Slipped insulating sleeve creating an air pocket below the EPB tip that will give a low reading.	Check the insulating sleeve, reposition, and fix back in place. Could be removed if needed.
EPB always reading on.	EPB tape shorting against the recorder floor. *Note: Damp timber floors can cause shorting.*	Install a plastic guide ring.
Other EPB problems?	Lubrication of the reel's axle insulating the reel.	Do not lubricate with oil or graphite. The fibre washer in the clutch can be removed to improve electrical connection.

Annex C Hydrological Station History

On the following pages is an example of a Hydrological Station History form.

Site No......................................   Form SH 100721

HYDROLOGICAL STATION HISTORY

Station ....   River, at ....

Map reference(s): ....   Catchment area: .... km^2

Recording authority: ....   Client: ....

–

Section 1: RECORDS COLLECTED

Primary, Backup, Telemetry Logger/Sensor Type	Date Commenced	Date Ended	Remarks

Earlier SH or 16 forms held:
……

Section 2: BENCHMARKS

BM No.	Date Placed	Provisional R.L.	Datum	Final R.L.				Level Bk
				R.L.	Datum	Origin	Date adopted	

BENCHMARK ALTERATIONS

BM No.	Date Altered	From (RL)	To (RL)	Reason and Remarks	Level Book	Updated by:	
						Initials	Date

Section 3: STAFF GAUGES

Type	Location	Range	RL Zero m	Date Established and Level Bk No.	Updated by:	
					Initials	Date

Section 4: RECORDING INSTRUMENT

Type and Make.	Date Installed	Date Removed	Range m	Interval Resolution	RL Zero m	Remarks	Updated by:	
							Initials	Date

Section 5: RECORDER STRUCTURE

Type and Description	Date Constructed	Date Removed	Date Updated Initials	Date

LEVELS:

RL invert lower inlet pipe .... RL invert top inlet pipe ....

RL invert stilling well .... RL underside recorder floor ....

Transducer: Standard RL of sensor head .... Standard offset ....

Section 6: LEVELLING CHECKS

Date	Team	Level Bk/Pg	Items checked – list results (BM's, EPB, ESG)	Remarks and Results

Section 7: REACH

Nature of Control:
....
....
....

Gaugings - Cableway/Slackline cableway/Wading/Jet Boat/Dilution/Bridge/Other ....

Slope-Area Reach:

X-Sect. No.	BM No. to BM No.	Dist. between X-S's	Remarks

Section 8: SITE PLANS

Site Plan 1 As at Drawn by / /

(Show all BMs, staff gauges, rec. installations, details of reach, cross-sections, distances, etc.)

Site Plan 2 As at Drawn by / /

(Use for significantly different change in installations, reach, benchmarks, etc.)

Annex D Biennial Station Inspection

This checklist shall be completed for each and every biennial station inspection.

☐ Form heading

Provide a minimum of the site number, name or identifier, current inspection date, agency and party, and date of last inspection.

☐ Findings from last inspection

Review results of the last inspection before departing. Note any changes made at the time, unresolved issues, and required work or safety hazards identified.

On site, confirm actions taken last inspection and check if those issues, work, and hazards have been addressed. Note any work still not done and hazards and other issues still present. Note any new issues those actions may have created.

☐ Levelling check

Give the date and all level book or electronic file details of this levelling check, along with the start benchmark (BM). State name and reduced level (RL) of the start BM and the datum used for the survey.

Ensure when levelling that all benchmarks, staff gauges, electric plumb bob, stilling well reference points (see below) etc. are change points, or measured twice if read as intermediates. Reduce and calculate the close on site. It must be within ± 3 mm.

☐ Benchmarks

List the differences between the RLs measured and those on the Station History form. Record the datum used. If assumed, state which BM is assigned the nominal value. Indicate whether each BM's measured value is correct to within ± 3 mm and give explanatory comments if not. Document the state of the BM's and whether replacement is necessary. GPS the BM's location if not provided.

☐ Staff gauge zero

Determine and list the differences between the zeros measured and those on the Station History form. Indicate whether each zero is correct to within ± 3 mm. Give explanatory comments if not, including proposed remedies.

- [ ] ### Internal (electric plumb bob) gauge and zero

Record (with the staff gauge data) the internal plumb bob zero determined from the levelling and any difference with the value on the Station History form. Check that the electric plumb bob has a clear and stable index mark and the connection to earth is reliable. Clean the plumb bob and ensure it is secure.

- [ ] ### Recording zero

State what the primary reference is for the site (normally the electric plumb bob for wells and the staff gauge for transducers). Determine and list the difference between current logger and primary reference readings.

Note: Provided the primary reference zero is correctly set at recording zero for the station, this check will identify if the recorder is correctly set. Measurements from the primary reference are used at regular station visits to check logged data and to control any necessary adjustment of data.

- [ ] ### Instrument details

Record the details of make, type, serial number of all sensors, loggers (and software version) and other instruments and equipment used to collect or transmit data. Include sensor range (nominal and possible) and scan rates, logger sampling, averaging, and recording intervals, and transmit/download frequency.

Note: Nominal range refers to the sensor as specified. Possible range refers to the sensor as installed, e.g. by raising a float through its full operating range.

- [ ] ### Stilling wells

Record whether the installation is generally adequate, and whether the station as a whole promotes a professional organisation.

Check that the stilling well reference points (underside recorder floor, well invert, invert of upper and lower intake pipes) are unchanged.

Check the intake pipes for damage and sediment and any detrimental effect on the record. Determine if the flushing frequency, techniques, and facilities are effective.

- [ ] ### Float systems

Raise the float and check it for leaks, growth, and obstructions, that the connections are secure, and that the tape or wire is free of kinks and damage. Check that the float will travel through its full range without striking obstructions, and that the float tape or beaded wire is undamaged. Ensure that the data logger resumes its correct reading and beware of setting off alarms. Determine the level and/or depth of sediment accumulated in the tower.

Ensure encoder pulleys are operating freely and the float tape or beaded wire sits properly on the drive pulley.

☐ Sensors

Ensure sensors are clear of sediment and debris, protected from likely damage, and mountings are secure, and that the sensor tube or cable is protected from damage by stock, vandals, floodwater, and subsidence.

If the gas purge pressure sensor shows a discrepancy with the staff gauge, carry out a purge cycle and recheck.

Check the bubble rate is adequate. Inspect lines and fittings for leaks. Ensure gas supply systems (e.g. compressors) are drained and/or dry (including functioning desiccant cartridges where fitted).

Check vented wet transducers are fitted with desiccant cartridges, dry-boxes or bottles that are regularly serviced and currently functioning.

Check the transceiver surfaces of any non-contact instruments, e.g. radars, are clean and undamaged, signal paths are clear, and their mountings have structural integrity, are rigid and secure.

Check the transceiver surfaces of any submerged acoustic instruments are clean and undamaged, free of debris and sediment, signal paths are clear, and their mountings are secure.

Check whether the sensor calibrations are up to date.

☐ Recorder operation

For both the backup and main recorders, note whether they are accurate, securely mounted, and easy to service.

If logbooks are used, check that they are properly filled in and legible. If electronic field sheets are used, review entries since the last biennial inspection for completeness.

☐ Power supply

Consider whether adequate. Test the voltage during a reading. Check the wiring for tidiness, corroded terminals, unsoldered connections, undue tension, and potential breaks.

Batteries should be marked with date of entry into service, as well as having a record of charging, discharge testing, conditioning, etc., as appropriate. Check and test any solar panel, generator, lightning protection, etc.

☐ Safety

Consider whether access to the site and installations is safe.

Check the safety of the gauging location; bridges for flood and traffic hazards, cableways and taglines for navigation hazard, wading and other gauging sections for general safety of use.

Check the safety of gauging structures; bridges for soundness of decking and handrails, cableways and taglines for soundness of cable and winch, supports and anchors, and current operating certificate if required.

Check condition of power supply equipment, particularly mains power connections.

Note any new hazards.

☐ Weir or flume

Check the structure is clean, undamaged and there is no evidence or suggestion of leakage. Look for sedimentation and backwater effects that may be altering the rating.

☐ Gauging reach

Check whether the gauging reach has relatively laminar flow, uniform depth, parallel flow lines, etc., and absence of weed growth, vegetation, and other obstructions.

Check whether the gauging distance markings are clear if applicable, and if the gauging distances can be reliably referenced between gaugings to provide a record of riverbed movement in the gauging cross-section.

☐ Photographs

Digitally photograph all components of the installation, and recording and gauging reaches, including site controls (views upstream, downstream, and across).

Photos must be date-stamped and properly indexed and archived as part of the Station History.

☐ Records

Comment on the likely accuracy of the stage record, the stability of the control(s), and any other factors not so far covered that have a bearing on the accuracy of data since last inspection.

☐ Reporting and filing

Transfer any safety issues and new hazards to the agency's hazard management system.

Update the Station History with results from the inspection. Update instrument records, checking that calibrations where required are current for the instruments on site.

Alert staff processing the data to any identified issues of record quality.

Incorporate works or repairs required into the agency's work programme, e.g. by non-conformance under a quality management system, or team meeting, or budget planning process.

File the completed Biennial Station Inspection form appropriately as a permanent record of the effectiveness of the station and the integrity of its data.

The relevant manager should ensure that:

- the inspection has been carried out correctly
- any work required is done or is in the team's work programme
- completion of the work required is noted on the inspection form, and
- the completed form is filed.

☐ Certify correct

Certify that the Biennial Station Inspection is complete, and that the data from this site is being collected according to the required standards and procedures, unless otherwise noted on the completed form.

Annex E Schedule for Station Visits

Routine station visits should include the following checks, as applicable:

- [ ] ### Check telemetered data

In the office, check the telemetered data for any apparent problems related to communication performance, gaps or spikes in data, and any trends that may be due to impaired sensor performance, rating change, or any other possible problems.

- [ ] ### Arrange access

Make any arrangements required for access, such as keys, landowner permission, and vehicle and equipment bookings.

Check the weather forecast.

- [ ] ### Observe

Go to the site, and on arrival observe any issues with growth, debris, damage, etc. Take a photograph of anything significant.

Read the primary reference, and any other installed independent references (e.g. staff gauge, EPB, reference level pins, or distance meter). If no suitable independent reference exists, survey the current water level.

- [ ] ### Clear the site and control

Clean the staff gauge plates. Clear growth and debris from on and around the installation, sensor(s), and control structures (e.g. weir crest). Note any consequent changes in water level. Enter details of what was done and all reference readings into the field visit records (e.g. logbook or electronic field sheet).

Note. Weed growing between the recorder and control sections may ultimately become the control. Clearing this weed will cause a rating change and should be followed by gauging, but backwater effect created by the weed may take some time to drain. You may need to delay gauging by several hours, or into the next day, to ensure you are gauging in stable hydraulic conditions (see NEMS Open Channel Flow Measurement*).*

- [ ] ### Connect data logger

Connect to the data logger and/or key through the display to check the following:

- logged stage values agree with the reference reading(s) to within the tolerance defined for the sensor and range, and

  Note: If a difference occurs, a reason for that difference should be sought. It is essential to first check the reference itself is correct, and prudent to confirm any trend in differences over two or three subsequent visits before making any adjustment.

- time, and all other variables in the data logger, appear accurate and sensible.

If not telemetered, download the logged data, taking a backup onto separate media (e.g. memory stick or cloud service), then inspect the data for evidence of problems that might be fixed or further diagnosed while on site.

☐ Check bubbler gas pressure

Ensure there is sufficient gas supply pressure (check the chamber gauge, i.e. the gauge on the bottle if stored supply). Ensure regulated pressure to the bubbler is set at the manufacturer's recommended pressure for correct operation of the sensor (check the output pressure gauge, i.e. the gauge between regulator and bubble unit). Note the pressure gauge readings in the field visit records.

Note: When using industrial gas bottles the cylinder pressure (gauge closest to the cylinder) should be in the range 0 kPa (empty) to 20,000 kPa (full) and the regulated pressure to the bubbler (gauge furthest from the cylinder) should be at manufacturer's recommended pressure.

☐ Measure battery power

Measure the battery power supply voltage with a multi-meter and read the charge voltage if applicable. Note these in the field visit records.

☐ Check instrument housing

Check the following:

- The instrument housing for damage, leaks, insects, vermin, and birds. Clean and repair as necessary, including solar panels and aerials if fitted.
- All cabling, gas lines and their protection, and change desiccant (e.g. drybox, cartridge, or bottle) if installed.
- Any evidence of habitation in wells, e.g. nests, eels.

Note any maintenance to be attended to next visit in the field visit records.

☐ Carry out non-routine tasks

Carry out any non-routine tasks as required, taking care to follow the required procedures:

- Change Bottled Gas Supply
  Replace the gas cylinder once cylinder pressure is below 3000 kPa. Using the gas bottle spanner, close the cylinder valve, remove the regulator, and swap bottles. First, use the spanner on the new one to 'crack' the valve open momentarily, giving a squirt of gas to clear any dirt. Then connect the regulator, taking care to seat the connection properly. Tighten the nut firmly, but not over-tight. Turn on the cylinder valve, listen for leaks, and check both pressure gauges. If leaks are suspected, use a small brush to apply detergent mixed with a small amount of water to the connections and look for bubbles.

- Flush Stilling Wells
  Flush if it is suspected that the stilling well and/or intake pipes may be blocked with silt. Continue until the intake pipes run clear. See Annex F – Desilting Stilling Wells for the detailed procedure.

- Maintain smart sensors

  Respond to issues identified by on-board diagnostics as required. If cleaning is needed use the manufacturer's recommended methods. If the instrument is removed for maintenance, replace it in the same location and position, or otherwise in a manner that ensures datum is preserved.

- Reprogram the Logger
  If the logger is to be re-programmed, before making the change ensure that either the telemetered record is fully up to date (contact the office and ask for a data retrieval) or download the most recent data to a laptop, taking a backup onto separate media (e.g. memory stick or cloud service).

  If software is updated to a new version, perform a verification inspection before and after the update and note all changes including logger software versions, and offsets in the field visit records.

- Purge Gas Bubbler
  If there is discrepancy between logged stage and reference reading, purge the bubbler system. This ensures the gas line is not obstructed.

AVOID SENSOR DAMAGE by ensuring the valves are operated in the correct sequence when purging. Follow these steps to safely purge:

1. **Close the valve to the pressure transducer**.
2. **Open the purge valve (often the red knob at top).**

   This will send high pressure down the gas line to the orifice, where there should be strong bubbling readily visible in all but high flows. No bubbling may mean that the gas line is severely blocked, or you have wrongly operated the valves.

3. **Once purging is observed, close the purge valve (red knob)**.
4. **Wait for at least 30 seconds.**

   Note: This allows time for the line pressure to normalise.

5. **Open the valve to the pressure transducer.**

☐ Observe and record after changes

After any maintenance or changes at the site, read the references and check logger values again before departing. Record details of any instrument changes.

Photograph any significant changes to the installation, site, controls, and surroundings.

Photos must be date-stamped and properly indexed and archived as part of the site and/or visit metadata.

☐ Record comments

In the field visit records, comment on accuracy and reliability of the water level record since last inspection, stability of the control(s) including evidence of any recent activity at or near the control, and any other factor not so far covered that has a bearing on accuracy of the data.

☐ Store field visit records

Before leaving, confirm and save the electronic field sheet(s) for the visit, or remove and safely store the logbook page(s) for delivery to the office.

Annex F Desilting Stilling Wells

Stilling wells and intake pipes can be subject to deposition of sediment within them that restricts the free flow of water between the water body and well, causing well water level to be different from the external (open) water level.

Excessive build-up of sediment may block pipes completely and prevent water from entering or leaving the stilling well and may eventually interfere with the float and counterweight.

Silting of intakes and stilling wells can be a significant cause of substandard data. A planned programme of detection and prevention is crucial. An investment in effective (automated) flushing systems and equipment is likely to be most worthwhile.

Prevention

The most effective prevention is good design, construction, and installation. Refer to the requirements and guidance in sections 3.1.2.4 and 3.2.2.1.

Detecting silting

Effort shall be applied to detect silting before it becomes evident in the water level record. Sediment checks of the stilling well and intake pipes shall be carried out as part of routine station visits, and after high flows that may have deposited sediment.

Note: Once silting is evident in the data, the period affected will not meet QC 600 requirements and this is disappointing if due to avoidable poor and/or infrequent maintenance.

So that the depth of silt and the remaining 'freeboard' can be estimated, in the instrument housing, display:

- the stage height equivalent of the bottom of the well
- the invert of the lower intake pipe, and
- the level of the counterweight when the float is against the underside of the recorder floor,

  Note: Measurement of flood peaks may be compromised and/or the float tape may slip on the pulley if the counterweight is sitting on or in the silt.

Detect silting by:

- routinely sounding the depth of sediment in the well

- using the electric plumb bob, or
- if no electric plumb bob is installed, using a simple device such as a crowbar on a length of rope

- observing the amount of surge if it is a characteristic of the site.

  Note: This is usually most obvious during high flows when the river may be surging. However, even at low flow some surging may be observed due to turbulence, or seiche on a lake or pond. If the logger stage is slowly moving, even within 1 mm, then the intakes can be assumed to be clear.

Flushing

All stations equipped with stilling wells and intakes should be flushed at least annually as preventive maintenance, and more frequently if on rivers that carry a lot of suspended sediment.

The stilling well and intake pipes may be flushed together, however as the intake pipes are the most important but the most difficult to inspect, these may be done separately and more regularly.

The various methods are:

- installed flushing systems
- modified flushing systems, and
- portable or manual flushing systems.

Installed flushing systems

Valve and pipe systems fed by header tanks can be fitted into some stilling wells.

The system consists of a valve on each intake pipe at the stilling well end, usually capable of being operated from the top, which will close off the intake pipe from the well. On the river side of the valve, a pipe tee connects to the header tank. In operation, the valve or valves are closed, the header tank is filled, then water is released from the header tank into the intake pipe(s) to flush them.

The volume of water in the header tank is relatively small. An augmented supply (e.g. from an external tank fed from a hut roof or spring) may assist, and frequent use will ensure that intake pipes are kept clear.

Flushing of the stilling well must be carried out separately.

Modified flushing systems

Where installed systems are fitted but do not prove efficient, it may be better to replace the header tank with a convenient connection for a pump. This enables considerable pressure and a larger volume of water to be applied to the intake pipes to flush them effectively. Towards the end of the flushing, the valves can be opened with the pump still operating to also clean them of silt.

Re-plumbing of the existing header tank pipe can be done in galvanised pipe or a suitable plastic pressure hose, which can terminate inside or outside the stilling well. Use a quick release coupling for the pump hose such as a 'Camlock' brand fitting to improve convenience.

Portable or manual flushing systems

Connecting a pump to the static tube.

This can be an efficient method to flush the intake pipes but requires the stage to be low enough to get to the static pipe.

If the pump outlet hose has a 'free' end (i.e. no fitting on the end), then a very quick and simple method is:

- Remove the static tube
- Crease the end of the hose and insert it into the intake pipe for about 200 mm (this will only work for a 50-mm intake and pump hose, but these are the most common sizes).
- Once the pump is started, water pressure will expand the hose against the side of the intake pipe and produce a good seal.

The benefit of this method is that the full pressure head of the pump is applied to the intake and pumping for only a few minutes is usually all that is required to clear it.

The disadvantage is that silt will be flushed into the stilling well.

If two intake pipes are available, then the top intake is usually pumped, and the overflow will emerge from the lower intake. Pumping should be continued until clear water is flowing from the lower intake.

Flushing the stilling well.

The bottom of the stilling well operates as a reservoir for silt, the level of which should not be allowed to:

- approach the elevation of the lowest intake pipe, thus directly affecting the lower stage measurements, or
- prevent the counterweight from going down as far as is necessary to measure high stage floods.

Silt should be regularly removed from the stilling well to prevent these problems.

The most straight-forward method is to pump water into the well at a high flow rate so that the silt is stirred up into suspension and the mixture flows out of the intake pipe, finally flushing this as well.

With larger quantities of silt or heavier particles the above method does not work well. Alternatives include:

- one pump delivering water in and stirring up the sediment while another pumps it out
- alternating pumping water in and then out, particularly if the intake pipes are blocked
- using compressed air to stir up the silt into suspension while the mixture is pumped out
- with the intake pipes blocked off, using a suitable pump, e.g. a diaphragm pump, to remove the thick silt and water mixture directly, or
- entering the well and scooping out sediment directly, such as with a bucket on a rope.

Centrifugal pumps and most impeller pumps will not pump a thick mixture of sediment without damage to the seals or impeller. Diaphragm pumps can usually handle this. Consult the pump manufacturer's specifications to avoid high repair costs.

Entering the well is a ‘last resort’ method after all other alternatives have been considered and/or attempted. It can be effective but is often laborious. Health and Safety regulations with respect to entry of confined spaces and working at heights must be followed (e.g. harness, recovery winch, gas meter, etc.) and a hazard management plan must be devised and implemented, including an alternative to lifting full buckets by rope over a person down a well, which is unacceptably dangerous.

Annex G Intake Pipe Dimensions

The intake pipe diameter shall be large enough to prevent lag, but not so large that surging is not damped. Use a ratio of 1:12 between intake pipe and stilling well diameters as a general guide.

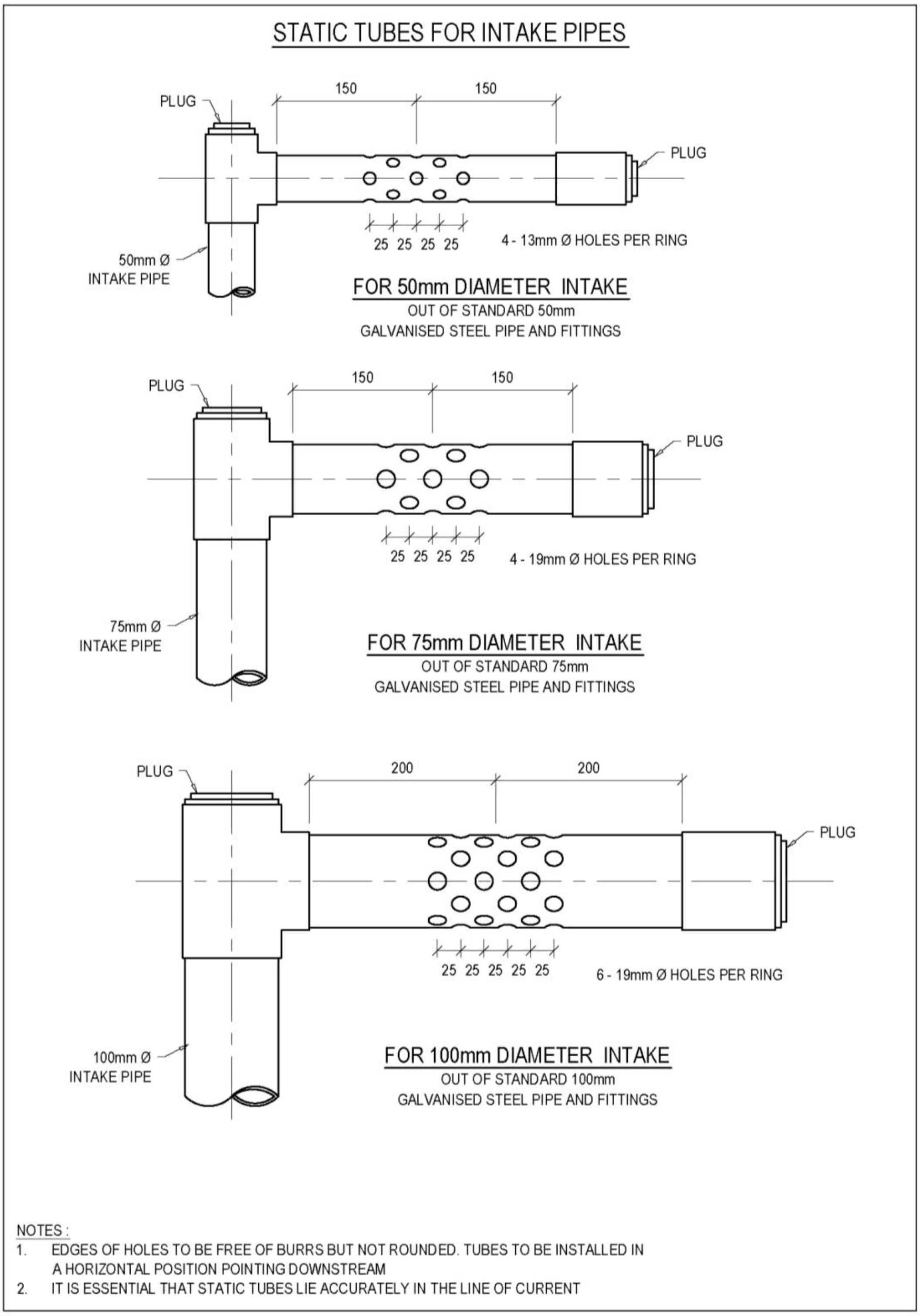

Figure G 1 – Static tubes for intake pipes.

Lag can occur during rapidly changing rising or falling stage, when levels in the stilling well lag behind the river because of head loss in the intake system.

The following relationship may be used to determine the lag for an intake pipe for a given rate of change of stage (Smith et al. 1965):

$$\Delta h = \frac{0.01}{g}\frac{L}{D_p}\left(\frac{A_w}{A_p}\right)^2\left(\frac{dh}{dt}\right)^2$$

where: Δh = lag, in metres (m)

g = acceleration of gravity, in m/s^2

L = intake length, in m

D_p = intake diameter, in m

A_w = area of stilling well, in m^2

A_p = area of intake pipe, in m^2

$\frac{dh}{dt}$ = rate of change of stage, in m/s

Note: The above equation converts directly to metric units from its originally published imperial units (Smith et al, 1965) without additional factors or terms.

Annex H Estimating Stage Height for the 200-year ARI Flood

Use the following guidance to estimate the approximate stage height of a 200-year average recurrence interval (ARI) flood event at a proposed river level site.

Area

- Survey a proposed recorder cross-section up to anticipated extreme flood level. Assumed datum is adequate but establish a reference benchmark.
- From the cross-section, develop a stage vs. area curve.

Mean velocity

- Estimate a likely mean velocity of flow for an extreme flood at the site. Local knowledge of nearby, similar sites may give insight.
- If no information is available, use a mean velocity of 3 to 3.5 m/s.

200-year ARI flood flow estimate

- Use frequency analysis of a long-term flood record from a similar neighbouring catchment, adjusted for catchment area difference, to estimate the 200-year ARI peak flow.
- Use the online regional flood estimation tool for New Zealand (Henderson and Collins, 2016 and 2018) to estimate peak discharge of the 100-year ARI flood.
    - Google (or similar) search for “NIWA’s Flood Frequency Tool”.
    - Once the ArcGIS web app is open, use the layer list to select “Flood Statistics 2018 REC1” then click on the proposed site location on the stream network to obtain the table of estimates.
    - For small catchments the Rational Method estimates may be more reliable, but the tabulated values must be multiplied by a suitable user-selected runoff coefficient.
    - The Henderson and Collins (2016) study, when tested against measured mean annual floods, resulted in ± 49% standard error for the mean annual flood, which is very large and considerably more than the ± 22% standard error attributed in Flood Frequency in New Zealand (McKerchar and Pearson, 1989).

- The Regional Flood Frequency analysis for small New Zealand basins (Pearson, 1991) may be more suitable for small catchments.
- Multiply the 100-year ARI flood estimate by 1.08 for western New Zealand and up to 1.15 for eastern New Zealand to obtain the 200-year ARI peak discharge estimate. This augmentation also introduces more error into the estimate.

Stage height for the 200-year ARI flood flow estimate

First, calculate the flood wetted cross-section area:

200-yr ARI flood section area = 200-yr ARI flood peak discharge ÷ flood mean velocity

Then use the stage vs. area curve to derive the corresponding stage height (in terms of the assumed datum) for the 200-yr ARI flood section area.

Annex I Pressure Transducer Accuracy

The following pages tabulate worked examples of accuracy specification comparisons for pressure transducers.

Shaded cells indicate where the specified sensor cannot meet the QC 600 accuracy requirements for the measurement of water levels under this Standard (see Table 3 of 'The Standard' and sections 2.2.2.3 and 7.2.3.1).

Rivers and lakes

Sensor range 0 – 5 m							
WL (m) (effective stage)	**QC 600 accuracy (± mm)**	**Sensor accuracy specification examples; error (± mm)**					
		0.06% FS	**0.1% FS**	**0.1% of reading**	**0.2% FS**	**0.2% of reading**
0	3	3	5		10	
0.5	3	3	5	0.5	10	1
1	3	3	5	1	10	2
1.5	3	3	5	1.5	10	3
2	4	3	5	2	10	4
2.5	5	3	5	2.5	10	5
3	6	3	5	3	10	6
3.5	7	3	5	3.5	10	7
4	8	3	5	4	10	8
4.5	9	3	5	4.5	10	9
5	10	3	5	5	10	10

Sensor range 0 – 10 m						
WL (m) (effective stage)	**QC 600 accuracy (± mm)**	**Sensor accuracy specification examples; error (± mm)**				
		0.03% FS	**0.1% FS**	**0.1% of reading**	**0.2% FS**	**0.2% of reading**
0	3	3	10		20	
1	3	3	10	1	20	2
2	4	3	10	2	20	4
3	6	3	10	3	20	6
4	8	3	10	4	20	8
5	10	3	10	5	20	10
6	12	3	10	6	20	12
7	14	3	10	7	20	14
8	16	3	10	8	20	16
9	18	3	10	9	20	18

10	20	3	10	10	20	20

Groundwater and sea level

Sensor range 0 – 5 m						
WL (m) (effective stage)	QC 600 accuracy (± mm)	Sensor accuracy specification examples; error (± mm)				
		0.06% FS	0.1% FS	0.1% of reading	0.2% FS	0.2% of reading
0	10	3	5		10	
0.5	10	3	5	0.5	10	1
1	10	3	5	1	10	2
1.5	10	3	5	1.5	10	3
2	10	3	5	2	10	4
2.5	10	3	5	2.5	10	5
3	10	3	5	3	10	6
3.5	10	3	5	3.5	10	7
4	10	3	5	4	10	8
4.5	10	3	5	4.5	10	9
5	10	3	5	5	10	10

Sensor range 0 – 10 m						
WL (m) (effective stage)	QC 600 accuracy (± mm)	Sensor accuracy specification examples; error (± mm)				
		0.03% FS	0.1% FS	0.1% of reading	0.2% FS	0.2% of reading
0	10	3	10		20	
1	10	3	10	1	20	2
2	10	3	10	2	20	4
3	10	3	10	3	20	6
4	10	3	10	4	20	8
5	10	3	10	5	20	10
6	12	3	10	6	20	12

7	14	3	10	7	20	14
8	16	3	10	8	20	16
9	18	3	10	9	20	18
10	20	3	10	10	20	20