

National Environmental Monitoring Standards

Water Level Recording

Measurement, Processing and Archiving of
Water Level Data

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NEMS

NEMS Standards Documents

The following standards can be found at www.landandwater.co.nz.

- National Quality Coding Schema
- Safe Acquisition of Field Data In and Around Fresh Water
Code of Practice
- Dissolved Oxygen Recording
Measurement, Processing and Archiving of Dissolved Oxygen Data
- Open Channel Flow Measurement
Measurement, Processing and Archiving of Open Channel Flow Data
- Rainfall Recording
Measurement, Processing and Archiving of Rainfall Intensity Data
- Soil Water Measurement
Measurement, Processing and Archiving of Soil Water Content Data
- Turbidity Recording
Measurement, Processing and Archiving of Turbidity Data.
- Water Level Recording
Measurement, Processing and Archiving of Water Level Data
- Water Meter Data
Acquisition of Electronic Data from Water Meters for Water Resource Management
- Water Temperature Recording
Measurement, Processing and Archiving of Water Temperature Data

Limitations

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

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When implementing these standards, the following act, regulations and code of practice shall be complied with:

- Health and Safety in Employment Act 1992
- Health and Safety in Employment Regulations 1995
- NEMS Safe Acquisition of Field Data In and Around Fresh Water, Code of Practice 2012

National Environmental Monitoring Standards (NEMS)

The National Environmental Monitoring Standards steering group (NEMS) has prepared a series of environmental monitoring standards on authority from the Regional Chief Executive Officers (RCEO) and the Ministry for the Environment (MFE). The strategy that led to the development of these standards was established by Jeff Watson (Chairman) and Rob Christie (Project Director). The implementation of the strategy has been overseen by a steering group consisting of Jeff Watson, Rob Christie, Jochen Schmidt, Martin Doyle, Phil White, Mike Ede, Glenn Ellery, Lian Potter, Lucy Baker, Eddie Stead and David Payne.

The development of these standards involved consultation with regional and unitary councils across New Zealand, electricity generation industry representatives and the National Institute for Water and Atmospheric Research Ltd (NIWA). These agencies are responsible for the majority of hydrological and continuous environmental related measurements within New Zealand. It is recommended that these standards are adopted throughout New Zealand and all data collected be processed and quality coded appropriately. The degree of rigour in which the standard is applied, will depend on the quality of data sought.

The lead writer of this document was Evan Baddock of the National Institute of Water and Atmospheric Research Ltd, with workgroup members, Martin Doyle and Matt McLarin (Tasman District Council), Paul Peters (Horizons Regional Council), Peter Davis (Hawkes Bay Regional Council), Phil Downes (Environment Canterbury), and Gareth Gray (Genesis Energy). The input of NEMS members into the development of this document is gratefully acknowledged; in particular the review undertaken by the NEMS Steering Group and non-technical editing by writer Chris Heath of Heath Research Services.

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Review

This document will be reviewed by the NEMS steering group in February 2014, and thereafter once every two years.

Signatories

 NEMS Project Director	 NEMS Chairman	 MFE	 NIWA	 Workgroup Leader
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Definitions

accuracy The degree of closeness of a measurement to the actual value.¹ Express the inclusive range of values that a reading might have, for example:

Example: ± 2 mm

benchmark A fixed reference point used when surveying to assign elevation to other points.

calibration The process of verifying and rectifying the quantitative measurements of any instrument.

comments file A metadata file associated with the data file. The metadata provides relevant information about the site and data.

control The physical properties of a channel, natural and artificial, which determine the relationship between stage height and discharge at a location in the channel.

datum A reference level from which elevations are measured. It may be relative to some known level e.g. mean sea level, or assumed. It should be used to determine elevation of station benchmarks.

discharge The volume of liquid flowing through a cross section in a unit time.

drawdown The effective lowering of surface water or groundwater levels relative to the surrounding water body. For example near the outlet of a natural or artificial structure, e.g., dam or lake outlet, or the lowering of the water table caused by pumping of groundwater from a well.

effective stage The height of the water surface above the zero measurement point of the sensor, or stilling well intake.

electric plumb bob See 'Internal Plumb Bob'.

flow The movement of a volume of liquid. This is used as a general term when referring to the movement of water, e.g., through a channel. See also: discharge.

hysteresis The dependence of a system not only on its current environment but also on its past environment.

instantaneous value A value sampled at an instant in time. This includes any value collected with an averaging interval of 20 seconds or less.

internal plumb bob A non-recording gauge that is normally used to measure the water level in a stilling well. Also referred to as an electric plumb bob or EPB.

invert The lowest part of the cross section of a conduit or pipe, including an intake pipe, or the underside of a recorder housing.

metadata Information about the data that may describe the content, location of (other characteristics of the data) and operations on or modifications to the data.

msl Abbreviation for mean sea level is frequently used as datum for traditional survey levelling of station benchmarks. True elevation of msl varies around the country and over time.

¹ http://en.wikipedia.org/wiki/Accuracy_and_precision

overall accuracy The combined uncertainty of all errors in a composite measurement of result.

precision The degree to which repeated measurements under unchanged conditions show the same results. Use in relation to how precise an instrument is.

primary reference gauge A reference gauge that allows a measurement of water level, independent of the sensor and in terms of the station datum, thus defining the relation between the level measured by the sensor and the station datum. For example, a station's electric plumb bob.

QC Abbreviation for quality code. For example, a quality code of 600 is referred to as QC 600

quality codes An overlying set of associated information that provides the end user with information about the quality and reliability of the data.

rating A relationship between two variables.

recording zero Reduced level of zero gauge height adopted for the station's datum.

reduced level (R.L.) A surveying term referring to the height above datum level associated with a station.

resolution The smallest increment that is measurable by a particular scientific instrument.

seiche A wave that oscillates in lakes, bays, or gulfs from a few minutes to a few hours, typically as a result of atmospheric disturbances (water sloshing to and fro).

sensor An instrument that aids in the measurement of water level.

site The geographical location of a station.

site number The site identifier for water level stations. A unique numeric identifier usually derived from the national river number system, for example, site number 75207, where 752 = Clutha River, and 07 = Balclutha Station.

stage or stage height The elevation of a water surface relative to a known datum, for example, mean sea-level or, as in common practice for hydrometric stations, to an arbitrary datum with a fixed but assumed value (benchmark).

station The collective term for sensing and recording equipment at a particular site.

stationarity of record The quality of a process in which the statistical parameters of the process do not change with time. Stationarity of record is maintained when variability, of the parameter being measured, is only caused by the natural processes associated with the parameter. Stationarity of record ceases when variability is caused or affected by other processes, e.g., moving the station, adjusting the height of the station's reduced level.

uncertainty A measure of accuracy of the readings. It is expressed as a range of error at a stated probability, for example, a stage gauge reading of $1.235 \text{ m} \pm 2 \text{ mm}$, where 2 mm is the uncertainty.

validation A check to determine if a device or procedure conforms to specifications.

water level The elevation of the free surface of a stream, river, lake or groundwater without reference to a known fixed datum e.g. water level read from staff is not stage until it is expressed relative to the site datum.

About this Standard

Introduction

Water level information is collected from a variety of water bodies and is used for a multitude of purposes. A water level record often acts as a surrogate for flow in rivers, as it is difficult to continuously measure flow directly. Water level used for this purpose requires a good understanding of the relationship between level and flow, and the problems faced when maintaining that relationship.

Water level is often analysed on its own (flood levels, tide), or used in conjunction with other parameters, in particular water quality. It is important to understand the range of uses to which the data can be put, and ensure that data collected for one purpose can be used as widely as possible in the future. Key to planning, maintaining and recording flow measurement is the understanding of, and catering for, stationarity.

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

In 1949 the first Hydraulic Survey parties were established, and during the 1950s and 1960s many stations were built for a wide variety of purposes including flood control and soil conservation studies.

The International Hydrological Decade (commencing 1964) was a notable period of growth in data collection and analysis, with the emergence of both the first truly accurate recording instruments and computers to analyse the data.

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

Objective

The objective of this standard is to both ensure that water level data from aquifers, lakes, reservoirs, flowing channels and the sea, is gathered, processed and archived in a verifiable and consistent manner and is suitable for 'at site' and comparative analysis.

Scope

The scope of the standard covers processes associated with:

- site selection
- equipment deployment
- the acquisition of water level data from automatic recording sites
- data processing, and
- quality assurance (QA) that is undertaken prior to archiving the data.

Scope Exclusion

The standard does not address industrial applications.

The Standard – Water Level Recording

For water level data to meet the standard the following shall be achieved:

Accuracy	Rivers & Lakes	The greater of: • ± 3 mm, or • 0.2 % of effective stage.
	Sea & Groundwater	The greater of: • ± 10 mm • 0.2% of effective stage.
Stationarity	Stationarity of record shall be maintained.	

Requirements

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

Units of Measurement			Express units in: • metres, or • millimetres.
Resolution			1 mm
Timing of measurements	Maximum Recording Interval	Rivers & Lakes	5 min
		Groundwater	15 min
		Sea	1 min
	Averaging	Rivers, Lakes & Groundwater	Instantaneous Value <i>Defined as no greater than 20 second averaging.</i>
		Sea	• 1 min (average), and • 1 Hz sampling interval (minimum)
	Resolution		1 s
	Accuracy	Rivers, Lakes & Groundwater	± 90 s / month
		Sea	± 20 s / month
Time Zone		Express time as New Zealand standard time (NZST) <i>Do not use New Zealand daylight time (NZDT)</i>	

Continued on next page...

Supplementary Measurements	Barometric Pressure	Required for unvented pressure transducers. <i>Note: Barometric pressure data is a useful supplement for the analysis of groundwater and sea level.</i>
	Measurement Statistics	Any supplementary data stream shall be defined in the metadata.
	Salinity	Required for pressure transducers in estuarine environments.
Validation Methods	Sensor Test	Required pre-deployment.
	Primary Reference Measurement	Nearest 1 mm with estimate of uncertainty.
	Inspection of Recording Installations	Perform sufficient inspections to ensure the collected data, are of known and acceptable uncertainty, and free from bias, both in level and time.
Calibration	Frequency	Where relevant follow manufacturers' specifications. Annually for pressure transducers.
	Method	Where relevant follow manufacturers' specifications.
	Primary Reference Gauge	Reduced level of recording zero demonstrated constant over time to ± 3 mm.
Metadata	Scope	Metadata (Annex G) shall be recorded for all measurements.
Quality Assurance		<i>Quality assurance requirements are under development.</i>
Processing of Data		All changes from raw record shall be documented in the metadata. All data shall be quality coded as per Quality Flowchart.

Continued on next page...

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

Archiving	Original and Final Records	File, archive indefinitely, and back up regularly: • Raw and processed records • Primary reference data • Supplementary measurements • Validation checks • Calibration results • Metadata
Auditing		<i>Quality assurance requirements are under development.</i>

Accuracy

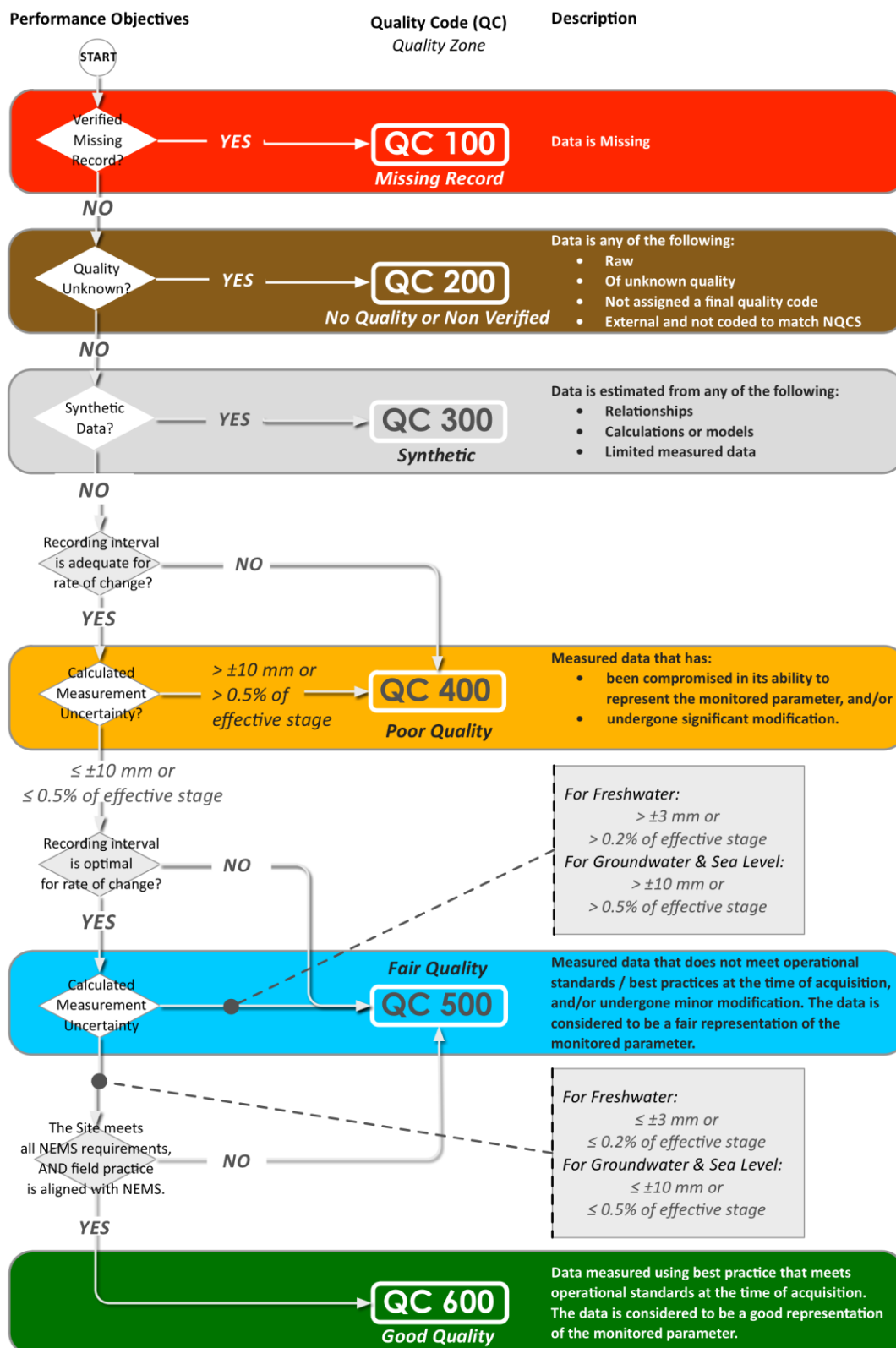
This standard takes the United States Geological Survey (USGS) approach to determining accuracy, (except for sea level and ground water, refer to the table above).

The USGS accuracy requirement is +/- 3 mm up to an effective stage of 2 m, and above this, 0.2% of effective stage ($2\text{ m} \times 0.002 = 4\text{ mm}$). The accuracy requirement is therefore constant at lower water levels, but lessens as levels rise. This makes allowance for water level sensors that cannot maintain accuracy over their full range, and acknowledges that accuracy diminishes in rivers as velocity and surge increase.

Rating curve accuracy contributes to overall uncertainty for open channel flow sites and may be significantly impacted by uncertainty in determining high flows. The accuracy required for general water level measurement is impractical for measuring water level in boreholes due to the physical restrictions and much larger ranges often encountered.

Quality Codes – Water Level Recording

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



Site Selection

1.1.1 In this Section

This section contains information on site selection. It primarily covers the site related variables to consider when selecting a site. Ensure that the stationarity, accuracy and operating requirements laid out in this standard are met.

By selecting the best available site and/or installing the best available 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.

1.1.2 Sources of Information

The following sources of information should be used to determine the most appropriate stretch of river or shoreline (site) for deploying a station:

- Topographical maps
- Aerial photographs and plans (where available)
- Local advice (where available) on access, stability and history
- Land ownership
- Consent information on local water takes

1.1.3 Practical Controls

1.1.3.1 Safety

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

1.1.3.2 Hazard Review

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

1.1.4 Stationarity of Record

Stationarity of record:

- is maintained when variability of the parameter being measured is only caused by the natural processes associated with the parameter, and
- ceases when variability is caused or affected by other processes, moving the station, or adjusting the recording zero height of the station's reduced level.

Without stationarity, a data record cannot be analysed for changes over time (such as climate change). While the accuracy of collection processes may change, it is critical that the methods and instruments used to collect water level record remain without bias over the lifetime of the record.

Because the methods of collecting continuous environmental data do change over time, an external reference should always be used against which the continuous data can be checked. In the case of water level, this is a staff gauge that is tied to a constant vertical datum, usually maintained by benchmarks.

1.2 River Stations

- 1.2.1 A number of factors need to be considered when selecting a site, particularly if flow is also to be measured. Hydraulic properties should be carefully considered along with operational aspects such as how the site will be constructed and maintained.

1.2.2 Site Factors

1.2.2.1 Access and Legal Requirements

The following access issues of a site shall be considered:

- Site safe access over the anticipated range of measurement
- The ability to position machinery and materials during construction
- Safe access to the river's edge
Safe access is required for reading staff gauges and to carry out flow measurements
- A long-term access agreement
Establish an agreement with any landowners whose land must be crossed to gain access to the site
- Environmental effects
- Resource consent requirements

1.2.2.2 Hydraulic Properties

The following hydraulic properties of the river reach shall be considered:

- The location of a suitable control
If flow is to be derived from water level a suitable control in the river reach is required. For more information, see '2 Controls'.
- The availability of a section without significant turbulence
- Whether sedimentation will occur around an intake or sensor
- The possibility of backwater effects
For more information, see '2 Controls'.
- The likelihood of degradation or aggradation
To the extent where water level cannot be measured.

There shall be a suitable gauging reach without any inflows or outflows affecting results.

Note: This could result from tributary inflow, losses to groundwater, or water takes to irrigation or other uses.

1.2.2.3 Installation

The selection of a suitable stilling well location or sensor site shall consider the following factors:

- Public safety and site security
- Constructability and durability
Pay particular attention to protection from flood damage.
- A solid structure to build a stilling well or on which to mount a sensor
- Maintenance of the datum, for example:
 - the installation of suitable benchmarks, and
 - the possibility of building suitable reference gauges.
Example: External staff gauge, or similar.
- An adequate power supply
For example: solar, mains or other power sources.
- Adequate communication for telemetry, and
- The ability to deploy a sensor or intake that will cover the full range of levels.
Note: This should ensure the largest possible flood level will be measured, as well as any possible low flow level. Ensure you have included a generous allowance for extra large floods and future degradation of the river bed.

Note: The above considerations may result in a trade-off between accuracy and cost.

1.3 Lake Level / Reservoir Stations

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 this data can provide a record of lake inflow and, for an uncontrolled lake, outflow.

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.

1.3.1 Site Factors

The following aspects shall be considered when selecting a site on a reservoir or lake.

1.3.1.1 Access and Legal Requirements

The following access issues of a site shall be considered:

- Site safe access over the full anticipated range to be measured
- The ability to position machinery and materials during construction
- Safe access to the river's edge
Safe access is required for reading staff gauges and to carry out flow measurements
- A long-term access agreement
with any landowners whose land must be crossed to gain access to the site
- Environmental effects
- Resource consent requirements.

1.3.1.2 Hydraulic Properties

The following specific lake properties shall be considered:

- When outflow is required, the site should be located near to the outlet, and away from any drawdown
- The sensitivity of lake level stations will depend upon the section control at the outlet, and possibly on the channel control downstream
Note: In alluvial formations, lake outlets tend to be shallow and wide, and hence insensitive. Weed growth can also be an issue at lake outlets. For more information, see '2 Controls'.
- Choose locations sheltered from waves
This avoids surging at the sensor, erosion, dampness and physical damage. In reservoirs, waves can cause an unmeasured loss of water over a dam that may, at times, be significant.
- How to get an intake or sensor to record the lowest possible level
Often lakes have shallow edges and long intakes or sensor cables may be required.

1.3.1.3 Installation

You will need to look for a suitable stilling well location or sensor site. Aspects to be considered shall include, for example:

- public safety and site security
- constructability and durability
 - In particular, consider protection from flood or wave damage.*
- the substrate for building a stilling well on, or to mount a sensor
 - The substrate needs to be solid.*
- how the datum will be maintained, for example:
 - Can suitable permanent benchmarks be installed?
 - Is it possible to build suitable reference gauges?
 - For example: an external staff gauge or similar.*
- an adequate power supply from solar, mains or other power sources
- adequate communication for telemetry
- ability to deploy a sensor or intake that will cover the full range of levels, and
- navigation issues for watercraft that may result from the installation.

1.4 Groundwater Stations

Monitoring groundwater levels usually requires the installation of underground sensing equipment. Often the water level to be monitored is in a narrow bore casing, often some distance below the ground.

1.4.1 Site Factors

Often there will be no choice on the location at which to monitor groundwater levels, e.g., where accessing an existing bore.

For new bores, the following shall be considered:

- A location that is likely to be representative of the groundwater level of the aquifer being monitored
- The proximity of abstraction or reinjection wells or localised surface discharge that may affect readings
- The ability to obtain a long term access agreement with the landowner
- Environmental effects
- Resource consent requirements

1.4.1.1 Installation

Refer to NZS 4411:2001 Environmental Standard for Drilling of Soil and Rock

The following factors shall be considered when installing groundwater level monitoring stations:

- Constructability and durability
In particular, consider protection from well head damage.
- The full range of groundwater movement (including artesian)
Is the sensor suitable to measure this range to the desired accuracy?
- The height of the mounting
This is so the artesian head can be measured
- Construction of the bore head to allow equipment access
Allow for an external reference depth to be taken ((plumb bob or similar) or (pressure fitting)). Where possible install a dipper tubing to allow 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.
- How reduced level will be maintained, for example:
 - Can you install suitable permanent benchmarks?
 - Is it possible to build suitable reference gauges? (external staff gauge or similar)
- Adequate power supply from solar, mains or other power sources
- Adequate communication for telemetry
- Climatic factors such as frosting and freezing
- The ability to deploy a sensor or intake that will cover the full range of levels
- Public safety and site security.

1.4.1.2 Bore Considerations

Aspects to consider if a bore is being constructed for the purpose of monitoring water level:

- The bore/well is suitably constructed (refer to the reference above under installation).
- Is the diameter of the bore sufficient for the type of sensor to be used?
- The bore head allows equipment access
Allow for an independent reference depth to be taken ((dipper or similar) or (pressure fitting)).
- Access to the water table
Access to the water table A straight pipe at least 30mm diameter leading from the top of the bore casing to below the water table must be specified.
- Will the bore cover the full range of water levels expected
Including artesian levels and that it is deep enough to allow for siltation.
- Avoid the screening of multiple intervals if possible as can potentially enable the connection between otherwise separate aquifers.

1.4.1.3 Required Metadata

Where practicable, the following metadata shall be recorded:

- Location and reduced level of the bore components
- Photographs
- Relevant water extraction data
- A geological well log that also records the following:
 - drillers name , date and method
 - screening type and depth
 - depths, type and diameter(s) of casings
 - hydraulic properties at the time of construction, e.g., transmissivity and storativity
- Well use
For example: production or monitoring.

1.5 Sea Level Stations

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, the dynamics of a site will often make this option untenable. In addition to the float-operated encoder, the more usual choices of gauge include radar, immersed pressure transducer, and dry transducer using a gas-bubbler system.

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

1.5.1 Site Factors

The following aspects shall be considered when selecting a site to measure sea level.

1.5.1.1 Location

Site positioning, where practicable, shall consider the following:

- Environmental effects

Note: Sea level measurements should ideally be accompanied by observations of atmospheric pressure and wind, which are of direct relevance to sea level analysis. Consider whether and how these variables will be monitored when selecting the site's location.

- Resource consent requirements

- Protection from waves

Large waves carry an enormous amount of energy, and so the site should be protected from waves as much as possible.

- Tidal range attenuation

When measuring open sea level, there must be no attenuation of the tidal range.

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

- Tidal dynamics

When measuring in a harbour consider the tidal dynamics.

Note: If silting and harbour changes occur, will these give a false impression of changing tide levels. A small deep, wide mouthed harbour without a river flowing into it should be a good option.

1.5.1.2 Access

Site access shall consider the following:

- Site access

Site access shall be safe when site visits are likely.

- Access agreement

Preferrably attain long-term access agreements with any landowners whose land must be crossed to gain access to the site.

- Sensors are to be installed below low-tide level

You will need to access the sensor safely in the majority of sea conditions

1.5.1.3 Installation

Site equipment installation shall consider:

- a solid structure on which to mount both sensors and logger housing for the gauge
Where relevant, the type of rock should be considered. If it is easily weathered then it will not be suitable in the long term, while hard rock provides a much more secure substrate.
Note: Rock crevices in which to install sensors (in the case of pressure transducers and gas bubblers) give some protection, but they also magnify surging and are not desirable in this respect.
- whether the sensor or stilling-well intake covers the full range of levels, that is:
 - the greatest tidal range at the location
 - the extra rise or fall due to barometric pressure
This could be as much as $\pm 800\text{mm}$
 - how large the wave action is, and
Ensure the sensor is not exposed during large wave troughs at spring-low tides
 - tsunami effects in terms of level, recording interval and instrument range.
- sufficient sunlight for solar charging, or mains power source
- adequate communication for telemetry
- navigation issues for watercraft as a result of piles driven
- public safety, and
- site security and the potential for vandalism.

1.5.1.4 Other Considerations

Other aspects to consider that may affect sea level measurement include:

- instrument selection
For example: radar, bubblers, stilling wells and pressure transducers
- the effect of salt incrustation & corrosion
For example: electric plumb bobs and float tape
- density of seawater corrections for bubblers and pressure transducers
Note: This is slight, but becomes significant if high tidal ranges exist in that location.
- bubblers that have an outlet bell
Note: This ensures wave action doesn't cause under-reading.
- the use of sacrificial anodes, and
- bio fouling

1.5.1.5 Datum

Site datum is crucial at sea level stations and shall be maintained by:

- Installing suitable benchmarks, and
- where practicable, installing a reference gauge (staff gauge or similar)

Note: Sea level measurements should ideally be accompanied by observations of atmospheric pressure and wind, which are of direct relevance to sea level analysis. Consider whether and how these variables will be monitored when selecting the site's location.

Controls

2.1.1 In this Section

This section contains information on the requirements for controls at a site. When selecting a site, the channel's physical characteristics (at the gauge location and downstream of the gauge) shall be used to assess the suitability of the site as a control. These characteristics are:

- stability, and
- sensitivity.

Note: To achieve the standard, controls need to be considered in order to minimise uncertainty. The nature, configuration, and vegetal cover of the streambed and banks influence the stability and sensitivity, which in turn affects the relationship between discharge and stage.

The sensitivity of the sites control has a large effect on discharge derivation, especially at low flows. For more information, see '2.3 Sensitivity'.

2.2 Stability

2.2.1 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 (which are unlikely to move)
- Man made substitute e.g. weir, grade control or bridge

Note: These features provide a downstream steepening of the slope of the water surface, which suggests that the feature is relatively resistant to erosion. These features may be considered permanent or semi-permanent. Unless a control is composed entirely of bedrock, its stability is extremely difficult to determine visually. Flood debris becoming caught on bridge piers can alter a rating, not just at the time of the flood, but over a period afterwards as gravel builds up behind the obstructions.

With a stable control, a station's rating may hold for a number of years, but an unstable one may alter a rating several times per year.

2.2.2 Unstable Features

Where practicable, the following features shall be avoided:

- Diverging Reaches
- Sand Bars
- Gravel Bars
- Dunes

Note: Bed 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 beds, aggradation may occur during lower flows followed by a short period of degradation during a flood.

2.2.3 Vegetal Growth

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

Note: Vegetal growth on the bed and banks can cause gradual and usually seasonal rating changes. The normal remedy is either to visit frequently and clear weed before the change becomes significant, or to frequently file rating changes that merge over long periods. Neither tends to be satisfactory, so reaches with significant weed are best avoided. Algal growth on weirs can cause small but significant rating changes; frequent cleaning with a brush is the usual remedy.

2.2.4 Human Interference

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

Note: River works, ranging from major earth works for bridge construction, river protection, down to minor gravel extraction or even the use of a ford can affect a section or channel sufficiently to alter ratings. Children's summer pastimes can often include building weirs to enhance a swimming hole; having a site in such a locality can be a problem.

Sensitivity

The stage height measured at the recorder shall be sensitive to changes in discharge in the river. High sensitivity of the stage height recording improves resolution of the rating, thus improving accuracy of the flow record.

Note: The shape of a control's cross-section governs sensitivity. This term can be explained with reference to a simple V-notch weir. A very shallow angled V-notch (almost flat) would provide a small change in stage height for a considerable change in flow and would be considered insensitive. A more acute angled V-notch (say a 90° one) would give a greater change in stage height for the same change in flow and would thus be more sensitive. Similarly a narrow cross-section (approaching the shape of the V-notch) in the reach and its control provides greater sensitivity than a wide shallow reach. The degree of sensitivity of the control(s) is indicated by the slope and shape of the rating curve, as depicted in Figure 2.

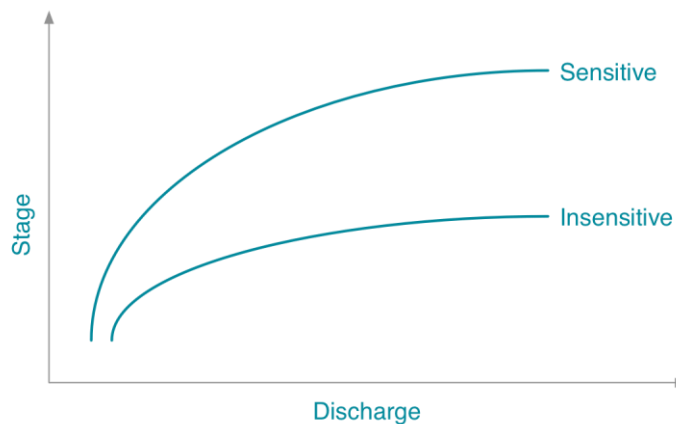


Figure 2: Rating Shapes for Sensitive and Insensitive Controls

Note: Broad insensitive controls therefore make it difficult to achieve the standard; more so if instrumented with a sensor with less resolution, so equipment selection to suit site characteristics can be crucial.

2.4 Natural & Artificial Controls

2.4.1 Natural Controls

Satisfactory controls are often difficult to find because topography, geology, and the range and frequency of flows. For instance, gorges cut through bedrock provide better control sites than riverbeds on alluvial plains.

2.4.2 Artificial Controls

Purpose-built artificial controls can often provide a stable rating for a small stream site, albeit at some cost in construction. They can be classified as either:

- pre-calibrated structures, or
- bed controls.

For more information, see 'Annex H – Calibrated Structures'

Pre-calibrated structures are weirs or flumes which, when built accurately to standard designs, have a mathematically-derived rating which may or may not hold true in practice, depending on a range of factors, which include:

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

Where practicable, an existing natural or artificial control, can be altered to improve its sensitivity or stability. The means of doing this will vary according to the site and other factors.

Note: Culvert pipes are good if kept clean, but are prone to blockage and because of this, the rating will vary.

2.4.3 Siting Artificial Controls

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

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

Note: Sufficient fall avoids being drowned out, but this fall should be minimised to:

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

Backwater Effects

Even if a suitable control exists for a site, downstream effects can sometimes overwhelm that control and affect the rating. Examples of this are:

- tidal levels moving upstream towards a site
- a large tributary inflow from a stream entering just downstream of the recorder, and
- civil works in the riverbed occurring downstream.

Note: A stream or river that has a low gradient is especially vulnerable to this problem.

As a general guide, when a rapid exists downstream of the recorder a backwater effect should not propagate up through this, provided the rapid is not drowned out e.g. by flood or the downstream effect.

Knowledge of backwater effects is important when drawing rating curves and selecting a site. If a backwater effect does occur, the only possible way to keep continuous flow records may be to utilise an instrument that measures river velocity continuously.

3 Deployment

Once a site has been selected, the design and construction of the installation type and deployment of equipment follows.

3.1.1 In this Section

This section contains information on:

- acceptable installation types and components
- deployment of equipment and instruments to measure water level, and
- basic accuracy requirements.

It primarily covers two factors that influence deployment. These are:

- the site-related variables that determine the type and installation of equipment, and
- the degree to which the equipment is:
 - fit for purpose, and
 - operated to minimise errors and maximise accuracy.

3.1.2 Functional Requirement

All equipment used to measure water level must be deployed and maintained to ensure:

- stationarity of record
- appropriate resolution of time and recorded stage, and
- the overall accuracy of water level data.

3.2 Station Planning

Planning a station requires consideration of a number of factors that can affect the quality, availability and long-term usefulness of the data that is collected.

These factors are:

- site access
- materials
- design, and
- construction method.

Note: Where practicable any construction work shall be preceded by a site survey.

3.2.1 Site Access

Safe and convenient access to recording stations is crucial for data collection.

Where permission shall be obtained for access over and installation of equipment on land, whether private, local authority, corporate or government owned.

Construction work on a site shall begin with work on the access itself, including foot tracks and steps to the work site.

3.2.2 Site Survey

It may be useful to precede construction work with a site survey for the purposes of design. At the least, a station history form should be filled out for the site as soon as records begin, updated following changes, and checked during the annual site inspection (see site factors above).

3.2.3 Materials

All materials used in installations shall be of adequate strength, thickness and durability for the purpose, and conform to the New Zealand Building Code and Regulations.

Note: Remember that many temporary works can become permanent, or be re-used for another purpose.

Generally:

- timber should be treated against rot to an appropriate specification (or better)
- exposed and structural steelwork should be hot-dip galvanised or stainless steel
- wire ropes shall be galvanised, and
- bolts and nuts shall be galvanised or made of stainless steel.

3.2.4 Design

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

- New Zealand Building Code and Regulations, and
- Health and Safety Act and Regulations

3.2.4.1 Signage

Where relevant, signage shall be installed to warn of any hazards.

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

3.2.4.2 Security

Where relevant, security gates or systems shall be installed for the safety of anyone who visits the vicinity, and to protect the station from vandalism. Protect installations where practicable from interference and damage, including deliration from flora and fauna.

3.2.5 Construction Method

3.2.5.1 Rivers and Lakes

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

Generally, recorder stilling wells require concrete foundations to:

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

Generally, weirs require deep cut-off walls to prevent:

- leakage, and
- overturning of the structure.

Cleaning and preparation of the foundation is essential.

Note: Rock bolts can be useful methods of fastening equipment to bedrock, large rocks or concrete structures. These can range from substantial bolts grouted into holes drilled in bedrock by a compressor-powered drill, to masonry fasteners driven into holes in concrete.

3.2.5.2 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.

3.2.5.3 Sea Level

Because of the coastal location of sea level sites, the following should be considered:

- The use of Grade 316 stainless steel components
- The low cycle of a 'king' tide
- The use of an epoxy that sets underwater

For example: Sikadur UA Concrete Fix (mix by hand, use like putty) or Ramset Epcon C6 (mixed in a glue-gun nozzle, very rapid hardening, suitable for injecting into holes even full of water).

- Use battery-powered tools

For when working near salt water.

- Stainless threaded anchors

For example: Ramset Dynabolts, etc) do not come in lengths much longer than 100mm, and longer bolts are usually required which can be made from lengths of threaded stainless rod then epoxied into slightly over-size holes

3.3 Station Documentation

3.3.1 Site Identifier Allocation

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

Note: It is the responsibility of the recording agency to catalogue and register the site ID.

The index to hydrological recording sites in NZ shall be used to allocate site identifiers.

Note: New Zealand has a system of water-level recording station numbers based on river numbers. Regional and district councils, NIWA and various other companies use this system. Stations are listed in a site index publication (Refer: Walter, K. 2000: Index to hydrological recording sites in NZ. NIWA Technical Report 73).

3.3.2 Station History

3.3.2.1 Station History Record

As a minimum, a station history record shall be established for all water-level stations as the main part of their metadata and:

- filled out for the site as soon as records begin
- checked and updated during the periodic site surveys
- updated whenever there are changes to site parameters
- updated whenever there are changes to what is recorded on the form, and
- any updates of an existing record should be in the form of an additional record rather than an overwrite.

Note: The Station History form provides a record of, for example, installations, equipment types, data collected, benchmarks and levels, location, the sites initial purpose (e.g., low flow and flood) ownership of land and history for each station. For more information, see 'Annex C – Hydrological Station History Form'.

3.4 Reference Levels

3.4.1 Vertical Datum

Stage height data shall be referenced to a consistent vertical datum throughout the life of the installation. This datum should be an established survey datum but may be arbitrary if impractical.

Note: An important factor is that the water level will not be likely to fall to negative values over the life of the station.

3.4.2 Benchmarks

To ensure that the stations can be checked for movement and re-established (if moved or damaged), the datum of the measuring equipment shall:

- be related to a set of permanent benchmarks, or
- a particular datum above mean sea level.

A minimum of three benchmarks shall be installed (or located, if in the vicinity) and the reduced levels of the following shall be measured and recorded in the station history record and metadata.

The levels at a site that should be related to the known datum are the:

- staff gauge zero (for each staff gauge)
- internal plumb bob zero
- reference point for distance meters
- beam source and recording zero for radar and ultrasonic sensors
- the invert of all intake pipes, bubbler orifice or submersible transducer elements
- the underside of recorder house floor / stilling well ceiling, and
- stage of zero flow.

That is, the lowest point of the control or reach below which the river stops flowing.

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

3.4.3 Reference Gauges

The reference gauge is the means by which an instrument is referenced to the recording zero. At least one reference gauge shall be installed at each site.

The reference gauge shall be:

- referenced to benchmarks
- of robust and stable construction
- readable to within 1 mm, and
- cover the full range of anticipated stage.

3.5 Primary Reference

3.5.1 Local Datum

Any water-level measurement shall be resolved using a convenient local datum.

The local datum shall be established on site using at least three benchmarks (BM's).

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.

A GPS (Global Positioning System) reference can be used to establish site datums or confer existing datums, however the horizontal and in particular, vertical resolution may not be sufficient to achieve the required accuracy.

All components shall be levelled in from the primary datum, using traditional survey methods.

3.5.2 Assumed Datum

When establishing an assumed datum, an assumed level shall be conferred, for example, 100.000 metres to the most immovable of the site's benchmarks, and level in the other benchmarks and installations to this.

100.000 metres is a useful assumed level to choose, unless the site is at something like this elevation above mean sea-level (M.S.L.), in which case it may at some time be confused with M.S.L. datum, and thus an alternative value should be used.

Note: An assumed datum can be used instead of one established to a proper surveyed datum, as in some cases stage height is recorded as a function of flow and the level itself is not the information required. A common exception to this is the case of reservoirs or groundwater stations where levels may be well defined in terms of a local or regional datum.

3.5.3 Adopting a Recording Zero

The recording zero of a station shall:

- be placed below the lowest level to which the water surface will fall, and
- take into account possible degradation at the site that may lower the water level below the recording zero.

When adopting the recording zero, choose one that is:

- a sensible number where possible, e.g., 50.000 metres, and
- below the anticipated minimum water level.

Note: This ensures all stages are recorded as positive.

3.6 Equipment for Reference and Measuring

3.6.1.1 Basic Requirements for Collecting Water Level Data

The collection of water level data, either manually or automatically, requires a range of instruments, or components, to be deployed at a site.

For water level data to be useful, a permanent datum shall be maintained and specified accuracy limits shall be met. These details are documented in the station history file and metadata for individual sites.

3.6.1.2 Primary Reference Gauges

The primary reference or gauge and the measured water levels are used to determine the stage height. The following are examples of primary reference gauges:

- Staff gauge
 - Sloping staff gauge
 - Electric plumb bob
 - Electronic water level indicators
- For example: A groundwater probe.*

3.6.1.3 Equipment Selection

Any of the following devices may be used to measure water level:

- Shaft encoder
- Pressure transducer
- Gas purge sensor
- Acoustic transceiver
- Radar

When establishing a station the sensing device and logger shall, where practicable, be selected to meet:

- the accuracies and resolution required by this Standard
- the full range required
- any present and future (anticipated) data needs, and
- the time interval required to measure the fluctuations occurring at the station.

3.7 Staff Gauges

A staff gauge:

- is a graduated staff that is mounted either vertically or inclined, and
- provides an inexpensive, simple, robust and absolute method of determining water level.

At a site equipped with an automatic recorder, the staff gauge provides an independent check on recorded water levels.

Generally, with a stilling well this external staff gauge is an essential check on whether the intake pipe is blocked by silt.

Generally, with a transducer or gas bubbler orifice directly in the river, the staff gauge is the only direct check on its performance.

Where the range of water levels exceeds the capacity of a single vertical gauge, other gauges shall be installed, as much as practicable in line with the recorder cross-section.

The scales on a series of stepped staff gauges shall overlap by not less than 15 cm.

3.7.1 Usage

A staff gauge shall only be used for spot measurements and shall include an estimate of uncertainty.

Note: It can be difficult to obtain readings in the field with a true resolution better than ± 3 mm. Floods cause surges and standing waves which can introduce a bias.

3.7.2 Vertical Staff

The most common form of gauge is the vertical staff. It normally consists of a series of 1-metre long plastic plates that are graduated at ten-millimetre and 1-decimetre (100 mm) intervals fixed to a secure mount, e.g., treated timber board or concrete wall.

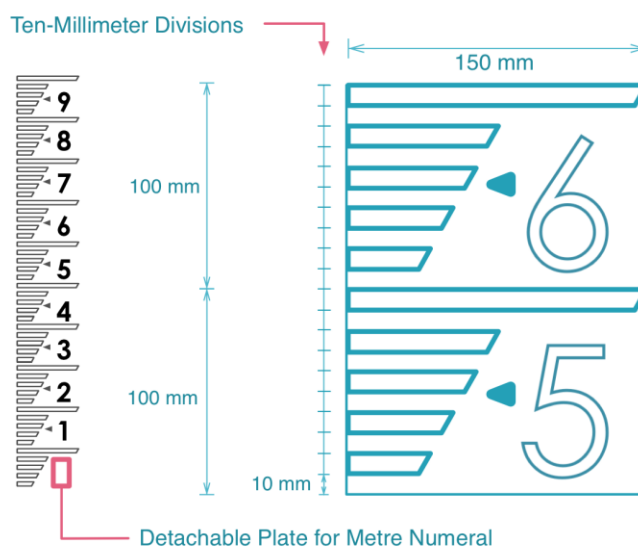


Figure 3 – Staff Gauge Plates

Illustration: Chris Heath

3.7.3 Sloping Staff

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 will achieve a better resolution than a vertical staff gauge because distance up the slope is greater than corresponding vertical height.

Gauges, e.g., a plank or concrete pad (Figure 4) shall be set at a known angle. 30° is recommended, as staff plates exist for this angle.



Figure 4 – 30° Sloping Staff Gauge

Photographer: Evan Baddock

If standard vertical plates are used at 30°, the values read off the sloping staff gauge can be halved to obtain the actual water level.

Note: At 30°, the slope distance is twice the vertical height.

3.7.4 Installation

Staff gauges shall be installed so that:

- the zero of each gauge is at the recording zero.
The R.L. level should be below the lowest possible water-level, given that the bed may degrade significantly over the life of the station.
- there is overlap between the top of the one gauge and the bottom of the next
- the staff gauge mounts are immovable and not prone to settling
- the method of fastening the timber to the mount is positive
Friction should not be relied on to prevent slippage.
- the water-level is easily and accurately read at any time
- the gauges are protected from high velocities, and
If high velocities are unavoidable, keep the gauges short and have more of them, or glue plates to a concrete face.
- the gauges are on the same river cross section as the intake pipes or sensor orifice.
Especially with low flow gauges, staff gauges shall be as close to the intake pipe or orifice as possible.

3.8 Electric Plumb Bob

3.8.1 Introduction

The electric plumb bob (EPB) is a non-recording gauge that is normally used to measure the water level in a stilling well.

Note: It gives an independent check on the internal water level and therefore provides a check on the recorder.

It consists of a plumb bob connected to a graduated steel tape, wound on a brass reel (Figure 5). 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, and thus the plumb bob can be raised or lowered so that it is only just touching the water surface, and a reading taken from the tape graduations.

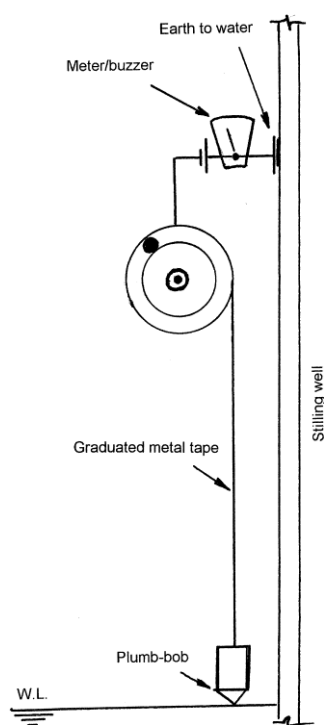


Figure 5 – Electric Plumb Bob Schematic Diagram

In Groundwater applications, electronic water level indicators are used. These consist of a spool of dual conductor wire with a probe attached to the end as an indicator. When the probe comes in contact with the water, the circuit is closed and the meter light and/or buzzer will signal contact. Measurements should be made and recorded to the nearest 10mm.

For details on the installation and set-up of an electric plumb bob, see 'Annex B – Procedures'.

3.8.2 Usage

An electric plumb bob (EPB) shall be used to provide an accurate indication of water level in situations where access and visibility are impaired, i.e., within a stilling well or a borehole.

An electric plumb bob can provide acceptable accuracy when the distance to the water surface is of the order of tens of metres.

Note: Electric plumb bobs may not work in waters of very low conductivity.

Due to their accuracy, electric plumb bob's are generally used as the primary reference check at stations where they are installed. Although they are the best check of the instruments in a stilling well, they are prone to the same silting. Each electric plumb bob reading should be paired with an external staff gauge reading to identify possible silting.

3.8.3 Mounting

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

3.8.4 Precision

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

3.8.5 Deployment

An electric plumb bob shall be installed at each stilling well site.

Note: Discrepancies between the recorder and the electric plumb bob will sometimes occur. For more information, see 'Annex B – Procedures'.

3.9 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.

For more information on weirs and flumes, see 'Annex H – Calibrated Structures'.

3.9.1 Weirs

The location of the water-level recorder and staff gauge shall be at a distance upstream of the weir that is at least three times the maximum head to avoid any drawdown caused by flow over the crest.

The approach channel should be straight with a uniform cross-section and be free from obstructions (such as boulders).

Flow in the approach channel should be uniform and steady. The velocity distribution should approximate that found in long, smooth-sided and straight channels.

Note: Baffles and flow straighteners can be used to simulate normal velocity distributions, but their location with respect to the weir should be no closer than approximately 10 times the width of the nappe at maximum head.

3.9.2 Confirmation of Calibration

In practice, all structures shall be verified to confirm that the formula is the true rating. Very often it will not hold true because of small discrepancies in the as-built design or because of unsuitable channel conditions, such as significant velocity of approach (particularly at higher flows).

All gauging stations with structures, therefore, shall be gauged at an adequate frequency (at least twice per year) and over the full range.

Despite this need to extensively check weir ratings, the expense of their installation can at times be justified against the bed stability obtained, or perhaps the greater confidence in defining or extending the ratings.

Note: Generally such weirs and flumes are for comparatively small flows and, when carefully constructed, installed and maintained in accordance with the design specification, can provide flow records with high accuracy.

Sensing Devices, Wells & Recording Requirements

4.1.1 In this Section

This section contains information on devices that:

- have direct contact with the water
- take an indirect measurement of water level, and
- radar instruments.

It also provides information relevant to the selection and maintenance of stilling wells and recorder housings and instruments.

4.1.2 Direct Contact with Water

Devices that have direct contact with water include:

- shaft encoders
- pressure transducers, and
- gas purge sensors.

4.1.3 Indirect Measurement of Water Level

Devices that indirectly measure water level include:

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

Note: Each of these direct and indirect methods have differing accuracies, and in choosing a sensor, the appropriateness to the site must be considered. There are other sensing devices available; some of these don't meet the standards. Price may also be a consideration.

4.2 Sensor Selection

Selecting a sensor can be complex, however to assist in the correct sensor being selected, consideration should be given to:

- whether it is fit purpose, and
- compatibility.

4.2.1 Fit for Purpose

To be fit for purpose the sensor shall cater for the following where required:

- Client or site requirements and accuracy
- Long term monitoring site
- Short term investigation site
- Flood warning site

4.2.2 Compatibility

The sensor shall:

- be easily interfaced with existing hardware, and
- have common industrial output protocols.

4.2.3 Site Characteristics

Every water level site is unique.

The maximum and minimum measuring range at the site shall be determined. This will ensure the sensor covers the full range and hence no loss of data.

When selecting the appropriate sensor, the site characteristics shall be considered in conjunction with the following factors:

- Seasonal conditions
- Environmental conditions
- Power budget assessment

4.2.3.1 Seasonal Conditions

Seasonal conditions and factors can influence or damage the sensor, for example:

- heat
- weed and algal blooms
- frost and ice
- recreational activity
- sediment flushes
- floods, and
- flood debris build up.

4.2.3.2 Environmental Conditions

Environmental conditions can influence the sensor, for example:

- wind
- waves
- bank stability
- movement of bed materials
- river works
- water turbulence, and
- migrating channels.

4.2.3.3 Power Budget

When used with a particular logger and telemetry system the power budget and maximum demand shall be considered to cover mains power outages.

Items to consider include:

- low solar charge
Winter periods
- temperature conditions at the site, and
Below freezing over periods
- battery capacity.
Will this sustain the power requirements through the worst conditions?

Note: Backup systems and equipment isolation (separate backup logger batteries) also need considered.

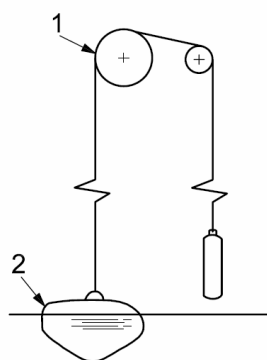
Shaft Encoders

A shaft encoder:

- is an electro-mechanical float and counterweight gauge
- consists of a pulley rotated by the float and counter-weight system
- converts pulley rotation to millimetres of rise and fall, and
- converts each millimetre of rise and fall into an electrical pulse with an additional up or down signal.

The pulses are counted by the device to obtain the current value, which is retained and read by a data logger at regular intervals, for example, every 5 minutes. If the initial position is known current water level can be calculated.

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



Key: 1 driven pulley

2 float

Figure 6 – Float and counterweight configuration

Used on its own, a float gauge can provide a direct readout of stage height without requiring an external energy source, however most encoders are now electronic, link to a separate data logger, and require constant power to operate. It provides almost uniform resolution throughout the range and good accuracy at low stage.

Note: A float gauge is a mechanical device and is therefore subject to errors from change in temperature, hysteresis and friction. It requires a stilling well, which can be expensive to construct and maintain.

4.4 Submersible Pressure Transducers

4.4.1.1 Theory

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 will measure the pressure head of the system but in most cases will report to an equivalent head of water. It is important to understand this relationship and the effects that it will have on given measuring situations. The relationship is:

$$h = P / (\rho \cdot g)$$

where P = pressure, g = gravitation constant and ρ = density

The international standards used in deriving the equivalent head of water are:

$$g = 9.80665 \text{ m/sec}^2$$

$$\rho = 1000 \text{ kg/m}^3 \text{ derived at } 4^\circ\text{C}$$

When comparing the pressure transducer against a body of water this relationship needs to be considered. In most situations the error involved is small and proportional to the head of water over the sensor.

Note: For groundwater systems and deep lakes the ability to effectively validate a system is dependent on these factors and especially the temperature of the water as this will determine the density.

For artesian groundwater systems the temperature effect can be further influenced with exposure of inspection tubes to radiant heating. Purging the tube prior to inspection or direct comparison to another pressure reference is required in these systems.

When verifying the performance of the pressure transducer a direct pressure comparison is preferable as this will check the sensor independent of gravity and density variations that are found with water measurements. The system can be validated against external references to monitor the overall site performance.

There are two main categories of pressure transducer used in the measurement of water level, submersible and gas purge

4.4.1.2 Submersible Sensors

Submersible pressure transducers are mounted directly in the water and can have vented, (open to atmosphere), or non-vented cable to provide a gauge reading. They 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.

Note: Vent tubes must be kept clear or measurements will be affected by barometric changes. Non vented transducers are available and have their advantages; however measurements from these require compensation for barometric pressure. Even if barometric pressure is measured in conjunction with water level, compensation rarely produces results that meet the accuracy required of this standard.

Submersible pressure transducers require a relatively simple installation, hence lower costs, due to no stilling well being required.

Note: It is not normally possible to set the sensor at the recording zero, so an offset is usually needed. It must be recorded in the logbook at the time of installation and applied to the record either in the logger or when processed. In any case transducers must be checked frequently for drift; an offset or change in offset may subsequently be required.

4.5 Gas Purge Sensors

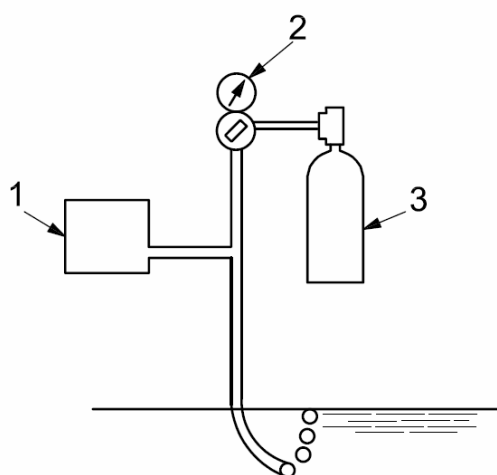
Gas purge sensors differ from a submersible pressure transducer by having the transducer located well above water level, normally within the recorder housing.

The transducer senses water level at an underwater orifice that is connected to the transducer by small diameter tubing. This in turn has a small feed of gas from a cylinder bubbling out through the orifice. The backpressure in the tubing is proportional to the water pressure over the orifice and hence the water level.

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

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 of the gas purge system.

These systems must be installed correctly, with regard to manufacturer's instructions on bubble tube length, avoidance of dips in the bubble line, and a suitable orifice system that prevents under-reading in surging waters and will measure a fast rate of rise.



Key

- 1 pressure sensor
- 2 regulator
- 3 compressed gas

Figure 7 – Gas purge system

4.5.1 Accuracy Requirement for Pressure Transducers

The accuracy requirement for water level measurement follows the USGS framework for sensor and site accuracy.

The sensor shall have an accuracy of $\pm 3\text{mm}$ or 0.1% of effective stage, whichever is greatest.

Note: This gives a high degree of accuracy at low levels with a proportional decrease over the sensor range.

Manufacturers 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.

For example:

A sensor with a range of 10mH²O and accuracy of 0.1%FS has an error of 10mm over the entire 10m range whereas a sensor of the same range and accuracy of 0.1% of value has an error of 10mm at full range but only 5mm at half range.

A sensor with a stated accuracy of 0.1% FS can be used if the calibration relationship is known and falls within the accuracy tolerance of ± 3 mm or 0.1% of effective stage, this can be requested on purchase or can be determined and scaled with a portable calibrator.

For sensors with an error greater than 0.1% FS then the range of the instrument must be selected to ensure that the error does not exceed 3 mm; i.e. for a 0.2% FS sensor the maximum range is 1.5 metres.

A calibration certificate showing the relationship of the sensor to a traceable reference shall be supplied on purchase detailing the sensors accuracy

4.5.2 Installation and Commissioning

The most important component of installing a pressure transducer system is applying the correction to gauge zero. This requires an offset to be derived and applied to the raw signal on the data logger.

Note: The sensor output may require additional scaling to return the correct engineering units for the water level measurement; this is most important on voltage and milliamp outputs but can be important for digital signals as well.

Where possible the orifice or sensor mount should be surveyed to the datum to provide the offset, and monitored for stability over time.

Alternatively the sensor can be set to a suitable primary reference gauge. It is important to adequately record the offset information and ensure that the reference gauges are correctly aligned to recording zero.

4.5.3 Sensor Verification and Validation

The sensor shall be checked at a frequency suitable with the type of measurement in accordance to the manufactures guidelines. If variation and inconsistencies are showing in the relationship between the sensor and references then further analysis shall be undertaken and the site monitored more frequently until the system is stable or fault resolved.

In general on inspection the sensor shall be checked against the external reference, the wiring and tubing condition checked for signs of deterioration and leaks.

For pressure transducers the sensor drift can be checked by venting to atmosphere and comparing the reading against the site offset, if this shows an error then the sensor and system shall be fully investigated and potentially the sensor removed for calibration.

Note: There is a tendency for semi-conductor pressure transducers to drift in calibration over time. This is usually most evident in the first 6 months of use, but usually improves with age. This drift effectively causes a progressive change in offset.

Sediment accumulating at the sensor orifice can affect its accuracy, and where this occurs frequent cleaning is required.

4.5.4 Sensor Calibration

The use of a portable calibrator is highly recommended for managing pressure transducer installations and if not available then a suitable testing agent shall be used.

Portable calibrators:

- provide traceability to accredited laboratories
- provide the ability to acceptance test new sensors
- allow for field checks of sensors
- provide a system leak test
- permit in-house calibration of sensors
- reduce cost and time involved in using external agents for calibration and sensor verification.

All pressure transducers shall be acceptance tested on purchase to characterise the nature of its calibration before deployment. It is recommended that the sensor be calibrated to minimise the sensor error in accordance with the calibration procedure

The sensor shall then be calibrated annually with the calibration valid for 18 months. The calibration shall occur in the office under controlled conditions with a replacement sensor swapped into the site.

Inspection and instrument relocation records are to be fully documented to trace the instrument movements.

Note: Sensors that fail calibration shall be clearly identified in the metadata and the nature of the failure characterised. Usually the record obtained can be repaired. Sensors shall only be re-spanned if the failure has not affected the sensor stability. Damaged sensors shall be assessed and repaired by the manufacturer or suitable agent.

4.5.4.1 Use of Portable Calibrators

A range of portable calibrators is available on the market and provides a cost effective means of managing deployed pressure transducers.

The calibrator should be selected with a suitable accuracy and measuring range with the required inputs to test all deployed sensors.

The calibrator shall be annually tested at an accredited laboratory.

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

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

The sensor shall be tested to its:

- native setup, and
This shall be independent of any measurement conversions or output modifications, that is, no resistors for mA to volts conversion.
- full range.
With particular emphasis on zero point and full range.

Note: Enough data should be collected to determine the calibration performance of the sensor and detect any sensor drift or non-linearity. Increasing and decreasing applied pressure runs should be undertaken to detect any hysteresis in the sensor. Care should be taken in the setup of the calibration to ensure no leaks in the system and the environment is stable as these factors will introduce error and variability in the test. Sensors will be deemed to have passed if they conform to their stated manufacturers accuracy.

4.6 Acoustic Instruments

Acoustic instruments offer a simple deployment method for measuring water bodies and reduce the need for complex and costly installations for mounting sensors directly into river systems.

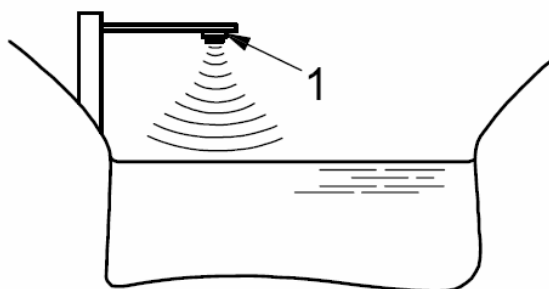
However they generally have a lower accuracy standard than other methods and care should be taken when choosing a sensor to ensure the required level of accuracy is met for the purpose of the site.

4.6.1 Acoustic Transceiver – Sound Path in Air

The sound-path-in-air 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, and
- is more accessible than a sound-path-in-water transceiver.

The sound-path-in-air acoustic transceiver's accuracy is typically ± 10 mm over the range.



1 = transceiver mounted above flood levels

Figure 8 – Air Path Ultrasonic Level Sensing

To avoid contact with the water surface, the transceiver shall be mounted above the channel's maximum flood level, but as close as possible to the water level.

Either the air temperature shall be measured directly, or a reference bar shall be located at a known distance below the transducer.

Note: The velocity of sound in air is strongly proportional to temperature, and a technique for compensating for this effect is required.

The transceiver shall be mounted:

- offset from the side of the channel so it remains over an open water surface at all times, and
- so that the instrument is robust and unable to move.
This is to prevent vertical movement which will change the recording zero of the instrument.

Note: If mounted flush with the side of a channel, the acoustic beam will have difficulty focussing on the water surface. The temperature sensor only measures temperature

in one place. Temperature gradients over the length of the ultrasonic beam give rise to errors.

4.6.2 Acoustic Transceiver – Sound Path in Water

The 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
- converts this time to distance, and
- is less accessible than a sound-path-in-air transceiver.

Accuracies higher than the general $\pm 3\text{mm}$ or 0.2% of effective stage can also be achieved.

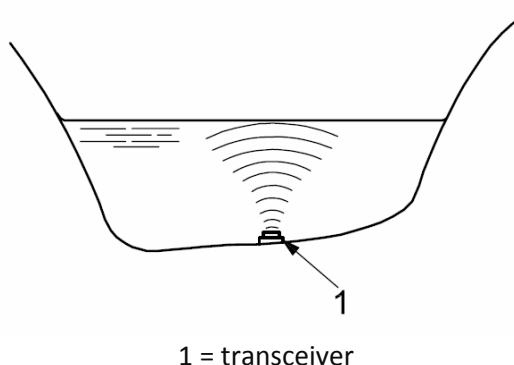


Figure 9 – Water path ultrasonic level sensing

4.6.3 Usage

The instrument operates without a stilling well.

The transceiver shall be mounted:

- so that the instrument is robust and unable to move
- level
- to prevent vertical movement which will change the recording zero of the instrument, and
- where practicable, below the minimum water level on a stable bed location.

Note: The velocity of sound in water is strongly proportional to temperature and a technique for compensating for this effect is required.

Either the water temperature shall be measured directly, or a reference bar shall be located at a known distance above the transceiver.

Note: Because the transceiver is fully submerged it:

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

Care shall be taken to ensure that there is no risk of reflection from channel edges at higher water levels.

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

Note: The 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.

4.7 Radar Instruments

4.7.1 Echo-Location

A downward-looking radar unit (Figure 8, Page 41) is able to determine the relative position of a water surface. The value returned relates to the area covered by the beam.

4.7.1.1 Usage

An 'echolocation' instrument operates without a stilling well and has a typical absolute accuracy $\pm 3\text{mm}$ for 15-30m range sensors.

4.7.1.2 Design and Deployment

When designing and deploying radar instruments:

- the 'echolocation' instrument shall be mounted in air where it is accessible for maintenance
- the mounting of the instrument must be robust and unable to move, and
This prevents vertical movement that will change the datum of the instrument
- the radar may be mounted on an arm extending over the flow.
The arm shall be long enough to ensure that the conical beam does not strike channel walls. Alternately, it may be mounted on a bridge span beyond interference from abutments, piers and other structural features.

4.8 Stilling Wells

4.8.1 Usage

Stilling wells shall be used to:

- dampen the fluctuations present in open water
- protect the sensors, e.g., float and counterweight sensors, and
- provide, within the well, an accurate representation of the water level in the channel.

4.8.2 Stilling Well Design

Stilling wells are generally made either of spiral-welded pipe or standard rolled sections 1200 mm in length.

A steel recorder housing bolts to the flange of the top section.

The following diagram shows one design that consists of a number of sections; each section being 600 mm in diameter and 1200 mm in length.

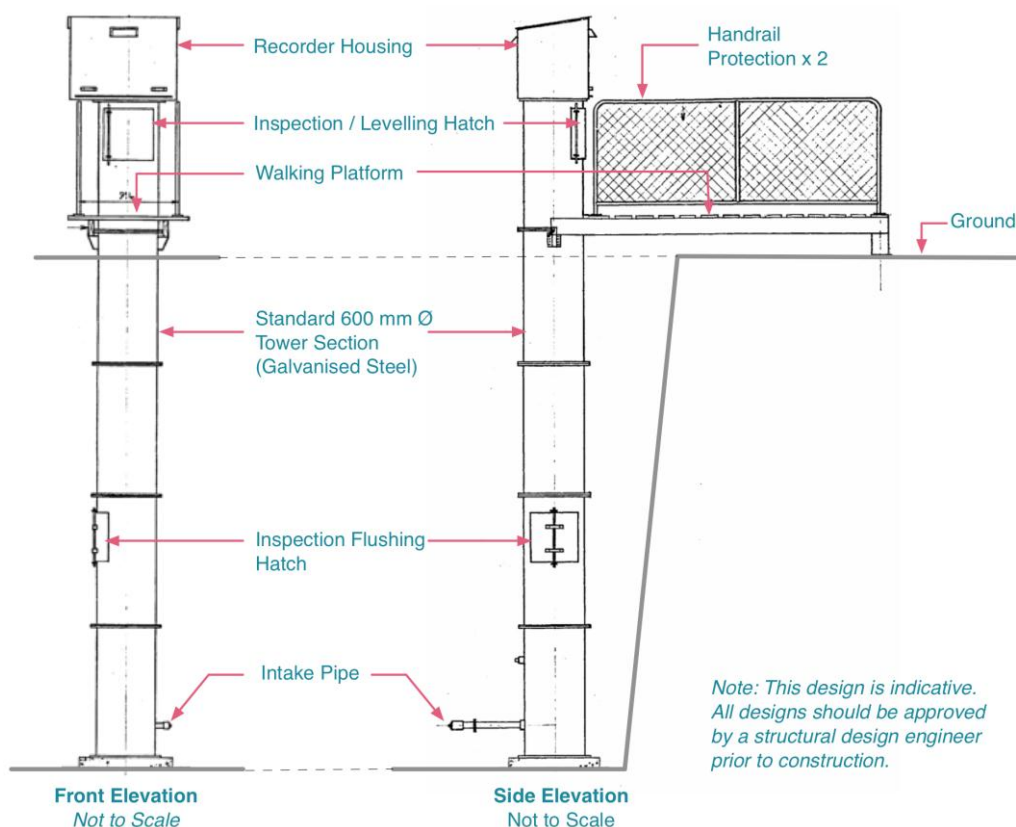


Figure 10 – Typical Stilling Well and Housing Setup

Note: Other designs and materials may be as good or better in certain situations. Alternatives include pipes of concrete, plastic (PVC), spiral-welded steel, fibreglass and corrugated culvert pipes.

4.8.3 Connection to Open Water

The well shall be connected to the lake or river by means of suitably sized intake pipes.

Where velocity past the river end of the intake is at times high (i.e. above 1.5 m/s) drawdown of the water level in the well may occur. To reduce this, a capped and perforated static tube shall be attached, oriented parallel to the direction of flow ($\pm 10^\circ$).

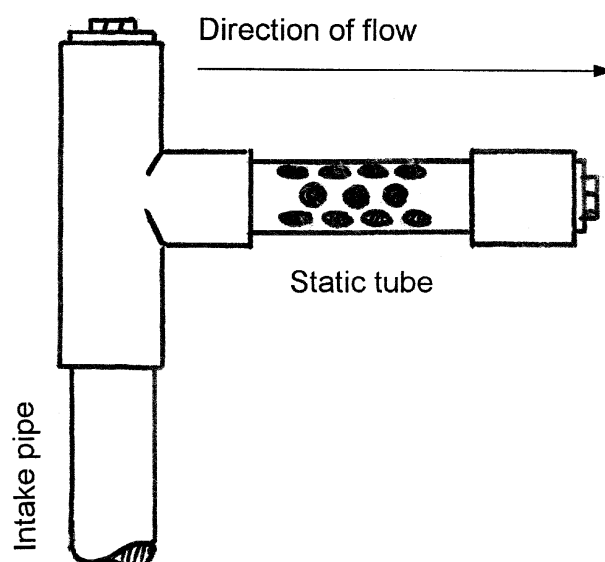


Figure 10 – Typical Static Tube Setup

4.8.4 Cross-Sectional Area

The cross-sectional area of an intake pipe shall be large enough relative to the diameter of the well to follow rapid changes in the external water level without significant lag.

For more information, see 'Annex I – Intake Pipe Dimensions'.

4.8.5 Site Requirements

4.8.5.1 Intake Pipes

Intake pipes shall be laid:

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

The lowest intake pipe shall be at least 150 mm below the lowest anticipated water level (but considerably further if degradation of the bed is possible).

Note: This is a very important decision that may impact considerably on the usefulness of the structure over time.

The lower intake pipe shall be at least 300 mm and preferably 1m above the bottom of the stilling well, to avoid blockage by sediment.

The intake pipes' diameters shall be large enough to keep lag within acceptable limits, but not overly large so that surging is not damped.

For more information, see 'Annex I – Intake Pipe Dimensions'.



Figure 11 – Example of Intake and Static Pipe

4.8.5.2 Stilling Well Construction

The stilling well shall:

- be vertical within practicable limits
- not allow the float and counter-weight systems to come in contact with the walls.
- have sufficient height and depth to allow the float to freely travel up and down the full range of water levels, and
- be firmly founded so that subsidence will not occur.

Note: Foundations that sit directly on bedrock are preferable, otherwise a substantial concrete mass poured into hard alluvium is required.

All construction joints of the well and intake pipes shall be watertight.

Note: Watertight joints ensure that water can only enter and leave through the intake.

A means of access for flushing the well and intakes shall be provided, either by:

- pumping a head of water, or
- directly emptying the pipes and well.

Note: Pipes are usually emptied using drainage rods. Wells are usually emptied using buckets or submersible pumps.

4.8.6 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 stilling well must be flushed as soon as possible.

Note: Indications of a blocked or partially blocked stilling well are usually apparent on the recorded hydrograph. It may show up as uncharacteristically flat recessions, rounded peaks or a slow response to changes in external water levels.

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 – De-Silting Stilling Wells'.



Figure 12 – Water Level Station Showing Multiple Sections and Housing

Recorder Housing

The recorder housing shall:

- be installed above maximum possible water level
- 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 in 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 other creatures.

All equipment within the housing shall be installed in a secure and orderly manner.

Note: For example, wires, cables, pulleys must not interfere with operation and servicing.

4.9.1.1 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.

4.9.1.2 Chest Height Types

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

- at chest height on the recorder stilling well, or
- if the sensor is connected only by cable or tubing, in a suitably protected location.

Note: Exposed cabling and tubing also requires protection from the elements and interference.



Figure 13 – Typical Stilling Well Housing design

4.10 Recording Instruments

4.10.1 Electronic Data Loggers

An electronic data logger shall be able to store at least the equivalent of four digits per reading. Where a data logger includes the sensing device, the resolution and uncertainty shall relate to the stored value.

There are many data loggers on the world market with a large range of price and capability. Generally they all have the capability to interface to several different types of sensors, vary the recording interval and output the data in various electronic formats to computers.

Chart recorders shall not be used.

The main capabilities and factors to consider when choosing a data logger are the:

- ability to interface to relevant sensors
- digital resolution (how many bits) and accuracy
- telemetry capability and compatibility
- adequacy of set-up and downloading software
 - With digital devices, there can be poor on-site access to the data without specialised equipment or software.*
- the ability to average and record other statistical information such as standard deviation
- recording of data at some distance from the sensor
- reliability, compactness, and cost
- power requirement
 - The power requirement should be low*
- storage capacity
- clock accuracy, and
- scan rate.
 - This is the frequency a logger is able to measure and process signal then receive data.*

Site & Station Maintenance

All stations shall be maintained in good order so that they are:

- reliable and operate effectively
- fit for carrying out their intended task, and
- sufficiently tidy for efficient work practice.

Note: A well-maintained station will project the impression of a professional operation.

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

- The recorder housing shall be kept tidy.

Note: Bare galvanising is often acceptable, particularly once weathered.

- Hinges and locks shall be kept lubricated

Note: Use graphite powder on locks; not oil but keep it away from electronic and electrical components and aluminium surfaces that may become wet. Use sparingly or it may bind locks.

- Signage relating to hazards shall be maintained
- Access tracks shall be maintained in a safe condition, including being clear of vegetation.
- The visual effect of the station on the environment shall be minimised.

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

Data Acquisition

5.1.1 In this Section

This section contains information on the standards required for data acquisition, in particular, standards associated with:

- measurement
- data retrieval and conversion
- timing
- on-board processing
- site visits, and
- instrument validation and calibration.

In hydrology, water level data are used to measure changes in lake or reservoir storage, aquifer and sea levels, flood heights, and to record flow by means of the relationships that generally exist between stage height and discharge in river channels.

5.2 Data Retrieval and Conversion

5.2.1.1 General

The retrieval of stage height data varies according to the type of recorder used, and to the urgency of acquiring the data. The majority of stage height data is transmitted, received, decoded, and entered into local databases through various telemetry systems, such as over radio, cell-phone and satellite systems.

Data can also be retrieved from a site by manually downloading to a mobile device or laptop computer, or by extracting a data card from the logger and downloading data from the card to a computer.

5.2.1.2 Data Retrieved by Manual Downloads

All data retrieved by way of manual downloads, electronic data cards, and electronic downloads:

- shall be considered original stage height data, and
- should be protected against loss or damage.

5.2.1.3 Data Transmitted via Telemetry

Data that are transmitted via radio, cell, satellite, or other telemetry method, shall be considered original and must be preserved as such.

5.2.1.4 Data from Automated Data Collection Sites

Original data from automated data-collection sites shall be:

- defined as unaltered (no changes in magnitude) data
- acquired from the primary data series as required and clearly identified (and backup logger, as needed), and
- converted to conventional (engineering) units using a standard format.

5.2.1.5 Format

The various recorded data in various formats must be deciphered and converted into a format that can be easily used by data-processing systems.

5.3 Timing

5.3.1.1 General

Instrument timing and accuracy is crucial for good record keeping. Where timing is part of the instrument specification, the timing method used shall be clearly stated in the metadata.

The recommended recording interval shall be 5 minutes or less, and a maximum of 15 minutes is required.

Note: Some specialised sites such as sea level require short period intervals such as 1 minute.

The uncertainty of digital timing devices used in water level measuring devices shall be within ± 90 seconds of New Zealand Standard Time.

On-Board Processing

Modern data loggers have the ability to store not just data from sensors, but also apply programs and processing to that data for storage or output to other devices, for example, flow levels for gate settings.

The value archived shall be the instantaneous value recorded on the logging interval as defined in this standard.

All other supplementary measurements may be stored and shall be described in the site metadata (example, flow or averaged data).

Note: Sub interval averages, medians, standard deviations are useful extra data, and collection of these is recommended. When they are archived they need to be described and used properly. Issues such as induced hysteresis and phase shift can occur from using averaged data

5.5 Site Visits

The station shall be visited at intervals sufficient to ensure that the data collected is free of error and bias, both in level and time. For a schedule of station visits and checks, see 'Annex E – Schedule of Station Visits'.

The extent of possible error and bias can depend on:

- the nature of the installation and instrumentation
- whether telemetry checks are carried out, and
- the presence of back-up instruments.

5.5.1 Site Inspection Intervals

Site inspection intervals will vary depending on the individual site requirements; therefore there is no set standard as to how often a site should be inspected. However resourcing must be adequate under normal circumstances to ensure stations are visited often enough to ensure quality of the data collected.

Note: Maximum intervals of one visit every three months are suggested, and one visit per month is recommended, as a minimum for troublesome sites. For example, these may be sites with unstable ratings or sites where the bubbler system needs more attention than others.

As a minimum, an inspection record for water level should contain the:

- site name or number
- date and time of the logger and reference time
- reference reading with uncertainties, and
- instantaneous logger/sensor value.

5.5.1.1 Proximity to Logged Value Time Stamp

The inspection shall be completed as close to the logged value time stamp as possible and filled out at that time.

Note: Noting the logged value on the inspection record should be completed as good practice. This means that an inspection can be carried out at any time in the logging interval as verification of the logged values. This is especially useful when you have rapidly changing stage values or noisy data and if the logger only displays the value without an associated time. 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. However, bear in mind some loggers do not update their display at every scan.

5.5.1.2 Uncertainty

The reference level shall always be accompanied by an uncertainty. For example: 756 mm $\pm$ 5 mm. For an electric plumb bob the uncertainty is assumed to be $\pm$ 1 mm unless otherwise noted.

The observations collected and the uncertainty carry a lot of meaning when the data is processed and shall be carried out with utmost diligence.

Note: It is recommended the reference is read before the logger value.

5.5.2 Resetting a Logger after a Fault

When resetting a logger after a fault, the value from the primary site reference is the value that the logger is reset to. If this is done during times of varying stage, an inspection is needed soon after, during a period of relatively stable water level, to confirm the logger was correctly set.

5.6 Instrument Validation and Calibration

5.6.1 Performance

All sensors shall be regularly validated and calibrated to ensure they perform to their specification and that measurement, taken over the life of the data series, are accurate.

This includes not only deployed sensors but those about to be used from storage, because the length of storage may be beyond the recommended calibration interval.

It is expected that any purchased instruments be delivered with a calibration certificate that is less than 12 months old.

Note: The value of the sensor record is of upmost importance here, as the sensor is producing the final archive record, so we need to ensure that the sensor is checked appropriately and is performing to its own specifications and the sites requirements

5.6.1.1 Validation Method

Validation is a field check of the sensors ability to conform to its specifications. Where practicable, the validation method shall be consistent with the manufacturer's instructions.

Where field validation is not possible then proceed straight to a calibration process, potentially by swapping a new calibrated sensor for the current questionable sensor.

5.6.1.2 When to Validate

Validation shall be performed when the operator determines that the sensor is not providing an accurate record of the measured variable. For example, any time two consecutive verification readings are outside the defined tolerance for that sensor.

Sensor devices shall be validated:

- at least annually
- as a result of observed fault or major discrepancy at any site inspection indicating that the instrument requires checking
- if consecutive site inspections identify trend in verification readings outside tolerance for that sensor, or the data collected between inspections contains evidence that the instrument requires checking.
- If, at any two consecutive visits the difference between recorder water level and verification readings from one or more reference gauges is outside the defined tolerance for that sensor.

5.6.2 Calibration of Sensors

All items of equipment used for measurements shall be calibrated to manufacturer specifications, and their calibration dates recorded in a suitable register.

A calibration may involve the physical adjustment of the device.

5.6.2.1 How and When to Calibrate

All sensors shall be regularly calibrated, and their calibration dates recorded in the site metadata. Calibration results shall be retained indefinitely as part of the station history records.

Sensors shall be calibrated in accordance with the methodology recommended by the manufacturer or servicing agency:

- when the instrument validation check has failed to conform with the specifications,
- when field validation is not possible, and
- at the frequency recommended by the manufacturer.

Note: Pre-calibration data can be used to help reconstruct problem data record.

5.6.2.2 Where to Calibrate

Sensors shall be calibrated in a:

- controlled laboratory environment, or
- suitable office or workshop.

Note: The controlled laboratory is the preferred environment for calibrating sensors.

If an instrument requires repair, pre and post repair calibration results shall be requested and obtained from the service agent.

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

5.6.2.3 Who Shall Calibrate

Calibration shall be undertaken by a recognised service provider who can comply with the manufacturers' specifications.

6 Data Processing & Preservation

6.1.1 In this Section

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

It defines the standards relating to:

- missing records
- synthesising records
- editing records
- metadata and comments
- the quality coding of data
- preservation of record, and
- quality assurance.

6.1.2 Performance

The methodology used to process and preserve data shall be documented.

Note: The methodologies applied by each agency vary depending upon the software utilised for hydrological data processing and archiving.

6.2 Missing, Synthesised & Modified Records

6.2.1 Introduction

Even with the best of equipment and field practices it is inevitable that some corrections will be required and some missing records will occur.

Future analyses of the record become difficult and the data is of limited value if the gaps in the record are not filled.

6.2.2 Level and Time Corrections

Data shall, whenever possible, be corrected for level when it falls outside the standard:

- as determined from one or more references, or
- for time as measured by a timepiece.

Any changes to the raw record shall be documented and archived with the data.

Note: This may be achieved by quality codes or other data tags, or by time stamped comment file entries, or a combination ; best practice is for quality coding and/or data tags to cater for repetitive detailed point-to-point changes and comment file entries to provide broader explanation of method and action on part or all of a dataset.

6.2.3 Modifications to Data

Any modification to data shall be:

- conservative
- traceable
- documented
- performed under the guidance of experienced personnel
- described in a time-bounded time stamped comment, and
- quality coded appropriately.

6.2.3.1 Traceability & Data Integrity

The modification of any data shall be accompanied by evidence explanations and comments that ensure traceability and data integrity. All such evidence, explanations and comments shall be permanently stored as part of the station records.

6.2.3.2 Scientifically Defensible Assumptions

All assumptions on which any modifications are made shall be scientifically defensible and recorded.

6.2.3.3 Modifications Explained

Any assumption or explanation of any modification shall be:

- recorded on, or attached to the original data plot that is held in the site file, and
- electronically recorded by a comment in the metadata.

6.2.4 Percentage of Record Required

The goal shall be zero missing record, and it is recommended that the site be built and maintained with the goal of reducing missing record to less than 5 days in only one year out of two consecutive years.

Note: This may require the use of both primary and secondary (back-up) recorders, both of which must be reliable.

6.2.5 When and How to Fill Gaps

The following sections state how gaps or missing record should be handled.

6.2.6 Who Synthesises Records

The agency and staff that collects the data shall wherever possible fill any gaps (missing record) that occur in the data.

6.2.7 Synthetic & Interpolated Data

Synthetic data is contrived data that was not genuinely recorded. Interpolated data is a special case where new data is created only within the range of known data. Thus in hydrometric applications where both time and magnitude are relevant we may synthesise but cannot interpolate a peak or trough but may interpolate between reference readings if confident the actual variation is not a recorded maintained trend and remained within the range of bounding reference values.

6.2.7.1 Application

Synthetic data and interpolation may be used to fill a gap in water level record.

Note: A Comment shall be filed (in the site metadata) that explains the reason for the missing record and comprehensively describes the derivation and limitations of any synthetic data or interpolation.

6.2.7.2 When to Synthesise

Where trained personnel are on-site for the whole period of missing record (e.g. flushing) and undertake manual observations, the gap may be filled with these values and interpolated accordingly.

If interpolation is not possible synthetic data is needed. The decision on the method used to construct synthetic data shall be based on the:

- duration of the synthetic data required
- availability of supporting data from other sites
- availability of primary reference readings from the problem site
- length and quality of the existing record, and
- expected reliability of the synthesised data.

Note: Synthesising missing data is best done when record from the site is available, both before and after the missing period.

Note: Be cautious using data from, or predicting data for sites in catchments where activities may modify the natural flow regime, e.g., wastewater, power station, irrigation.

6.2.7.3 Use of an Adjacent Station

An adjacent station may have been deployed (e.g., near a power station, or by another agency) that has recorded:

- the same data, or
- almost the same data.

Where the station's data and adjacent station's data is effectively the same, the:

- adjacent station may be used as a backup recorder, and
- gap can be filled using the corresponding record from the adjacent station.

A comment containing the details of the relationship between stations shall be filed.

6.2.7.4 Exclusions

Synthetic data other than interpolation shall not be used under any of the following circumstances:

- Where the station is located on a lake that normally has seiche or wind tilt.
- Where the station is a sea-level site.
- Where the resulting plot of the data is inconsistent with the data on either side of the gap.

6.2.8 Archiving Filled-In Data

Any data used to fill gaps in primary record shall be:

- merged appropriately with the record in a controlled manner
- clearly distinguished from the primary data, and
For example, assign an appropriate quality code.
- described comprehensively in metadata.
Include an assessment of uncertainty.

Any recipient of record, or analysis containing or comprising filled-in data shall be:

- alerted to its presence
- informed of the uncertainty involved, and
- supplied with any other documentation required for interpretation of that information.

Note: Quality coding and metadata can be used to express uncertainty.

Note: Other documentation required for interpretation may include, for example, copies of procedures, explanation of codes applied.

6.2.9 Marking Gaps

Gaps shall be filled, whenever possible, to achieve a continuous record. If this is not possible, an explanation shall be provided in the metadata, e.g., comment file, for each period, as to what methods have been attempted and why they have failed.

Note: Future methods, technology or data may permit gaps to be filled at a later date and such guidance will be valuable.

Methods used to fill gaps shall be one of, in decreasing order of preference:

- Backup data from site
- Interpolated data at site
- Adjacent station data
- Hydrological or hydraulically modelled, correlated, estimated by other means

Metadata shall include comprehensive details of:

- period
- method
- other sites and data used
- description of models
- statistical confidence, and
- expected reliability of filled-in record.

6.3 Telemetry Data

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. This is achieved by various methods such as radio, cell and satellite 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 channel control, and
- sedimentation problems e.g. orifice burial or silting of the stilling well.

Note: The system should be used to its maximum capabilities in this respect as it can save on missing record and minimise expensive return trips to repair faulty equipment by identifying a fault early and then getting to the site quickly.

Remote station configurations may also be changed via telemetry. New sampling programs may be uploaded to the remote logger from the office. Sensor scaling and offsets may be applied at the telemetry base, or a combination of both. Systems may have automatic update capabilities e.g. remote clock synchronisation with base.

Note: It's good field practice to routinely download the data log.

The following conditions apply to telemetered data:

- The data shall be coded as QC 200 (raw) until verified.
- Implemented automatic features must be described, and changes to those features controlled and tracked in the station history and metadata.
- Performance of automatic features shall be checked regularly, e.g., confirming each field station time is correct during daily system checks.
- Ad-hoc changes applied at or initiated from base, e.g., rescaling a sensor or changing a sampling method, must be controlled and documented in a manner equivalent to making the change on-site.

Note: An 'office' logbook kept by the telemetry base is useful for this purpose.

Note: There could be multipliers in the data at the base/or field station which need to be documented and carefully controlled.

6.4 Preservation of Record

6.4.1 Performance

The following data shall be archived and retained indefinitely:

- Final checked and verified data
- Unedited raw primary and backup data
- Associated metadata, including;
 - data comments
 - site details
 - recording accuracy and resolution
 - station history inspections and surveys of references
 - equipment calibration history, and
 - any other factors affecting data quality.

All original records, annotations and supporting data shall be retained indefinitely by the recording agency.

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

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

6.4.2 Comments

An essential part of any hydrometric metadata is a file of appropriate site and data comments. These describe in time-stamped text format:

- information about the site, station and characteristics of the data
- alerts and supporting information intended for end users of the data, and
- aspects not easily quality coded or otherwise quantified in point detail.

Note: Current software packages provide several ways to build a database of comments. Comments can be entered into an unstructured file of text. If the comments are entered into an ODBC (Open Database Connectivity) database, they can be accessed by any ODBC compliant software. Therefore this method is recommended.

Comments are very useful to explain unusual features or events in the record that users of the data should be aware of. In addition, routine comments are required for key information. These should include, but not be limited to:

- the site details:
 - Site purpose
 - Recording agency/ies
 - Site location in coordinate system supported by Land Information NZ
 - Site name and past and present aliases
 - Names and/or indices of relevant environmental features (river, lake, coast)

Note: Lat/Long coordinates e.g. WGS84 must be minimum 6 decimal places.

- the start and end date of site and record
- related sites and records
- reference to the standard used
- sensor and recorder details including media, for example, specifications of:
 - chart
 - tape
 - datalogger
 - storage card, and
 - telemetry capability .

Note: Use terms and references defined, and types as described in these standards rather than brand names, models or serial numbers so future users need only refer to this Standard to interpret the comment

- instrument relocation dates
- data capture and/or retrieval method, for example:
 - digitised
 - manual CSV import, or
 - telemetered.

- calibration results

Note: It is preferable to use an agency instrument/asset management system.

- information about:
 - legal requirements
 - confidentiality agreements,
 - intellectual property, and
 - any other restrictions related to data access.

Comments relating to gaps, missing record, synthetic record and time related events that affect the data are also required in a standard format.

All comments shall be time stamped at the start of the interval to which they apply e.g. a gap or synthetic data comment will be filed one recording interval after the last actual data collected, and an event comment at the time of the event.

Comments covering the accuracy of data and gaps in records should be informative, coherent and identify the period(s) for which the data are suspect or missing. For examples of these types of comment formats, see 'Annex G – Comment/Metadata Template'. Where quality coding is implemented and suitably identifies affected data, comments about repetitive events and/or repairs to data may be aggregated to avoid overwhelming the comment file.

6.5 Quality Assurance

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

Note: This is to ensure standardisation of data-sets that enable meaningful analyses and comparison of water level data within regions, across regions and nationally.

6.5.1 Audit Cycle

Quality assurance processes shall include at a minimum, an audit of the data:

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

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

Unaudited data that is released for use shall be identified as being unaudited.

Note: Stations other than those under review may be included in the audit to help with comparisons. Where available, reliable records from stations operated by other agencies may be used.

6.5.2 Minimum Audit Report Requirements

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

- catchment and site details
- comments and quality coding
- data tabulations
- data plots
- comparisons, and
- annual station inspections.

6.5.2.1 Catchment and Site Details

The following two items shall be included in the audit report:

- Catchment Details Summary
- A location map, with all relevant station locations identified

The catchment details summary shall:

- identify the catchment or region
- include associated rainfall stations if available, and any stations used for comparisons, and
- for each station, identify:
 - the period of record covered
 - the station name and number
 - map reference
 - altitude, and
 - sensor type.

6.5.2.2 Tabulations

The following tabulations shall be included in the audit report:

- Listing of gaps
Note: This should be compared with the listing of comments.
- Listing of comments
- Extremes - of stage height for the full period.

6.5.2.3 Data Plots

The following data plots shall be included in the audit report:

- Station Plots
 - for period under review plus the year prior.
 - Full scale of data recorded
 - Partial range to permit inspection of low to medium levels (usually sufficient to trim range at upper quartile of stage recorded)
 - For decade i.e. period under review plus previous years to make ten in total; full scale and partial range
- Decade Stage Height Plots
Note: Include both full range and a partial range, and with the previous years to make 10 years.
- Comparative Plots
Note: it is left to the review compiler's discretion to choose and present a method of comparing against at least one other station (flow, rainfall, gate openings) to demonstrate that there are no obvious anomalies in the record. Statistical techniques such as double mass curves, direct comparisons of parameters, or relationships between parameters (e.g. addition, subtraction, correlation) may be employed.

6.5.2.4 Annual Station Inspections

Annual station inspection results that cover the period under review shall be included. Where applicable, the most recent results, and the most recently prior results shall also be included.

6.5.3 Other Requirements

6.5.3.1 Outputs

Recommended report outputs include:

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

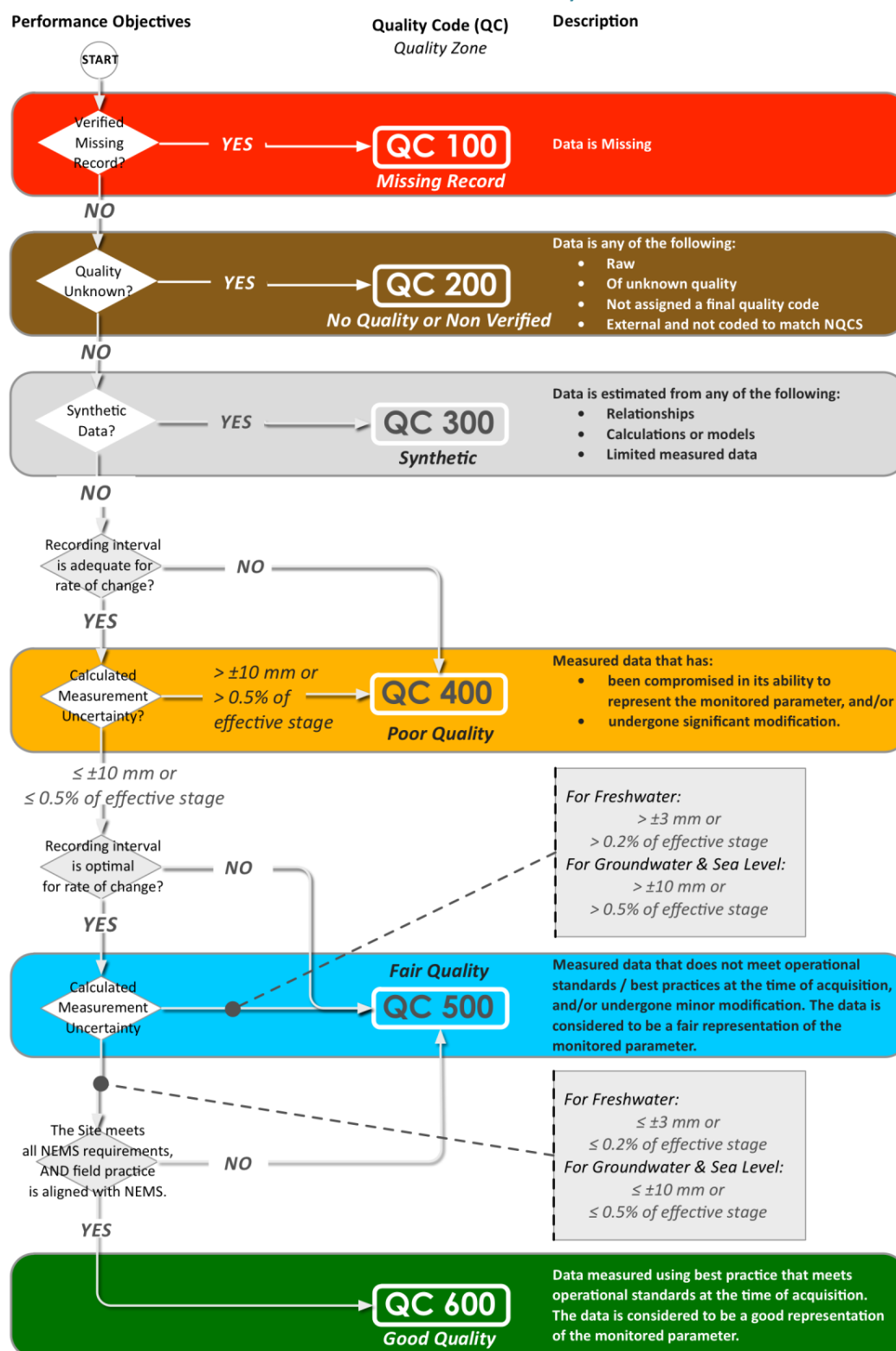
6.5.3.2 Audit Certification

The completed audit shall contain the name and signature of the auditor and the date that the audit was completed.

6.5.4 Quality Codes

All data shall be quality coded in accordance with the National Quality Coding Schema. The schema permits valid comparisons within a data series and across multiple data series. Use the following flowchart to assign quality codes to all water level data.

Table 2 – Water Level Quality Codes



Annex A – List of Referenced Documents

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

ISO 1438 (2008) *Hydrometry -- Open channel flow measurement using thin-plate weirs*

ISO 772 (2011) *Hydro Terminology*.

NEMS (2012) *Open Channel Flow Measurement – Measurement, Processing and Archiving of Open Channel Flow Data*. National Environmental Monitoring Standards, New Zealand

USGS (2010) *Stage Measurement at Gaging Stations* (Chapter 7 of Book 3, Section A).

NZS 4411:2001 Environmental Standard for Drilling of Soil and Rock

NIWA (2012) *Hydrometric structures, Part A: Design guide for timber footbridges*.

Ministry of Works (July 1958) *Standard specifications for automatic water level recorder installations and current meter gauging stations*.

Walter, K. (2000) *Index to hydrological recording sites in NZ* (NIWA Technical Report 73).

Annex B – Procedures

Installing an Electric Plumb Bob

Although a simple device, the installation of a plumb bob requires some thought and care.

Before You Begin

Before installing an electric plumb bob, ensure that you have sufficient tape to measure the amount of siltation at the bottom of the well.

To install an electric plumb bob:

1. Mount the reel assembly.

Mount the reel assembly over the stilling well where it will not touch the recorder float, pipes or the side of the well. It should also be in a position that can be easily reached and where the meter and index point can be easily read. A good approach is to screw it to a piece of 150 x 25 mm timber that has been bolted across the back wall of the housing.

2. Mount the battery.

Use a suitable power source.

3. Attach the battery.

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

Note: Either use the stilling well or the bolts connecting the housing floor to it or, in the case of concrete or fibreglass stilling wells a ladder, pipe or purpose-built earth (perhaps a weighted length of copper wire).

4. Fix the zero (or - 1 m) end to the reel.

Ensure this stage height value is at least 0.5 m below the lowest intake pipe and preferably at or below the bottom of the well. This will enable sounding of sediment levels as described above.

If not, add in a length of strong plastic-coated wire or similar, marked each 10 cm.

5. Temporarily fix the plumb bob to the other end of the tape

Ensure the adjusting screw is at its approximate mid-point. Check the electric plumb bob to ensure it is working.

6. Set up a level.

Set it up in a position where the plumb bob can be sighted through a hatch or inside the recorder housing.

7. Take the backsights.

Take a backsight on a benchmark, an intermediate on the well or river water-level and calculate the reduced level of the height of instrument (H.I.)

Calculate the reduced level (H.I.) by adding the staff reading to the benchmark's R.L. Use a water-level shot as a check.

8. Convert the H.I. to a stage height equivalent.

Subtract the recording zero (noted in the Station History) from the H.I reduced level..

9. Take an electric plumb bob reading.

Take the reading with the bottom of the plumb bob at the cross-hairs of the level.

This will require one person observing through the level with another person operating the electric plumb bob.

10. Subtract the stage height equivalent of the H.I. from the electric plumb bob reading.

Result: This will give the length of tape that must be cut off.

11. Using the graduations on the tape, measure back this length and cut off the tape.

12. Remount the plumb bob at this point.

13. Observe the tip of the plumb bob.

Observe through the level and use the electric plumb bob adjusting screw for fine adjustment to bring the tip of the plumb bob to the tip of the cross-hairs.

14. Tighten the locknut firmly.

What's Next

Check the electric plumb bob reading of water-level against the staff gauge and the levelled values.

Troubleshooting

Problem	Possible Cause	Resolution
No Power	Battery may be flat.	Check the battery and replace if flat.
No Power	Wires may be loose.	Check that the wires in the circuit are not loose or corroded. Reconnect wires if loose or no longer connected. Replace wiring if corroded.
Electric plumb bob not working	Earth connection has corroded. <i>Note: The earth connection always seems to corrode; sometimes just by leaving the battery connected, not withstanding that the operating switch is left off.</i>	Test by touching the disconnected earth wire across the electric plumb bob tape with the operating switch closed. However this needs to be done very briefly as it will put a lot of current through the milliammeter. If there is trouble getting a good earth, install a weighted length of copper wire down into the well. If the needle on the meter deflects in the wrong direction, reverse the battery polarity
Poor electric plumb bob reading	Corrosion may form on the tip of the plumb bob.	Scrape or sand any corrosion off the plumb bob.
Electric plumb bob Reading is Lower than Expected	The insulating sleeve around the plumb bob has slipped down, creating an air pocket that will give a low reading.	Check the insulating sleeve, reposition and fix back in place. Could also be removed if needed.
Electric plumb bob always reading on	The steel tape may have shorted against the recorder floor. Damp timber floors can cause shorting.	Install a plastic guide ring.
Other electric plumb bob problems?	If the axle of the reel is lubricated with oil, this may insulate the reel.	Do not lubricate with oil or graphite. If having problems, the fibre washer in the clutch can be removed and this will improve the electrical connection.

Annex C – Hydrological Station History Form

The following 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: km²
 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

Type and Description	Date Constructed	Date Removed	Date Updated	
			Initials	Date

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

[illegible]

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 – Annual Station Inspection

Checklist for Annual Station Inspection

☐ Form Heading

Provide, for example, the site number, 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, 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 details of this levelling check, along with the start BM. State name and RL of the start BM to the survey datum used.

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.

☐ 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 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 and Sensors

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.

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.

Check vented wet transducers are fitted with dry-boxes or bottles that are regularly serviced and currently functioning. Ensure gas supply systems e.g. compressors are drained and/or dry.

Check the transceiver surfaces of any non-contact instrument are clean and undamaged, signal paths are clear, and their mountings are secure.

☐ 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, 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.

☐ Recorder Operation

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

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

Review the logbooks; they should be filled in properly and be legible.

☐ Power Supply

Consider whether adequate. Test the voltage during a reading and 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.

☐ Float Systems

Raise the float and check it for leaks, growth, 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 is undamaged. Ensure that the logger resumes its correct reading, and beware of setting off alarms. Sound the depth of sediment in the well.

☐ 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 river bed 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 which 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 calibrations where required are current for instruments on site.

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

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

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

A Manager should ensure that:

- The inspection has been carried out correctly
- Any work required is done or is in the team's work programme
- The completion of the work required is noted on the Inspection form
- The completed form is filed

☐ Certify Correct

Certify that the Annual 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 Inspection form.

Annex E – Schedule of Station Visits

Routine Station Visits and Checks

Stations will be visited 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.

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, notifications, 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 staff gauge or reference level pins. If no suitable reference exists survey the current water level.

☐ Clear the Site

Clear any growth or debris, clean the staff gauge plates and weir crest, and note any change to the staff gauge reading. Enter details of what was done and all readings in the logbook.

☐ Connect Logger

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

- Logged stage readings agree with the staff gauge reading to within the tolerance defined for the sensor and range.

Note. Any difference may signal that a change is required to the offset (or sometimes a correction to the scaling) of a pressure, acoustic or radar sensor, or the encoder needs adjustment. However, 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.

- Velocity measurements are sensible, and/or agree approximately with a current meter spot measurement (see below).
- All other parameters in the logger, including time, appear accurate and sensible.
- If not telemetered, download the logged data, taking a backup on separate media (memory stick) then inspect the data for evidence of problems that might be fixed or further diagnosed while on site.

☐ Carry Out Gauging

As required to either define rating shape, confirm that it is stable, or track a change in the control and thereby establish a new rating, carry out a gauging.

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 several hours, or into the next day to ensure you are gauging in stable hydraulic conditions.

☐ Check Bubbler Gas Pressure

Ensure there is sufficient gas supply (chamber pressure gauge e.g. gauge on bottle if stored supply). Ensure regulated pressure to the bubbler (feed pressure gauge between regulator and bubble unit) is set at the manufacturer's recommended pressure for correct operation of the sensor. Note gauge readings in the logbook.

Note: When using industrial gas bottles the pressure (gauge closest to the cylinder) should be in the range 0kPa (empty) to 20,000kPa (full) and the regulated pressure to the bubbler (gauge furthest from the cylinder) should be at 400 ± 20 kPa.

☐ Measure Battery Power

Measure the battery power supply voltage with a multi-meter and read the charge voltage if applicable. Note these in the logbook.

☐ Check Instrument Housing

Check the instrument housing for damage, leaks, insects, vermin and birds.

Clean and repair as necessary, including solar panels and aerials if fitted.

Similarly, check all cabling, gas lines and their protection and change dry-boxes/bottles if installed.

Check wells for evidence of habitation e.g. nests, eels. Note any requirements for the next visit on the logbook page.

☐ 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 3000kPa. 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 well or pipes may be blocked with silt and continue until the pipes run clear. See Annex F for detailed procedure.
- **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 (phone the office and ask for a data retrieval) or download the most recent data to a laptop, taking a backup on separate media (memory stick).
- **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

Avoid sensor damage by ensuring the valves are operated in the correct sequence when purging, otherwise the pressure sensor may be damaged.

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 that should be readily visible in all but high flows. No bubbling may mean that the gas line is well blocked or you have wrongly operated the valves.
- 3. Once you have observed it purging, turn off the red valve.**
- 4. Wait for at least 30 seconds.**
This allows time for the line pressure to normalise.
- 5. Turn on 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 significant changes to installation, site, controls and surroundings. Photos must be date-stamped and properly indexed and archived as part of the Station History.

☐ Record Comments

Comment on accuracy and reliability of the 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 the accuracy of data.

☐ Store Logbook Page

Before leaving, remove and safely store the logbook page, and/or electronic file, for delivery to the office.

Annex F – De-Silting Stilling Wells

Stilling wells and intake pipes can be subject to deposition of sediment within them that prevents free flow of water between the river and well, causing well water level to be different from that in the river. Excessive build-up may block pipes completely and stop water from entering or leaving the well, and may eventually interfere with the float and counterweight.

Silting of intakes and wells can be a significant cause of substandard data. A planned programme of detection and prevention is essential. An investment in effective flushing systems and equipment is likely to be most worthwhile.

Prevention

The most effective prevention is by design when siting and building a stilling well:

- The lower intake pipe shall be at least 200 mm and preferably 500 mm above the bottom of the stilling well.
- Use a ratio of 1:12 between intake pipe and stilling well diameters (this is a nominal ratio, because it will be greatly influenced by the number of intakes and their length. for more information, see 'Annex I – Intake Pipe Dimensions'.
- All construction joints of the well and intake pipes shall be watertight.
- A convenient flushing system should be designed, incorporating a means of closing off the static pipe at the stilling well end.

Detecting Silting

Effort shall be applied to detect silting before it becomes evident in the record. Once evident in the record, the period affected will not meet the QC 600 standard.

Detect silting by:

- using a device such as a crowbar on a length of rope to sound the depth of sediment in the well
- routinely using the electric plumb bob to sound the depth of sediment in the well, and *In the instrument housing, display the stage height equivalent of the bottom of the well and the invert of the lower intake pipe, so depth of silt and the "freeboard" left can be estimated.*
- observing the amount of surge if it is a characteristic of the site.
This is usually most obvious during high-flow events 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 1mm, then the intakes can be assumed to be clear.

Sediment checks of the well and intake pipes shall be carried out as part of routine station visits, and after high flows that may have deposited sediment.

Flushing

This process is an important part of operating a water level recording station equipped with a stilling well. All such stations on rivers should be flushed at least annually as preventive maintenance, and more frequently if on rivers that carry a lot of suspended sediment.

Well and intake pipes may be flushed together, however as the intake pipes are the most important but the hardest to inspect, these may be done separately and more regularly.

The various methods are:

- Installed Flushing Systems
- Modified Flushing Systems
- Portable or Manual Flushing Systems

Installed Flushing Systems

Valve and pipe systems fed by header tanks can be fitted in to some recorder stilling wells.

The system consists of a valve on each intake pipe at the stilling well end, usually capable of operation from the top, which will close off the intake pipe from the well. On the river side of the valve, a pipe tee connects in a header tank. In operation, the valve or valves are closed, the header tank is filled and then the water released into the intake pipe(s) to flush them.

Although the volume of water in the internal tanks 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 well will need to 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 will enable considerable pressure and a large volume to be applied to the intake pipes to flush them effectively. Towards the end of the flushing, the valves could be opened with the pump still operating to clean them of silt also.

Note: Re-plumbing of the ex-header tank pipe could be done in galvanised pipe or a suitable plastic pressure hose, and it could terminate inside or outside the stilling well. Using a quick release coupling for the pump hose such as a "Camlock" brand fitting will be convenient.

Portable or Manual Flushing Systems

Connecting a Pump to the Static Tube

This can also be an efficient means of flushing the intake pipes, although it 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 to remove the static tube and crease the end of the hose so that it can be inserted 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 thus 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 all that is required. 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 emerging from the lower intake.

Flushing the Well

The bottom of the stilling well operates as a reservoir for silt, which shall not be allowed to approach the elevation of the lowest intake pipe. Silt shall be regularly removed to prevent this.

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 also.

With larger quantities or heavier particles this does not work well and alternatives can include:

- one pump delivering water in and stirring up the sediment as 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, or
- with the intake pipes blocked off, using a suitable pump, e.g., a diaphragm pump, to remove the thick silt and water mixture directly.

Note: 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. The pump manufacturer's specifications should be consulted to avoid high repair costs.

- entering the well and scooping out sediment directly, such as with a bucket on a rope

Note: This is a "last-resort" method after all other alternatives have been considered and/or attempted. It can be effective but often laborious. Health and Safety regulations with respect to entry of confined spaces 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 bucketfuls by rope over a person down a well, which is unacceptably dangerous.

Annex G – Comment Template

The following is an example of comments associated with a River or Lake Station and the information required to go with the data.

INITIAL COMMENT for ***** River at *****

Site number ***** on river *****

The site is situated *** km from the mouth at grid reference (*Specify coordinate type here – NZMG/NZGD – eastings/northings WGS84 Lat/Longs etc.*)

Drains ***** km² and controlled by *****

Additional information: i.e NIWA installed the recording sites for Genesis Energy to monitor flows for resource consent requirements.

The local recording authority is: *****

INITIAL COMMENT for the GAUGING STATION:*****

On the ***** River, river number *****

The station is situated at grid reference *****

Gaugings above stage height ***** mm are carried out by slackline cableway

Units, unless otherwise stated, are

- 1) Mean stage height in mm
- 2) Discharge in l/sec
- 3) Area in square cm
- 4) Mean velocity in mm/sec
- 5) Maximum depth in mm
- 6) Water surface slope in mm/1000m
- 7) Water surface width in mm
- 8) Hydraulic radius in mm
- 9) Wetted perimeter in mm
- 10) Sediment concentration in mg/l
- 11) Water temperature in degrees Celcius times 1000
- 12) Stage change code
- 13) Gauging method code (ccnn) where cc = method and nn = number of verticals
- 14) Number of verticals and sample points
- 15) The gaugings theoretical uncertainty (%*10)
- 16) A flag to indicate a comment was filed
- 17) A code number for the agency that carried out the gauging
- 18) Gauging number

The format changed from 15 items to 18 items in 2005; most gaugings prior to 2005 will not have gauging uncertainty (item 15) or a comment flagged (item 16).

The gauging is filed at the time of mean stage height.

-1 indicates missing data.

The local recording authority is NIWA, *****

RECORDER INSTALLED on 17-Sep-1997 (13:45) is a DAA 500xl datalogger with a recording interval of 15 minutes. The level sensor is a Unidata Encoder with Tait 8110 radio telemetry. The recorder has a water-level resolution of 1 mm.

BACKUP RECORDER INSTALLED on 17-Sep-1997 (13:45) is a Hydrologger 2001 with GPRS telemetry and the same resolution of 1 mm.

RATING COMMENT as at 1-Jan-2009

Maximum gauged flow is 35.2 m³/s (stage height 2.468 m)

Maximum recorded flow is 71.1 m³/s (stage height 3.119 m)

Minimum gauged flow is 1.25 m³/s (stage height 0.745 m)

Minimum recorded flow is 1.05 m³/s (stage height 0.680 m)

Mean velocity at maximum recorded flow = 2.8 m/s
MISSING RECORD from 15-Sep-2008 (02:15) to 7-Oct-2008 (10:15) due to failure of the Hydrologger.
The Hydrologger stage values are erratic and not sensible over this period and have not been included in the data.

BACKUP RECORD used from 18-Nov-2000 (12:15) to 7-Dec-2009 (14:15) due to failure of the primary Neon datalogger.

Comment options are:

Comment type: Site
Equipment
Data
Rating
Miscellaneous

Data type: All
Series
Gauging
Rating

Site Type: Flow-Level
Level Only
Rainfall
Water Quaility
Groundwater
Climate
Sediment
Air Quality, Misc

Annex H – Calibrated Structures

Weirs and Flumes

Weirs are essentially barriers constructed across a channel so that the upstream water level is contained by the structure and the bed is low enough on the downstream side so that free-fall occurs between the two.

Flumes consist of a symmetrical constriction in the sides or bottom of a channel, which for a particular range of flow, cause critical flow to occur within the channel.

Critical Flow

Critical flow is a condition that occurs at the crest of a free-fall, or other situations such as fast-flowing turbulence where standing waves are formed.

The relationship between depth at critical flow (the "critical depth") and velocity can be found from the definition of the Froude number, which for a rectangular cross-section of uniform depth, simplifies to a function only of depth.

$$F_r = \frac{v}{\sqrt{gd}}$$

where:

F_r is the Froude number (dimensionless)

v is the mean velocity, in m/s

g is the gravitational constant, 9.81 m/s²

d is the water depth in metres

Because the Froude number of critical flow equals 1.0, velocity and thus discharge can be calculated from a measurement of critical depth. The above formula can be rearranged to give the velocity at critical flow, v_c as

$$v_c = \sqrt{gd}$$

Note: This is very similar to the (simplified) formula for velocity of a free-falling object, $v^2 = 2gh$, and is, not surprisingly, derived from it.

Weirs

There are a number of standard weir designs, each having specific limitations and discharge formula. Each type is outlined below, with only the most common type, the thin-plate V-notch, being covered in more detail.

The main types of weir include:

- Thin-plate V-notch weirs that are suitable where the ratio of high to low flow is large, and where accuracy at low flow is important.
- Thin-plate rectangular weirs that are less sensitive and thus less accurate at low flows
- Broad-crested weirs that are in common use, but more as bed controls which are wholly field rated, rather than used as calibrated weirs
- Triangular profile weirs that consist of a low dam built across a waterway, normally with a 1:2 slope on the upstream face and a 1:5 slope on the downstream face
Suitable for natural watercourses where minimum head losses are sought, and where there is a relatively high sediment load.
- Flat-V weirs (**Error! Reference source not found.**) that are a modification of the triangular profile weirs with a shallow 'V' cross-section of 1:10 side-slope when viewed in the direction of flow.

Note: The "Crump" weir is of this type. They are more sensitive than the horizontal-crested triangular profile weir. They are expensive, particularly if erosion is liable to occur downstream necessitating protective works.

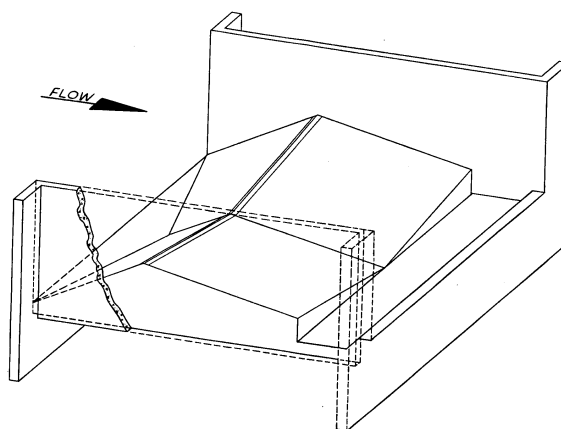


Figure 14 – Flat 'V' Weir (Crump)

Reproduced with permission from NIWA field manual.

Thin-Plate V-Notch Weirs

Thin-plate v-notch weirs are a versatile design that in various configurations, have been widely used.

Normally they consist of a thin concrete wall with a sharp metal crest. In smaller versions, the entire structure may be constructed of steel or alloy plate.

Free -fall of water over the crest at all flows i.e. an aerated nappe, is essential for the theoretical rating to hold.

Thin-plate weirs are well suited for temporary installations.

Weir Terminology

A weir is a barrier across a channel, which controls the water-level upstream of it so that there is free fall through the weir to the water-level downstream of the weir.

Upstream is the head-water, and downstream the tail-water. There should be free-fall between these two. This falling body of water between the head and tail water is called the nappe. If the nappe does not contact the structure it is said to be aerated.

When the tail-water rises above crest level the weir is said to be drowned. A weir intended to operate in this drowned condition at all times is called a submerged weir, and special conditions apply.

When a weir constricts the width of the channel the parts of the barrier between the weir crest and the river banks are called 'end contractions'.

A weir crest that occupies the full width of the channel is termed a fully suppressed weir, i.e., the end contractions are suppressed.

When a narrow weir is placed in a wide channel, and the banks of the approach pool have no effect on the flow through the weir, it is said that the contraction is fully developed.

Stage Discharge Relationship and Weir Formulae

Weirs and flumes are commonly called "pre-calibrated" but almost always require field rating, usually by volumetric or other gauging methods, to establish that the actual stage-discharge relationship conforms to the theoretical rating. (Refer: NEMS (2012) Open Channel Flow Measurement).

Because flow accelerates to critical velocity over the weir, a drawdown in water level exists for a short distance upstream. Accordingly the head measurement must be made at a sufficient distance upstream to avoid this area of drawdown.

Many weir formulae calculate discharge using equations that assume acceleration from rest, i.e. the starting velocity or velocity of approach must be relatively low. This is accomplished by constructing a sufficiently large weir pond upstream.

Such equations therefore only apply under those conditions of low or zero approach velocity; conditions which are commonly exceeded during higher flows unless the weir pond is sufficiently large.

Both weirs and flumes can be affected by approach and backwater conditions being less than ideal, by leakage and by sediment and debris carried in the flow.

Why Weir Formulae Work

$$v^2 = 2gh \quad (1)$$

Water dropping over a free-fall obeys this universal formula. The head h in this case is the loss in head that occurs between the upstream water level and the elevation of the water at the point of critical flow.

From the above it can be seen that if the depth at critical flow over a weir could be measured and subtracted from the upstream water level to give h , the velocity could be calculated; and with the depth known, all that remains to be added to the formula is the width.

Fortunately we are spared the difficult task of measuring depth at that elusive point because there is a relationship between critical depth and the upstream water level (head). For a simple broad-crested weir for instance, the depth at critical flow is $\frac{2}{3}$ the upstream head H . Therefore the head h in the basic formula is $\frac{1}{3}$ of the upstream head H .

From the basic formula of discharge,

$$Q = W \text{ width} \times D \text{ depth} \times v \text{ (velocity)}$$

$$\text{if } v = \sqrt{2gh} \quad \text{from (1) above,}$$

and we substitute $\frac{2}{3}H$ for the depth and $\frac{1}{3}H$ for the loss in head h , then:

$$Q = W \times \frac{2}{3}H \times \left(2g \times \frac{1}{3}H\right)^{1/2}$$

substituting 9.81 m/s^2 for g and calculating out gives us

$$Q = 1.70 W H^{3/2}$$

Other weirs have similar basic formulae to this, but with different relationships between head and critical depth, and with additional coefficients for the contraction effects of the various types of orifice.

V-notch, Thin-Plate Weirs

The most common and the most accurate of weir designs are the sharp-crested or thin-plate weirs that come in a variety of forms.

Note: The V-notch consist of a relatively thin wall across the stream with a straight sharp crest, and a cross-section profile of one of a number of more or less standard designs, as depicted below. The construction is usually of concrete with a steel or aluminium alloy crest, or of steel or aluminium plate.

Configurations of V-Notch Weirs

The angle enclosed by the straight sides of the V is usually one of a number of standard angles, such as 150° , 120° , 90° , the half-90 and the quarter-90.

Note: The terms half-90 and quarter-90 do not mean 45 degrees and 22.5 degrees but in fact refer to the area for a given head of water above the "apex". The actual angles are 53 degrees 8 minutes and 28 degrees 4 minutes.

V-notch weirs are particularly suitable for the accurate measurement of flows up to about $1.4 \text{ m}^3/\text{s}$. They can be used for greater flows if they are combined with another design that can accommodate the larger flows.

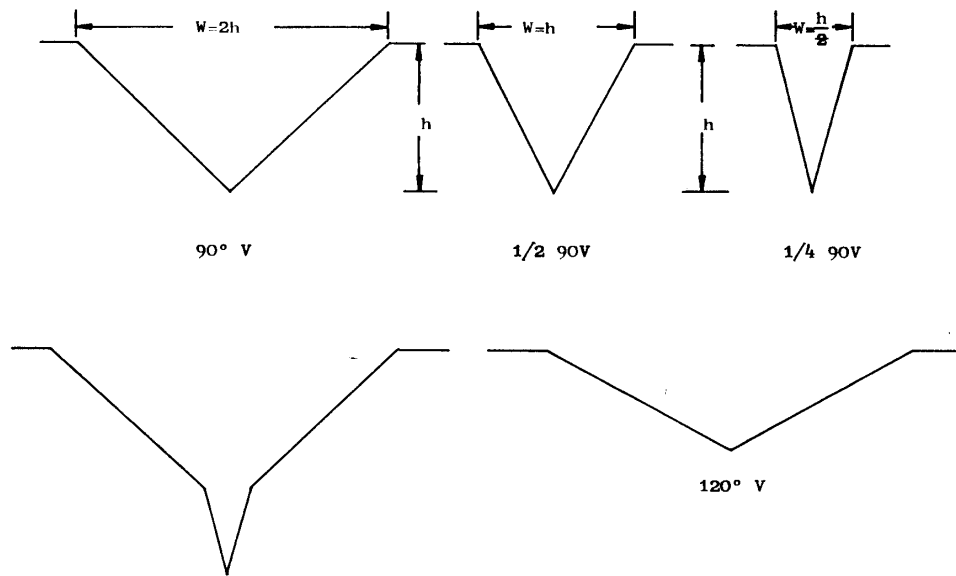


Figure 15 – V-Notch Weir Cross Section Profiles
 Reproduced with permission from NIWA field manual.

V-Notch Weir Specifications

The specifications for a V-notch thin-plate weir as set down in ISO 1438 (2008) are:

- Symmetrical V-shaped notch in a vertical thin-plate.
The line which bisects the angle of the notch shall be vertical and equidistant from the sides of the approach channel
- Smooth and plane, especially on the upstream side.
- Perpendicular to the sides as well as the bottom of the channel.
A "smooth" surface shall be equivalent in surface finish to that of rolled steel
- The crest surfaces shall be plane surfaces of width between 1 and 2 mm, which shall form a sharp right-angled edge at their intersection with the upstream face of the weir plate.
These surfaces shall be machined (or filed) perpendicular to the upstream face. The edges shall be free from burrs and scratches, and untouched by abrasive cloth or paper (these will tend to round the edges unacceptably).
- The downstream edges of the weir shall be chamfered if the weir plate is thicker than the allowable crest width. The surface of the chamfer shall make an angle of not less than 45 degrees, and preferably about 60 degrees, with the crest surface.
- The weir plate is usually made from corrosion-resistant metal.

V-Notch Weir Formulae

The general formula for a V-notch weir (ISO 1438:2008) is

$$Q = \frac{8}{15} \sqrt{(2g)} \cdot C_e \cdot \tan a / 2 h_e^{5/2}$$

where:

Q = Discharge in m^3/s

g = the acceleration due to gravity (9.81 m/s^2)

C_e = the coefficient of discharge (corrects for head loss and contraction; see below)

α = Notch angle in degree

h_e = effective head in metres (see below)

The coefficient of discharge C_e has been determined by experiment as a function of three variables, h/p , and p/B , where:

- p is the height of the vertex of the notch with respect to the floor of the approach channel
- B is the width of the approach channel, and
- h_e is defined by the equation, $h_e = h + k_h$

In which h is the measured head and k_h is a correction applied to compensate for the combined effects of viscosity and surface tension. The value of k_h varies according to notch angle; for fully contracted notches, a sample of values is given in the table below.

For weir notches that are small relative to the approach channel, the velocity of approach will be negligible and the effects of h/p and p/B are also negligible. For this condition (the fully-contracted condition), Table 1 provides values as a function of α for selected angles.

Table 1 –Values of C_e and K_h for some notch angles for weirs with negligible velocities of approach

α (degrees)	40	60	80	90
C_e	0.582	0.576	0.576	0.578
K_h (mm)	1.8	1.2	0.9	0.8

This information has been obtained from ISO 1438 (2008).

Application of the V-notch Weir Formula

Practical limitations applicable to the use of this formula can be seen in the following illustration:

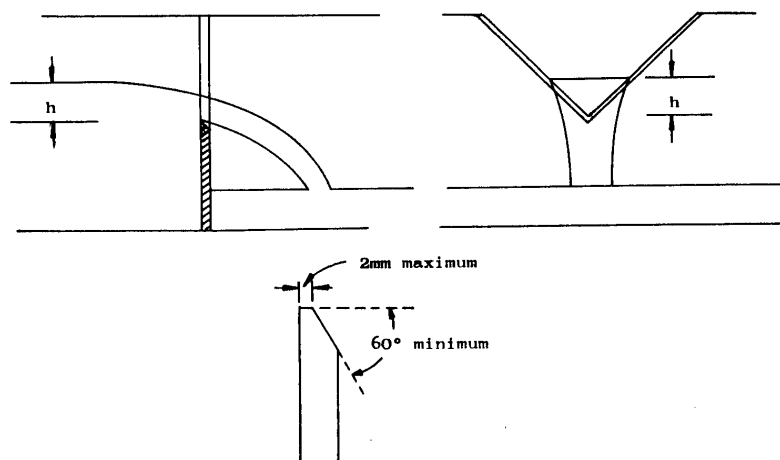


Figure 16 – V-Notch Dimensions

Reproduced with permission from NIWA field manual.

For the basic configuration of the V-Notch thin plate weir:

- α shall be between 20° and 100°
- h/p shall be less than 2.0 for $\alpha = 90^\circ$; h/p shall not be greater than 0.35 for other values of α
- p/B shall be between 0.1 and 1.0 for $\alpha = 90^\circ$; p/B shall be between 0.10 and 1.5 for other values of α
- h shall be not less than 0.06 m, and
- p shall be not less than 0.09 m.

Formulae for Specific V-Notch Angles (Fully Contracted Weir)

For V-notch weirs of full-90, half-90 and quarter-90 angles, the BSI formula in ISO 1438/1-1980 (E) is recommended:

$$Q = \frac{8}{15} C \cdot \tan \frac{\alpha}{2} \cdot \sqrt{2g} h^{5/2}$$

The experimentally determined values of Q and C are shown in Tables 1, 2 and 3 of that document.

There are also practical limitations on the application of this formula that are related to the dimensions of the structure and the approach channel; these should be examined before using it or designing a weir.

Flumes

Flumes consist of a regular artificial channel with symmetrical contractions in the sides and/or bottom, which, for a particular range of flow, cause critical flow and thus a standing wave to occur within the channel.

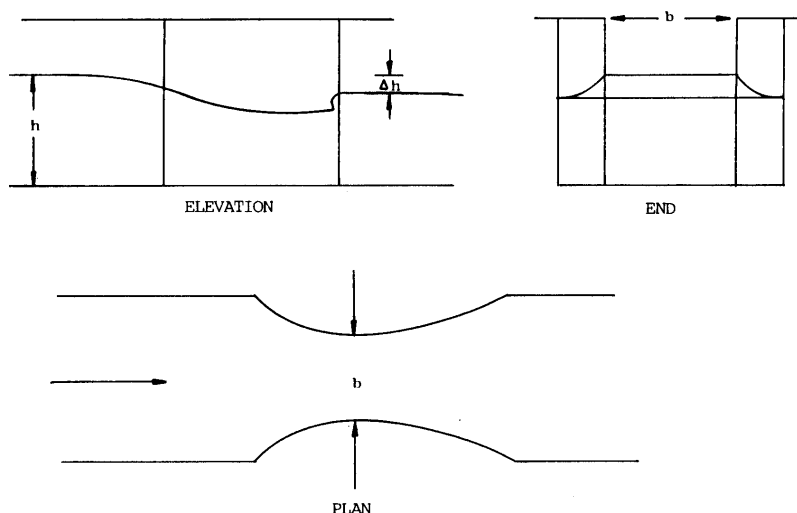


Figure 17 – Typical Flume

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Rectangular Flumes

These are also known as rectangular "standing wave" or "critical depth" flumes. They consist of a symmetrical constriction of rectangular cross-section, positioned centrally with respect to the approach channel, which will also be of rectangular cross-section.

The contractions can be either side or bottom contractions, or both.

Selection of a suitable design and site depends upon the channel configuration, the approach channel length (10x width required), the desired head loss and any downstream limitations. Rectangular flumes are almost universally used for measuring the inflow to sewage treatment works.

Trapezoidal Flumes

The trapezoidal flume differs from the rectangular flume by having a throat, entrance and exit of trapezoidal cross-section. Their application is also similar to rectangular flumes, being preferred if it is necessary to accommodate the structure in a trapezoidal channel. They can give relatively high accuracy over a wide range of flows.

U-throated Flumes

These are essentially a round-bottomed version of a rectangular flume. They are more sensitive in the lower range, and are better suited for some situations, for example in sewage systems where the flow enters from a pipe.

Venturi Flumes & Parshall Flumes

These contain a constriction that, in sub-critical flow, causes an increase in velocity and a consequent fall in water level. A measurement of two water levels, upstream and at the constriction, allows a calculation of the discharge.

H-Flumes

The H-Flume is a hybrid of the V-notch weir and a rectangular flume, and was developed mainly by the U.S. Department of Agriculture. Like weirs it requires free-fall over the lip, and is sensitive at moderate flows but not at low flows. Compounding it with a small angle V-notch weir downstream is one way used to overcome this problem. An advantage is its self-cleaning property, similar to a rectangular flume.

As for other flumes and weirs, the theoretical rating will require extensive field checking. The configuration of an H-flume is shown below.

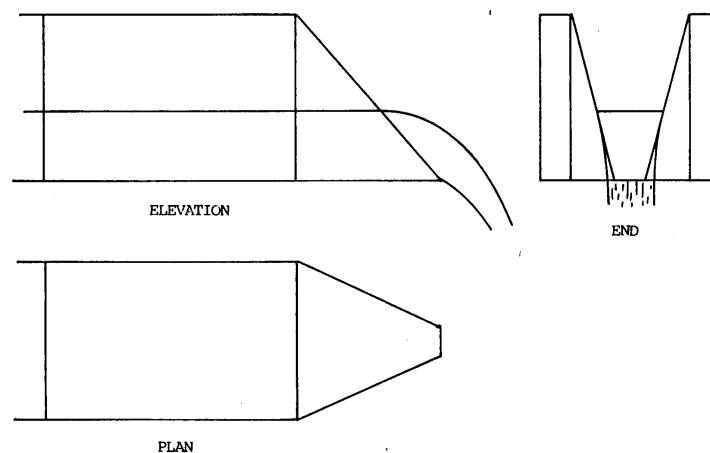


Figure 18 – H-Flume Configuration

Reproduced with permission from NIWA field manual.

Selection and Design

The criteria governing selection and design shall include the following considerations:

- The channel shape and configuration.
The structure should not obstruct the waterway to an extent which will cause flood flows to move or damage the structure, overtop the structure or banks, or create excessive backwater upstream.
- The maximum flow which the structure and channel are to contain.
Overflow of the structure can also cause scour damage to the ends and base of the structure.
- The low flow accuracy required and thus the sensitivity required at the low end of the range.
V-notch weirs with small angles are the most sensitive, but are easily overtopped and prone to debris lodgment.
- The amount of debris likely to be present in the flow at the various stages.
Note: V-notch weirs, particularly those with small angles are very prone to errors due to debris lodging in the notch. Guards such as wire mesh fences or floating booms may be required, and these will require checking following freshes and floods. the head loss available or permissible by virtue of the channel slope. As weirs require considerable head loss to provide a free overfall and an aerated nappe, their siting is more restricted than for flumes.
- The need for a sufficiently large weir pond to keep the approach velocity within the required limits.
- A straight approach channel upstream is required, of at least 10 channel widths.

Construction

When constructing weirs and flumes, the following should be taken into consideration:

- location, and
- construction method.

Location

Consider the following:

- The permeability of the ground into which the foundations are to be built, so that a sufficiently deep cut-off is incorporated.
- Accessibility, which may prescribe the method of construction and limit options for available materials.

Construction Method

Consider the following:

- The need for the weir or flume to be built precisely to the design and measurements for that type, for the rating to be valid
- The need for the structure to be watertight
Joints in concrete shall have a suitable waterstop material cast in, and joints between metal plates shall incorporate a suitable rubber sealer
- Forces likely to be exerted on the structure by the stream in flood, and thus the strength required in the walls and foundations
Sufficient steel and an adequate grade of concrete is required

- The ability to pass the stream flow around the construction site
Influencing the timing and methods of construction
- Options available for construction
Which can include the use of plywood shutters for formwork for concrete walls, alloy sheet for the wall in small streams, or pre-cast concrete walls, all set into a concrete foundation
- Possible future needs to de-water the weir pond to carry out repairs to the weir notch
Requiring a (well-sealed) drain pipe to be cast into the structure
- The need for all exposed metal to be corrosion-resistant
Either of aluminium alloy or hot-dipped galvanised steel
- Likely abrasion from sediment
Aluminium crests should be of a hard grade of aluminium alloy, and concrete crests may need the protection of steel angle
- Erosion potential of the water plunging over a weir
The apron downstream needs to be extensive, with deep foundations and possibly surfaced with cobbles to resist the abrasion of bedload.
- Crests need to be sharp, with no more than a 2 mm wide edge, and less for small structures.
They should have a machined or filed finish, untouched by abrasive paper.

Compound Weir/Flume Arrangements

In situations where high accuracy is desired for both high and low flows, weirs and flumes may be "compounded" to provide a highly sensitive structure for the low flows, and a higher capacity one for the moderate and high flows. This can either be done by combining two weir types on the one cross-section as depicted in Figure 15 (bottom left), or constructing two structures in series, each with its own stage recorder, such as the H-flume and V-notch weir arrangements installed in many experimental basins in New Zealand in the 1960's and 1970's.

End-Depth Method

Where free-fall occurs over an abrupt drop in a flat-bottomed channel, an approximate flow measurement can be made by measuring the depth at the brink.

The method is approximate, as factors such as the roughness of the channel and the uniformity of the bed have an influence. In practice, there will usually be difficulties in measuring the depth close to the lip, e.g., lack of relative accuracy in the case of small depths and severe hazards in the case of large flows.

The Culvert Method

The peak discharge through a culvert can be determined from high water marks that define the headwater and tail water levels. This method can be used to measure flood discharges from small catchments particularly where they pass under highways or roads. Like the use of flumes, it is based on measuring the energy losses occurring with abrupt changes in the character of flow.

Accuracy

The sources of errors with weirs and flumes are the:

- measured head (or stage)
- dimensional measurement and correctness of the structure, for example the angle, verticality and straightness of a V-notch, and
- various constants and corrective factors, for which estimates and tolerances are given in the relevant ISO standards.

With stage measured to only ± 1 mm, proportional errors at low stages and with small structures can be quite high. At sites where this may be a limitation, hook or point gauges with perhaps a vernier scale should be used.

The dimensional measurement and correctness of the structure is critical for the formulae to hold true, so the degree to which the theoretical rating is to be relied upon will govern the effort put into construction and measurement.

Practical experience in New Zealand shows that site factors such as sediment transport, relatively steep slopes and lack of sufficiently large weir ponds, have rendered theoretical ratings inaccurate; which means field rating by another gauging method is required. Thus accuracy of flow determination is generally governed by the quality of these gauging methods, their scatter on the rating curve, and the stability of the structures and their reaches.

Annex I – Intake Pipe Dimensions

The intake pipe diameter shall be large enough to prevent lag, but not overly large so that surging is not damped. A ratio of 1:12 between intake pipe and stilling well diameters can be used as a guideline.

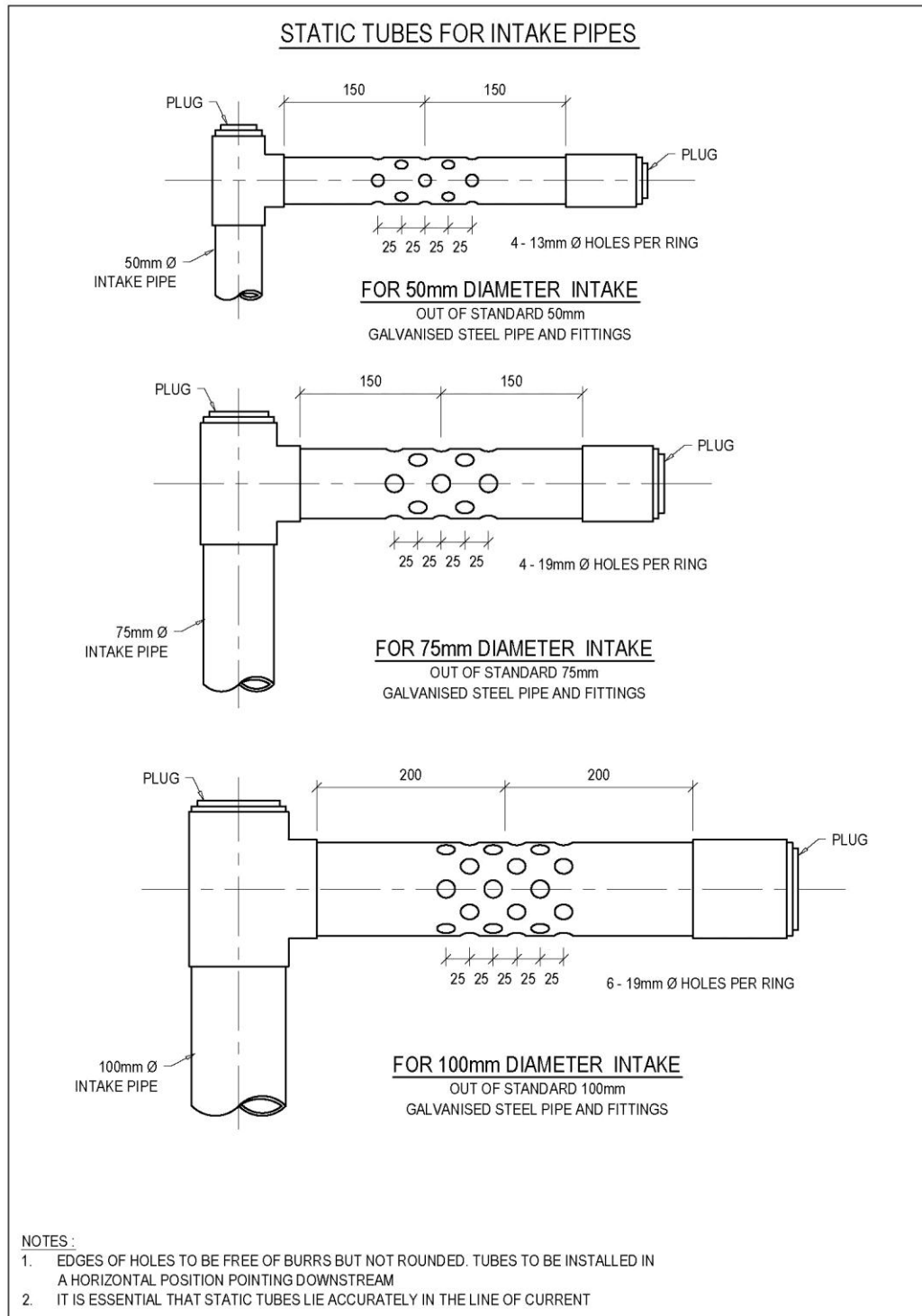


Figure 16 – Static Tubes for Intake Pipes
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The following relationship may be used to determine the lag for an intake pipe for a given rate of change of stage:

$$\Delta h = 0.01/g \times L/D (A_w/A_p)^2 \times (dh/dt)^2$$

in which:

Δh = lag, in meters,

g = acceleration of gravity, in meters per second per second,

L = intake length, in meters,

D = intake diameter, in meters,

A_w = area of stilling well, in square meters,

A_p = area of intake pipe, in square meters,

and:

dh/dt = rate of change of stage, in meters per second.

Smith, Hanson, and Cruft (1965) have studied intake lag in stilling-well systems, relating it to the rate of change of stage of the stream and to the various types and sizes of components which are used in the stilling-well intake system.



NEMS

