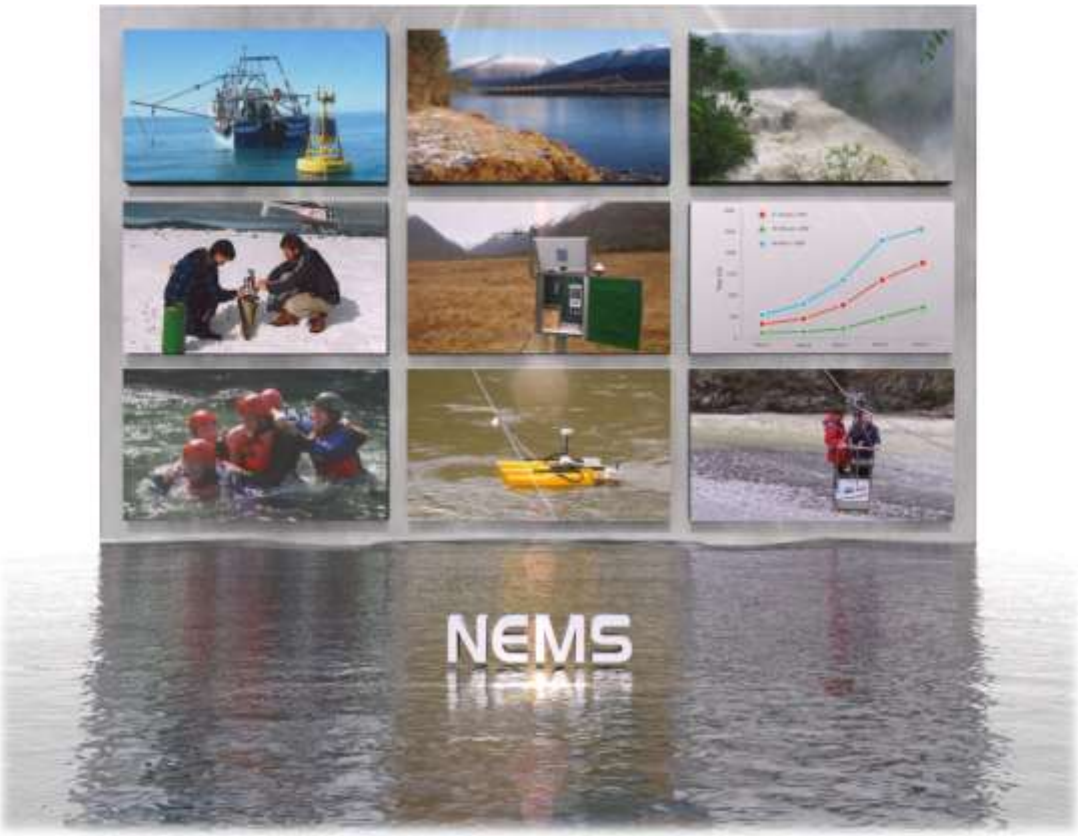
National Environmental Monitoring Standards

Site Surveys

Code of Practice

Version 1.0

Date of Issue: August 2016



The National Environmental Monitoring Standards

The following National Environmental Monitoring Standards (NEMS) documents can be found at www.lawa.org.nz:

Standards

- Dissolved Oxygen
  Measuring, Processing and Archiving of Dissolved Oxygen Data
- Open Channel Flow
  Measuring, Processing and Archiving of Open Channel Flow Data
- Rainfall
  Measuring, Processing and Archiving of Rainfall Intensity Data for Hydrological Purposes
- Rating Curves
  Construction of Stage-Discharge and Velocity-Index Ratings
- Soil Water
  Measuring, Processing and Archiving of Soil Water Content Data
- Turbidity
  Measuring, Processing and Archiving of Turbidity Data
- Water Level
  Measuring, Processing and Archiving of Water Level Data
- Water Meter Data
  Measuring, Processing and Archiving of Water Meter Data for Hydrological Purposes
- Water Temperature
  Measuring, Processing and Archiving of Water Temperature Data

Codes of Practice

- Hydrological and Meteorological Structures
- Safe Acquisition of Field Data In and Around Fresh Water
- Site Surveys (this Code)

Supplementary Material

- Glossary
  Terms, Definitions and Symbols
- National Quality Code Schema

Implementation

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

Limitations

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

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

The documents do not relieve the user (or a person on whose behalf it is used) of any obligation or duty that might arise under any legislation, and any regulations and rules under those Acts, covering the activities to which this document has been or is to be applied.

The information in this document is provided voluntarily and for information purposes only. Neither NEMS nor any organisation involved in the compilation of this document guarantee that the information is complete, current or correct and accepts no responsibility for unsuitable or inaccurate material that may be encountered.

Neither NEMS, nor any employee or agent of the Crown, nor any author of or contributor to this document shall be responsible or liable for any loss, damage, personal injury or death howsoever caused.

Development

The National Environmental Monitoring Standards (NEMS) steering group has prepared a series of environmental monitoring standards on authority from the Regional Chief Executive Officers (RCEOs) and the Ministry for the Environment (MfE).

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

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

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 to facilitate data sharing. The degree of rigour in which the Standards and associated best practice may be applied will depend on the quality of data sought.

The lead writer of this document was Phil Downes of Environment Canterbury, with workgroup members Jon Marks of Greater Wellington Regional Council and Peter Davis of Hawkes Bay Regional Council. The input of NEMS Steering Group members into the development of this document is gratefully acknowledged; in particular the review that they have undertaken.

Funding

The project was funded by the following organisations:

- Auckland Council
- Bay of Plenty Regional Council
- Contact Energy
- Environment Canterbury Regional Council
- Environment Southland
- Genesis Energy
- Greater Wellington Regional Council
- Hawke's Bay Regional Council
- Horizons Regional Council
- Marlborough District Council
- Meridian Energy
- Mighty River Power
- Ministry for the Environment
- Ministry of Business, Innovation and Employment – Science and Innovation Group
- National Institute of Water and Atmospheric Research Ltd (NIWA)
- Northland Regional Council
- Otago Regional Council
- Taranaki Regional Council
- Tasman District Council
- West Coast Regional Council
- Waikato Regional Council.

Review

This document will be reviewed by the NEMS steering group in February 2018, and thereafter once every five years.

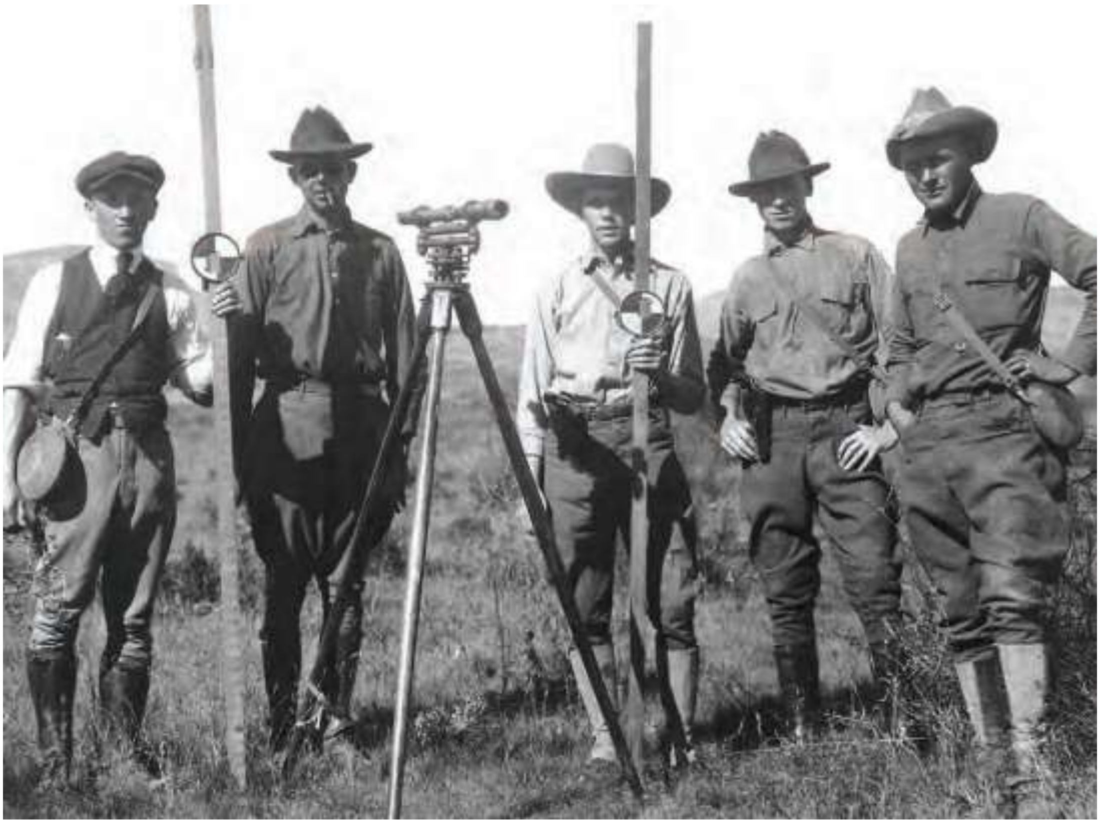


TABLE OF CONTENTS

Terms, Definitions and Symbols

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

Normative References

This Code of Practice should be read in conjunction with the following references:

- Health and Safety at Work Act 2015
- Ministry of Works and Development (1981). *Survey Manual*
- NEMS *Glossary*
- NEMS *Safe Acquisition of Field Data In and Around Fresh Water* (Code of Practice)
- NEMS *Water Level*
- Resource Management Act 1991
- US Geological Survey. (1990). Levels at streamflow gaging stations. In *Techniques of Water-Resources Investigations* (Book 3: *Applications of Hydraulics,* Section A-19*).* Reston, VA: US Geological Survey.

About this Code of Practice

Introduction

This Code of Practice has been developed following discussion and consultation with all regional and unitary councils within New Zealand as well as the National Institute for Water and Atmospheric Research Ltd (NIWA). Between them, these agencies undertake the majority of environmental data acquisition within New Zealand.

Objective

The objective of this Code of Practice is to ensure that environmental data acquisition across New Zealand that is gathered, processed and archived over time is suitable for at-site and comparative analysis.

Scope

This Code of Practice covers all processes associated with:

- site selection
- deployment
- the acquisition of data
- data processing, and
- quality assurance (QA) that is undertaken prior to archiving the data.

Exclusions

This code of practice only covers differential levelling using optical and digital levels.

The Code of Practice – Site Surveys

For data to meet the relevant NEMS, the following survey closure is recommended:

Survey Closure	Water level	± 3 mm ($CE = 0.001\sqrt{n}$) *
	Cross sections	± 3 mm ($CE = 0.001\sqrt{n}$) *
Stationarity	Stationarity of record shall be maintained.	

Requirements

Units of Measurement		Express units in: • metres
Reading Accuracy (survey staff)		Between ±1 mm and 10 mm depending on type of survey; for example, validating reference points versus cross sections.
Validation Methods	Variation on BM and other primary references surveyed are not greater than:	±3 mm (from NEMS *Water Level*)
Instrument Accuracy	Manufacturer specification	2mm/km or better double levelling run
Metadata		Metadata shall be recorded for all surveys.
Processing of Data		All changes shall be documented.
Stationarity		Stationarity shall be maintained and shall be demonstrable.
Validation Methods	Inspection of recording installations	Perform a collimation check on the survey instrument before use if one has not been performed in the last six months. Undertake a full survey of all benchmarks and reference points every five years and whenever a shift is suspected.

Continued on next page…

Archiving	Original and final records	File, archive indefinitely, and back up regularly: • raw and processed records • validation checks (collimation checks), and • metadata.

1 Introduction

Surveying is the science and art of determining the relative positions of points above, on or beneath the earth's surface and locating the points in the field.

Differential levelling is the process of measuring the vertical difference between a point of known elevation and a point of unknown elevation. By measuring this difference, an elevation can be determined for the point of unknown elevation.

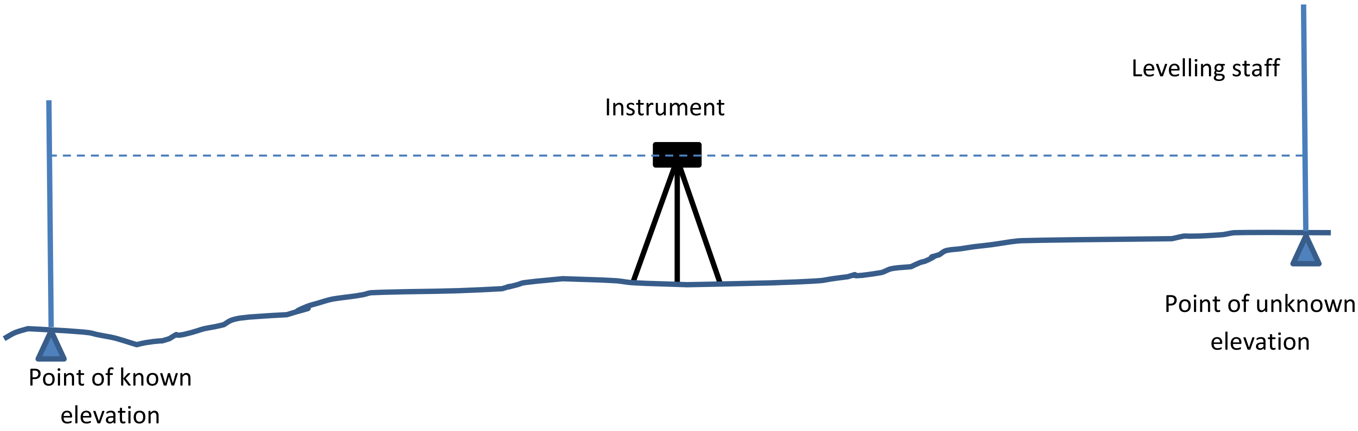


Figure 1 – Differential levelling

Differential levelling techniques are used at sites to determine elevations for benchmarks and reference points and the water surface. Benchmarks are objects (for example, steel rods and bolts) that are installed in the most stable locations and are used to adjust the recording equipment as necessary to keep them in agreement with the station datum.

Instruments selected for running levels at sites must be capable of meeting minimum precision and accuracy requirements.

1.1 Resetting External Staff Gauges and Electric Plumb Bobs

The main purpose of running levels at site is to verify that reference points, specifically the external staff gauge (ESG) and electric plumb bob (EPB), are properly set to read the stage at the site. The EPB or ESG should be reset if the absolute value of the differences between the elevation reading of the EPB/ESG and the site datum is greater than 3 mm. Before the EPB/ESG is reset, all elevations must have been computed and verified.

The verification of all benchmark must be checked and verified to ensure that the datum origin is the same as the original survey.

This means that all benchmarks are levelled and comply with the Code of Practice guidelines.

Once this condition has been satisfied, the EPB/ESG can be checked and reset where necessary and then another independent survey carried out to ensure that they have been adjusted correctly.

All of this information must be documented.

2 Equipment

2.1 Levelling Equipment

Levels at sites require measurements of vertical distance and do not need measurements of horizontal distance or horizontal angle. Optical and digital levels using a survey staff are the most common instruments used for running levels at sites. Most optical and digital levels meet the desired accuracy of less than 2mm/km double levelling run.

Surveying technology is continually changing, and other types of surveying instruments, such as tilting instruments, may be capable of meeting these accuracy and precision standards.

2.1.1 Optical Levels

Optical levels (Figure 2) are used to manually read the survey staff that is held on an objective point. When using an optical level, the operator reads the value off the staff at the cross hair of the level. Precision requirements call for the operator of an optical level to estimate measurements within 1mm. The ability to accurately estimate to 1mm is determined by the distance from the instrument to the survey staff, the magnification power of the level's optics, and environmental conditions such as the presence of heat waves. In general, the magnification of optical levels is about 30 times and allows readings as precise as 1mm up to a distance of about 30 m. Most modern optical levels are automatic, or self-levelling — the instrument levels itself precisely after being levelled manually with its circular (bull's eye) level. Many older optical levels, such as the Dumpy level, are not self-levelling and are time consuming to set up and level. They are also not considered accurate enough for these applications.

Leica NA2 Nikon

Figure 2 – Examples of optical levels

2.1.2 Electronic Digital Levels

Electronic digital levels automatically read a bar-code survey staff (held on an objective point). When using an electronic digital level, the operator sights on the bar-code survey staff using the optical view finder and then interrogates the instrument to make a measurement. The instrument then shows the value on its digital display screen. Many electronic digital levels are equipped with logging and computational functions that can be used when running levels. Electronic digital levels contain optical systems that also allow the level to be used manually. Like optical levels, distances to objective points and environmental conditions can limit the utility of electronic digital levels.

Electronic digital levels provide some distinct advantages over optical levels; for example, because the instrument automatically reads the survey staff, any subjectivity in manually estimating the measurement to 1 mm is removed. Similarly, the potential for misreading the survey staff is eliminated when using electronic digital levels. When using data-logging features common to many electronic digital levels, errors associated with manually transcribing measurements can also be eliminated. A disadvantage of electronic digital levels is that the electronic nature of these instruments introduces the potential for system failures to occur while in the field. Fortunately, the optical capability serves as a backup to the electronic system.

It is common when running levels at gauging stations to use a secondary device, such as a steel tape, to take shots on objects located in places where a staff cannot be placed. Furthermore, observations to some objects such as electric plumb bobs (EPBs) are made by sighting the object at the cross hair of the instrument. Most digital systems, which require a bar-code staff, cannot be used for such observations; however, there are digital levels that can be used optically.

Electronic digital levels are very sensitive and can be easily knocked out of alignment as a result of transportation or careless use so extreme care of the instrument is required.

Figure 3 – Example of a Leica digital level and a survey staff

2.1.3 Laser Levels

Laser levels are fixed to a tripod, levelled and then spun to illuminate a horizontal plane. The laser beam projector employs a rotating head with a mirror for sweeping the laser beam about a vertical axis. If the mirror is not self-levelling, it is provided with visually readable level vials and manually adjustable screws for orienting the projector. A staff carried by the operator is equipped with a movable sensor, which can detect the laser beam and gives a signal when the sensor is in line with the beam (usually an audible beep). The position of the sensor on the graduated staff allows comparison of elevations between different points on the terrain.

The laser level can be operated by one person and is easy to use; however, the accuracy of these instruments is poor (1.5 mm to 2.6 mm per 30 m).

Figure 4 – Example of a laser level and sensor

2.1.4 Survey Staves

Many kinds of survey staves are available for use in running levels at sites. Staves come in different lengths, many are expandable, and they are made of different materials. Telescoping aluminium staves are made of a light and durable aluminium alloy. The anodized sections are imprinted with special weather-resistant and corrosion-resistant inks. Tight tolerances on extruded aluminium sections allow for smooth extension and prevent unnecessary clattering and sloppiness. The sectional joints are injection moulded from a durable lightweight impact-resistant plastic. Staves are equipped with reliable and wear-resistant polycarbonate buttons that lock each section.

Self-reading staves with numeric scales (Figure 5a) are used with optical levels, while electronic digital levels use staves with bar-code scales (Figure 5b). The scales of self-reading staffs are typically divided into 5 mm or 10 mm increments by means of alternating black and white spaces and readings are visually interpolated in order to meet the measurement-precision requirement of 1 mm. For recording station levels, self-reading staves must be graduated to at least 10 mm. Bar-code staves often have a self-reading scale on the second side of the staff to use with the optical system of the instrument.

Regardless of the type of level, when running levels at sites, it is good practice to extend the staff no more than is necessary to take an observation because of the difficulty in holding a tall staff steady and level on an objective point. A survey staff should always be used in conjunction with a staff bubble.

Figure 5a – Example of a standard survey staff

Figure 5b – Example of a survey staff with bar code

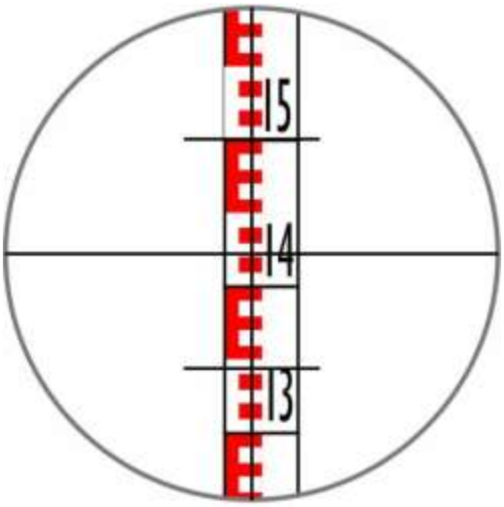


Figure 6 – Reading a staff gauge with mm estimated (1.422 m)

2.1.5 Staff Bubbles

A staff bubble must be used to ensure that the survey staff is held vertically at all times (Figure 7).

If a staff bubble is not available, the staff should be rocked slowly back and forth about the vertical in a line towards the instrument. The observer notes the smallest reading which occurs when the staff is vertical.

Figure 7 – Example of a survey bubble

2.1.6 Tripods

Tripods can be either wooden or aluminium but must be robust and solid (Figure 8). A quick-clamping system allows the tripod's legs to be extended and fixed very easily. Ensure the feet of the tripod are securely positioned to ensure a stable platform to level from.

Figure 8 –Example of a tripod

2.2 Instrument Checks

2.2.1 Checking Optical and Digital Levels

A properly calibrated optical level is assumed to be on a horizontal plane and measures the vertical height from objective points to the height of the instrument.

Collimation error is a measurement of the inclination of a level's line of sight, or the deviation from the horizontal plane. Collimation error is reported as a vertical deviation over a set distance, such as *x* millimetres per *y* metres. If horizontal distances from the instrument to each object that an observation is taken on are known, collimation corrections can be computed and applied. However, levels at sites do not require measurements of horizontal distance, and therefore the collimation error of the instrument is preserved in all measurements and is not corrected for.

Collimation error of an optical level is commonly determined by a two peg test. These tests check how true the instrument is sighting on a horizontal plane. Given the precision with which recording-station levels are run and the criteria that determine a valid level run at a recording station, the tolerance for the collimation error of an instrument cannot exceed the absolute value of 1 mm per 30 m. Instruments possessing collimation errors greater than 1 mm per 30 m should be adjusted by qualified personnel or by a certified facility. Following any adjustments made to an instrument, a collimation test must be performed and documented to verify that the instrument was adjusted correctly.

2.2.2 Two Peg Test

All instruments are subject to errors and so the checking of the instrument (level) is important. The main error is where the line of sight is not parallel to the horizontal line of collimation; in this case, your levels will not be correct. A common test for checking the instrument is known as the two peg test.

Establish two points approximately 50 m apart (Figure 9). Set the level exactly halfway between the two points. Take the two survey staff readings.

In Figures 9 and 10 below, the level is out of collimation where the actual line of sight does not coincide with the theoretical horizontal level. However, because the instrument is set up halfway between the two points, the collimation error is the same for both readings. The difference between the two staff readings equates to the true height difference between points A and B. For the example in Figure 9, the true height difference is 0.272 (1.540 – 1.268).

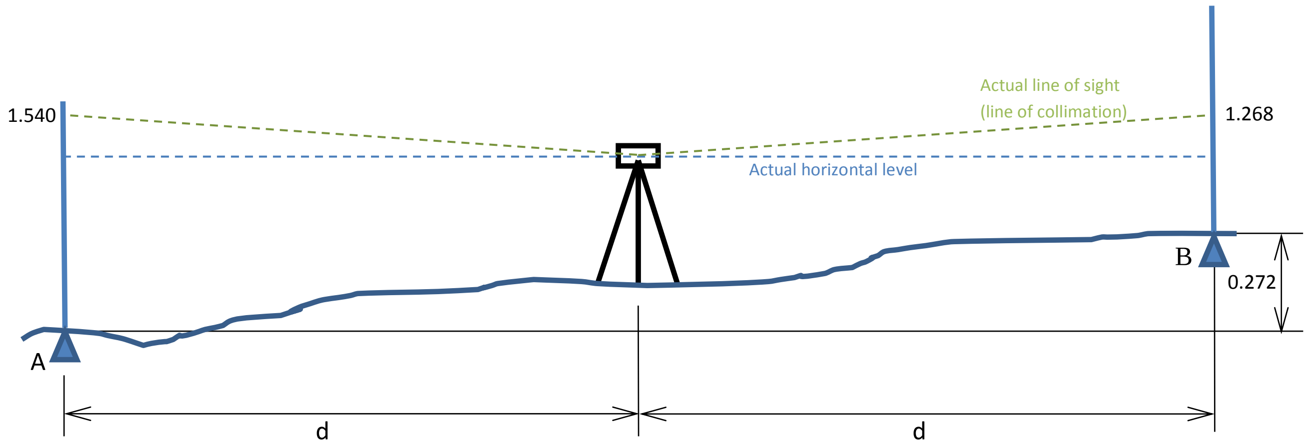


Figure 9 – The two peg test: Step 1, example 1

Figure 10 demonstrates the same situation with a different collimation error. As expected, because the instrument is set up halfway between the two points, the height difference between points A and B is the same as Figure 9; i.e. 0.272 (0.980 – 0.708).

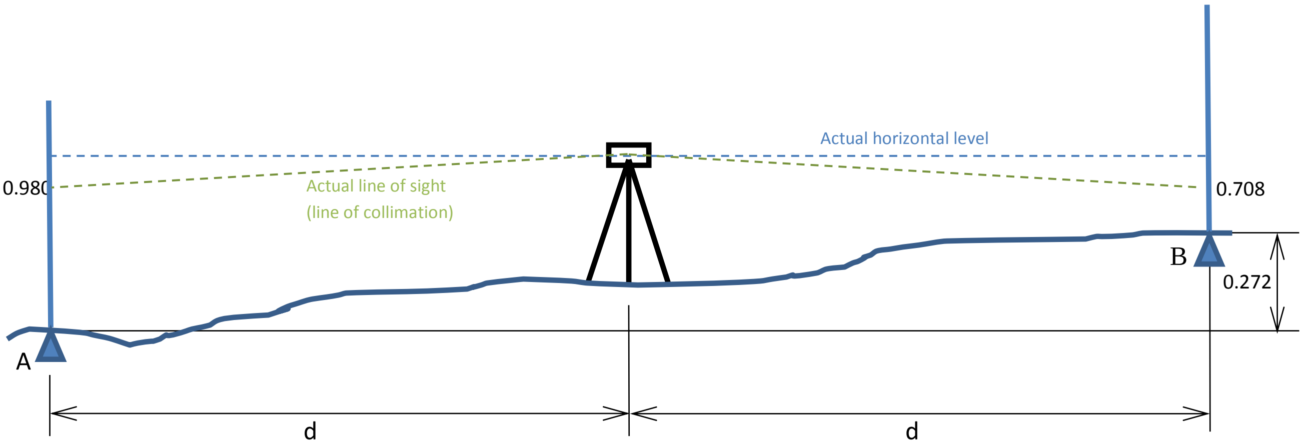


Figure 10 – The two peg test: Step 1, example 2

The next step involves moving the level as close as possible to one of the points; take both staff readings again. As the reading taken on point A in Figure 11 is over a very short distance, any error is negligible; however, the longer reading to point B will expose any significant collimation error.

In this example, the difference between the second set of readings is 0.529 (1.621 – 1.092). If the difference in height in step 2 is the same as in step 1, then the level is okay. However, in the example presented here, the difference in height in step 2 is not the same as in step 1, and so the instrument needs to be serviced.

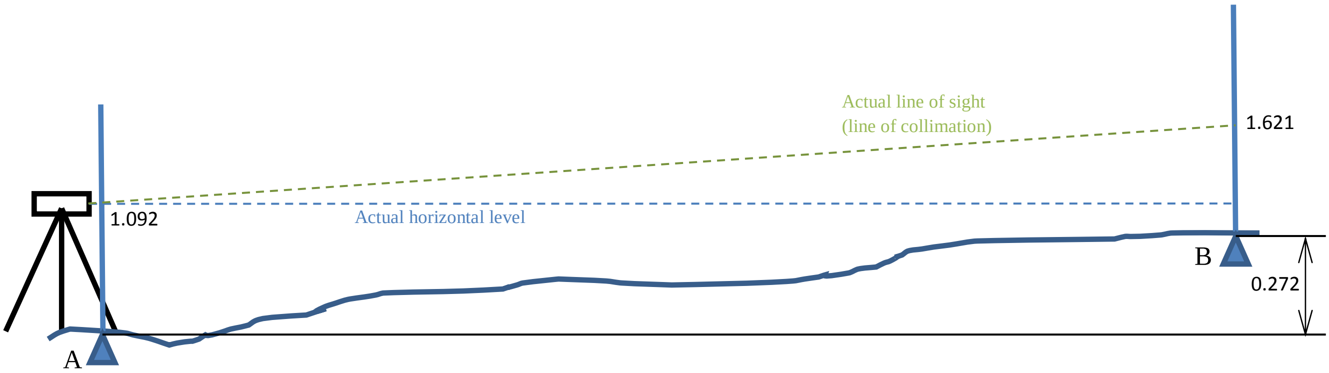


Figure 11 – The two peg test: Step 2

3 Benchmarks, Reference Points and Datums

3.1 Definitions

Benchmarks are installed and elevations are determined to a known or adopted datum when sites are established. Stable and permanent benchmarks facilitate maintaining stationarity of the station. Typical benchmarks include stainless steel pins and galvanised bolts cemented and drilled into rock outcrops, bolts drilled into masonry walls. or steel rods driven and cemented into stable ground.

Benchmarks provide a means for recovering the station datum if the station is destroyed or is removed and reactivated sometime later.

3.2 Benchmark Installation

The most stable locations for benchmarks are often rock outcrops and substantial masonry structures. Bridges can also provide a stable environment for benchmarks; however, bridges that sway or have a high traffic volume may not be desirable because precise measurements are difficult to make with a survey staff. In the absence of rock outcrops and stable masonry structures, benchmarks can be anchored at depths below the local frost depth in stable soils.

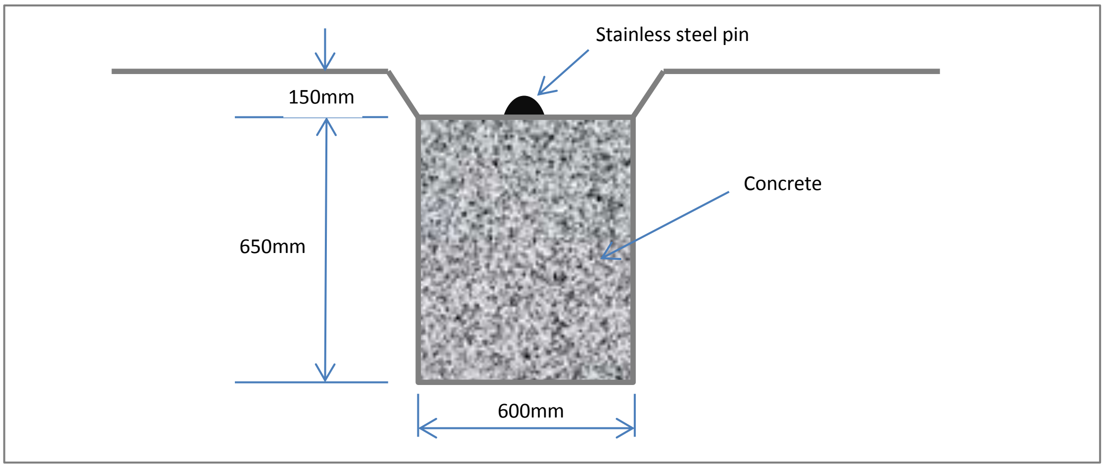


Figure 12 –Benchmark installation example

3.2.1 Number of Benchmarks

Sites should have a minimum of three independent benchmarks, although more than three are recommended whenever possible. For example, if one or more benchmarks are installed on a bridge structure, at least two others should be installed somewhere away from (and independent of) the bridge. Furthermore, benchmarks should be located independently of any structure or in-stream control structure, because benchmarks are used to track vertical changes over time to the gauges and to the other marks.

3.2.2 Positioning of Benchmarks

When locating benchmarks, other considerations should be made. Ideally, at least one reference mark should be located outside of the flood plain. When determining the locations of benchmarks, running levels should be considered and, if possible, marks should be located so that sightline distances are balanced and levels can be run in an efficient manner. The potential for damage or destruction of benchmarks related to construction, specifically road construction or future land development, should be considered. Finally, benchmarks should be easily found from descriptive statements in the station description document. As discussed later, site sketches showing the location of benchmarks should be prepared. If vegetation is likely to obscure marks over time, exact measurements from local objects should be provided and a witness post installed.

3.3 Datums

3.3.1 Vertical Datum

The vertical datum is the reference surface to which all water level measurements are set. The datum used should be well documented for each station.

There are a number of datums used around New Zealand; for example, local datums, mean sea level (MSL) and the New Zealand Vertical Datum (NZVD2009). It is acceptable to use an assumed datum where it is impractical or unnecessary to reference a known datum.

Where the datum is assumed it can be tied to an established datum, such as mean sea level (MSL), or to a local datum through the use of established benchmarks.

Heights in terms of local datums can be related to the NZVD2009 or NZGD2000 by using the NZGeoid2009 geoid model and the appropriate datum offset on the Land Information New Zealand (LINZ) website.

A survey grade Global Positioning System (GPS) is acceptable to tie the datum to an established datum (fit for purpose).

3.3.2 Mean Sea Level (MSL)

Sea level is known to vary around the coast of New Zealand, and offsets will occur between adjacent datums. It is therefore important that the vertical datum of a height is checked before it is used. Also, in most cases the level of MSL for the vertical datums was determined more than 50 years ago and has not been updated since then. Historic levels should be used with caution because there may have been changes since then; for example, sea level rise due to the effect of climate change.

Land Information New Zealand (LINZ) maintains a database of established benchmarks throughout New Zealand. This database can be used to find the location of the nearest benchmarks and its elevation.

3.3.3 Staff Gauge Zero

The staff gauge zero is represented by the extrapolated 0.000 m point of the external staff gauge and electric plumb bob.

When a recording station is being established where no station has existed previously, the datum should be set low enough to ensure that the lowest stage height ever likely to be recorded is below this point.

3.4 Station Survey History

A historical level summary including dates of installation, description of datum, level checks and reference to the levelling documents and the final elevations of all benchmarks from every level run should be maintained for all sites.

In addition, the following reference points should be recorded where relevant:

- staff gauge zero (for each staff gauge with its range being noted)
- internal plumb bob zero (with its range being noted)
- 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.

The level summary provides a way to track elevations and thus vertical stability of all benchmarks and reference points over the life of the station. The historical level summary should be updated immediately every time levels are run at the site.

The correct referencing of benchmarks is essential to maintain integrity at the site. This involves each benchmark having a unique reference number that must not be transferred to any other benchmark. For example, if a benchmark were to be lost or destroyed and a new benchmark established, then the replacement benchmark must have a new and unique reference number.

3.5 Site Maps

A sketch map of the site will help anyone who runs levels at the station. This is especially true for someone who is unfamiliar with a particular station. This map should show the locations of all the benchmarks and reference points with respect to the site. If relevant, the location of the low-water control along with the direction of flow should be included.

Recommended instrument set-up locations that provide ideal shot distances are useful as well.

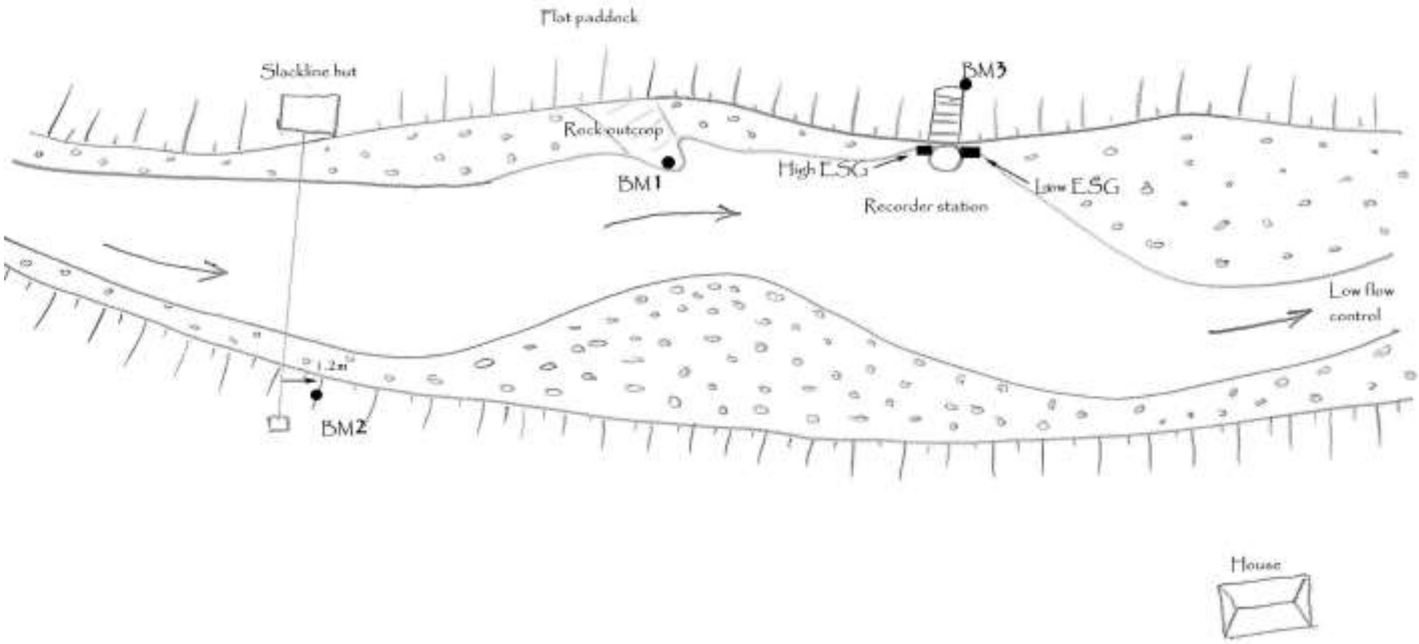


Figure 13 – Site map example

4 Survey Types

4.1 Control Surveys

Control surveys establish a network of horizontal and vertical bench marks that serve as a basis for more detailed surveys**.**

Control surveys are usually 1st-order or 2nd-order levelling (precise levelling). These surveys have a high accuracy and are usually carried out by qualified surveyors.

4.2 Geodetic Surveys

A Geodetic Survey is a land survey that is affected by and takes into account the curvature of the earth and astronomic observations.

Site surveys collect level datum at hydrometric stations which may include water level stations, groundwater stations, control cross-sections and long sections.

4.3 Site Surveys

Site surveys collect elevations of benchmarks and reference points at sites.

Site surveys are generally 3rd-order levelling. The circuit closure error should be:

$$CE = 3 \text{ mm, or } \sqrt{n} \text{ (whichever is the lower)}$$

where: CE is closure error (mm), and
n is the number of instrument set-ups.

The accuracy for all readings in a site survey should be 1 mm.

4.4 Cross-Section and Long-Section Surveys

Cross-section and long-section surveys are commonly carried out on river channels and coastal beaches. They are used to track aggradation and degradation of bed substrates over time.

Cross section and long section surveys are generally 3rd-order levelling. The circuit closure error should be:

± 3 mm or $CE = \sqrt{n}$ (whichever is the lower)

where: CE is closure error (mm), and
n is the number of instrument set-ups.

The accuracy for all foresights and backsights in a cross-section or long-section survey should be 1 mm. However, intermediate observations can be less accurate; for example, if surveying a river cross-section of cobbles or boulders, intermediate observations of 10 mm are acceptable.

5 Frequency of Site Surveys

Site locations and environments vary widely as do the factors affecting the stability of benchmarks and reference points. The relative stability of a site needs to be considered when determining the frequency at which levels should be run. For example, a site affected by ground freezing and thawing may require levels to be run annually in the spring, while a site with benchmarks fixed to bedrock that has demonstrated stability may require levels to be run only every five years. Levels should be run frequently enough to capture any movement that may occur.

A new site installation (including the installation of a new reference point at an existing site) should have three sets of annual levels, including the initial establishment set, acquired during the first three years of operation. After the first three sets of levels are acquired, a level frequency of once every two years may be adopted.

A decision tree (Figure 14) is provided below to help determine when levels need to be run at a site.

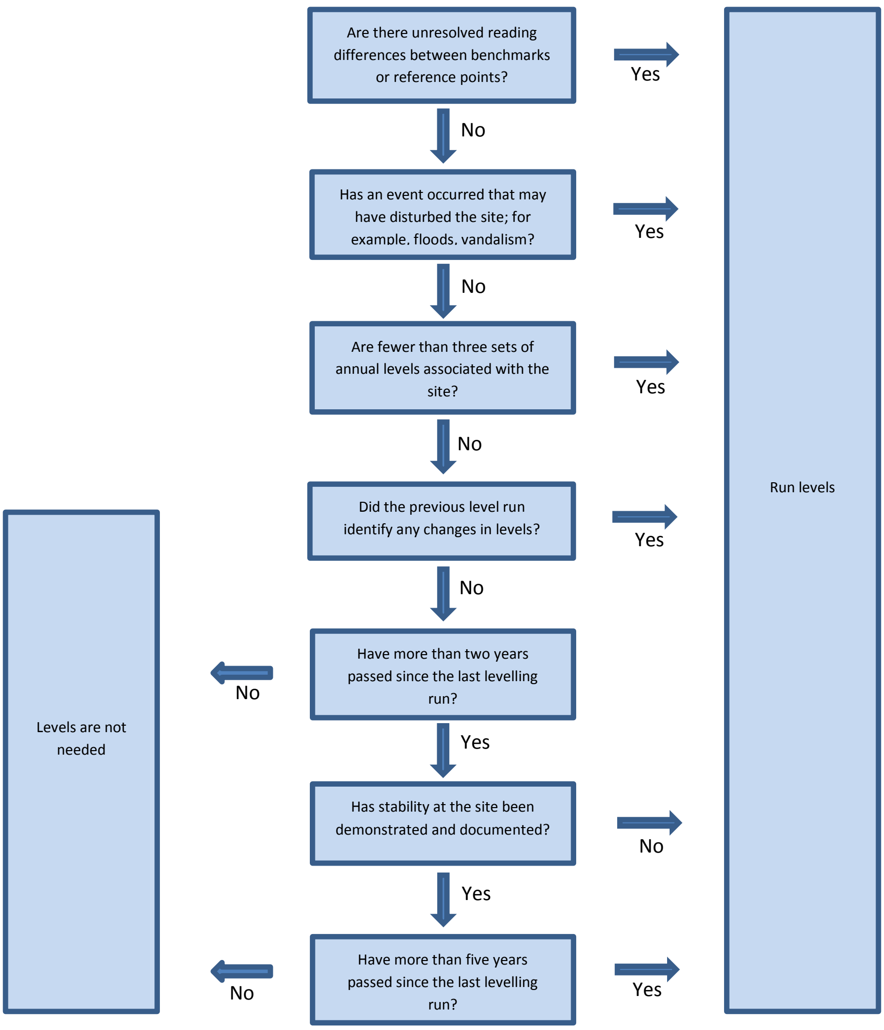


Figure 14 – Site survey frequency decision tree

6 Running Levels

After determining that levels are needed at a site and making the necessary preparations, levels should be run following the procedures outlined below.

To describe the procedures for running the levels, a very simple level circuit with two instrument set-ups is presented here (refer to Figures 15 and 16).

6.1 Survey Procedure

- Determine the order in which the benchmarks, reference points, water surface and other objects are to be observed.
- The instrument should be placed upon a firmly set tripod in a stable location at a height that allows for a comfortable position for the instrument operator and accurate readings of the survey staff on the objects to be observed.
- The instrument should be properly levelled using the levelling tools (feet) of the instrument.
- The initial instrument height of collimation is determined from a backsight (BS) to the origin benchmark (observation 1 below).
- Intermediate sights (ISs) should then be taken to the benchmarks, reference points, water surface and other objects that were planned to be observed from the current instrument set-up. These points are of only one reading and are not verified or used in the circuit close (observations 2 and 3 below).
- After taking the ISs on all points that were planned to be observed from the current instrument set-up, a change point should be established. The change point (CP) should be stable so that its validity is verified in the circuit closure. This point will be used to establish a new instrument height. Take a foresight (FS) on the change point (observation 4 below).
- It is good survey practice to do a CP on all benchmarks and reference points.
- Following this FS, the instrument should be moved and re-levelled in a location that again balances the distances to all the objective points, and where the CP is still observable.
- Take a BS to the CP (observation 5 below).
- Take any further ISs as required (observations 6 and 7 below).
- To close the levelling circuit, the final shot should be a FS taken on the origin benchmark (observation 8 below).
- It may be necessary to determine the level of the underside of a reference point such as the underside of a recorder hut. This presents no difficulty if the levelling staff is inverted and its base is held up against the surface to be levelled. Inverted staff

readings should be booked with a minus sign and the rise or fall determined algebraically. Make a note in the remarks column about the inverted staff.

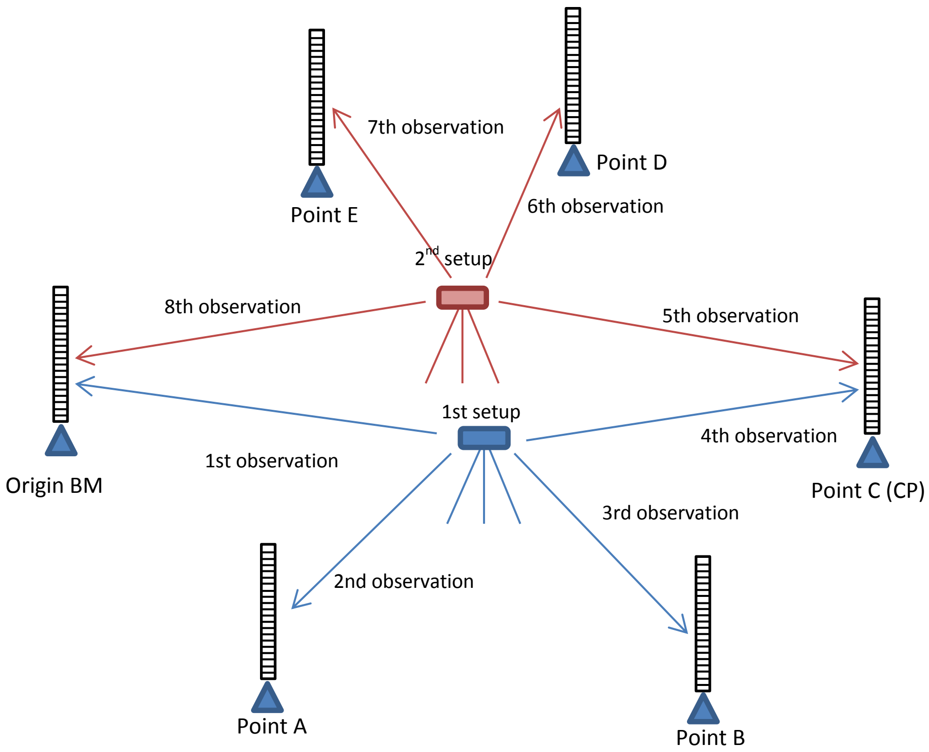


Figure 15 – Site survey set-up example

BS	IS	FS	Rise	Fall	RL	Remarks
1.525[1]						Origin BM
	0.862[2]					A
	1.113[3]					B
1.304[5]		0.889[4]				C
	0.652[6]					D
	2.339[7]					E
		1.940[8]				Origin BM

Figure 16 – Example of site survey observations

6.2 Reducing the Levels

It is good practice to reduce the levels on site in case an erroneous reading has been taken. A quick first check is to total the BS and FS columns; these should be the same.

BS	IS	FS	Rise	Fall	RL	Remarks
1.525[1]						Origin BM
	0.862[2]					A
	1.113[3]					B
1.304[5]		0.889[4]				C
	0.652[6]					D
	2.339[7]					E
		1.940[8]				Origin BM
2.829		2.829				

Figure 17 – Site survey BSs and FSs totalled

There are two common methods for reducing the levels: the rise and fall method, and the height of collimation method.

6.2.1 The Rise and Fall Method

The rise or fall is calculated from point to point along the line of levels and is booked in the appropriate column. If the staff reading is lower than the previous one, there must be a rise between the two points. If the staff reading is higher than the previous one, there must be a fall. The differences must only be taken between observations made from the same set-up.

As the elevation of the start point is known, the elevations of all the other points can be found by adding the rises and falls from point to point along the level traverse.

BS	IS	FS	Rise	Fall	RL	Remarks
1.525[1]					10.000	Origin BM
	0.862[2]		0.663[(1-2)]			A
	1.113[3]			0.251[(2-3)]		B
1.304[5]		0.889[4]		0.224[(3-4)]		C
	0.652[6]		0.652[(5-6)]			D
	2.339[7]			1.687[(6-7)]		E
		1.940[8]	0.399[(7-8)]			Origin BM
2.829		2.829				

Figure 18 – Calculating the rises and falls

Calculate the rise or fall for each observation. For example, in Figure 18, observation 1 – observation 2 = 0.663; the difference is a positive number so it is a rise. Likewise, observation 2 – observation 3 = -0.251; the difference is a negative number so it is a fall. And so on.

BS	IS	FS	Rise	Fall	RL	Remarks
1.525[1]					10.000	Origin BM
	0.862[2]		0.663[(1-2)]		10.663	A
	1.113[3]			0.251[(2-3)]	10.412	B
1.304[5]		0.889[4]	0.224[(3-4)]		10.636	C
	0.652[6]		0.652[(5-6)]		11.288	D
	2.339[7]			1.687[(6-7)]	9.601	E
		1.940[8]	0.399[(7-8)]		10.000	Origin BM
2.829		2.829	1.938	1.938		

Figure 19 – Reducing the levels using the rise and fall method

Using the known RL for the origin BM, add or subtract the rises and falls as appropriate. For example, in Figure 19, the RL of point A is 10.000 + 0.663 = 10.663; the RL of point B is 10663 – 0.251 = 10.412; the RL of point C is 10.412 + 0.224 = 10.636; etc.

The sum of rises and the sum of falls should equal each other and hopefully the RL of the origin BM should be the same (or very close).

6.2.2 The Height of Collimation Method

Adding the backsight to the elevation of that point gives the elevation of the "line of collimation of the instrument". The elevation of any other observed point from the same set-up is equal to the elevation of the instrument minus the staff reading.

BS	IS	FS	Instrument elevation	RL	Remarks
1.525[1]			11.525	10.000	Origin BM
	0.862[2]			10.663	A
	1.113[3]			10.412	B
1.304[5]		0.889[4]	11.940	10.636	C
	0.652[6]			11.288	D
	2.339[7]			9.601	E
		1.940[8]		10.000	Origin BM
2.829		2.829	1.938		

Figure 20 – Reducing the levels using the height of collimation method

Starting from the origin BM, the elevation of the instrument is computed (10.000 + 1.525 = 11.525). From this, the height of the first point (point A) can be computed (11.525 – 0.862 = 10.663). The RL of Point B will be 11.525 – 1.113 = 10.412. The next observation is a FS, so we need to calculate a new instrument height (11.525 - 0.889 + 1.304 = 11.940).

With this method, however, any error in reduction of intermediate points goes undetected unless the reductions are repeated.

6.3 Reference Point Observations

6.3.1 Vertical Staff Gauges

Vertical staff gauges are placed in direct contact with the water. They can be placed inside stilling wells or attached to various objects on the banks of a stream.

External staff gauges are perhaps the most commonly surveyed reference point at a site. Sites on streams that have a large range in stage often have a series of staff plates that are installed in vertical intervals along a sloping bank. Each separate staff gauge should be surveyed and the range noted.

The preferred method is to take an observation directly on the staff gauge plate; however, sometimes this technique is not always possible. The alternative method for taking an observation is to establish a reference point by partially driving a nail or screw into the staff plate backing next to the plate. The elevation of the reference point, in relation to the staff gauge plate, should be read from the plate and noted. The reference point is then levelled.

A spirit level should be used to verify that plates are vertical when levels are run.

Installation of vertical external staff gauges

1. Install timber staff gauge boards vertically to a stable structure.

Figure 21 – Timber boards attached to a stable structure

2. Place a nail (with the head removed so the survey staff can sit flat) in the side of the timber staff gauge board.

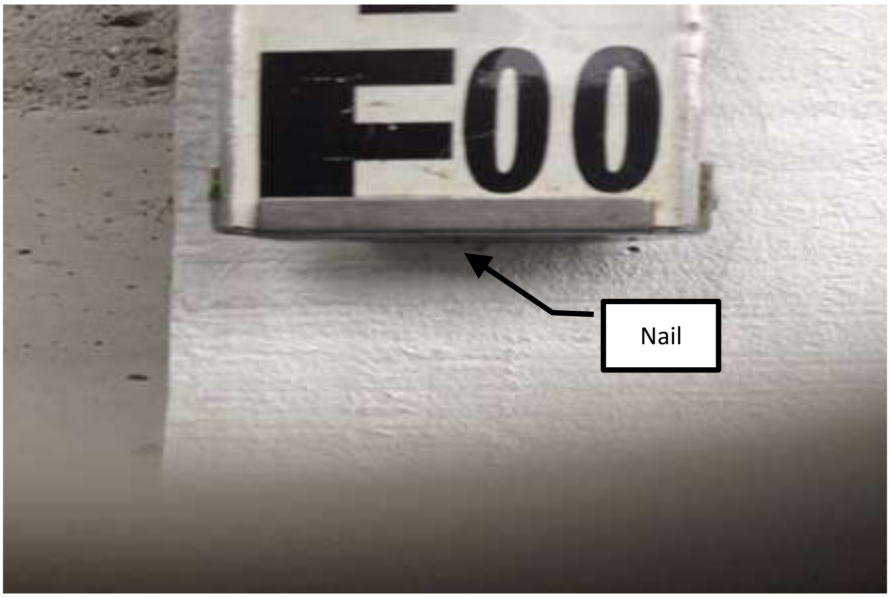


Figure 22 – Nail driven into a timber board

3. Survey the nail from a known BM.

Figure 23 – Nail being surveyed

4. Reduce the levels to obtain the reduced level (RL) of the nail.
5. Install the first 1-m staff gauge plate at the correct level as surveyed. In the example below, the nail has been levelled at 12.320 m and the staff gauge plate has been aligned accordingly.

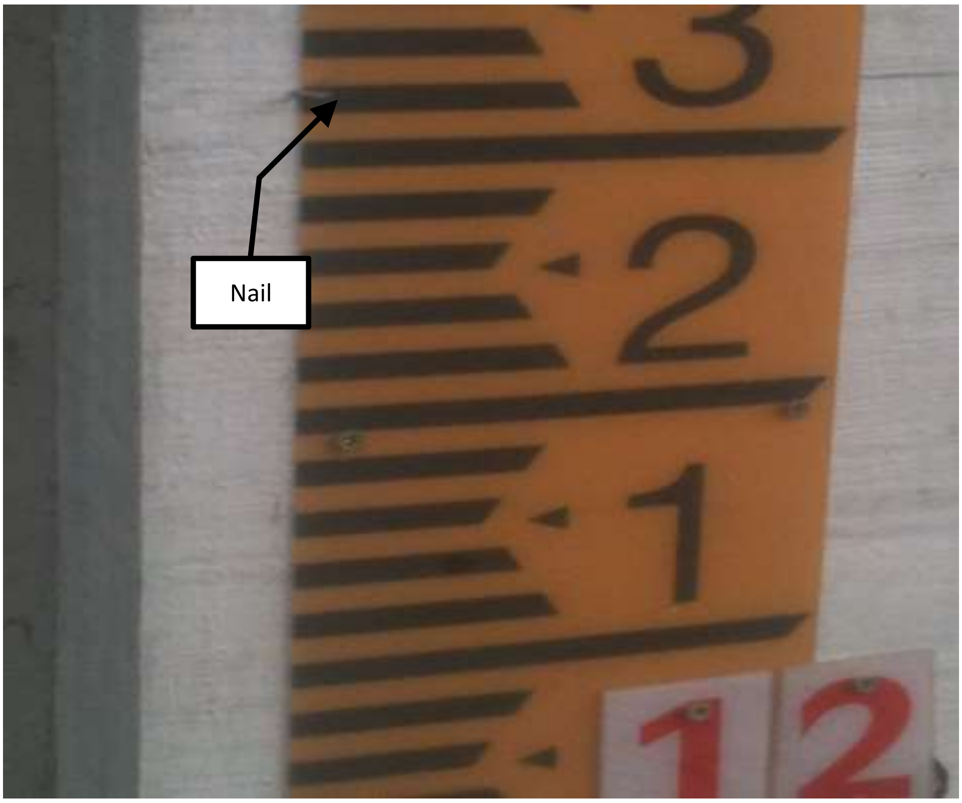


Figure 24 – Staff gauge plate aligned and installed adjacent to nail

6. Install other plates above and below this plate as required.
7. Attach the metre numbers (the red 12 in Figure 24 above).
8. Resurvey each staff gauge plate, preferably by taking direct shots onto each plate

6.3.2 Checking Reduced Levels of Vertical External Staff Gauges

The preferred method of checking reduced levels of vertical external staff gauges is to take an observation directly on the staff gauge plates; however, this is not always practical.

Other indirect methods are possible including:

1. placing the survey staff on the top of the staff gauge plate and adding the survey staff observation to the staff gauge reading
2. placing a nail (with the head removed so the survey staff can sit flat) in the side of the timber staff gauge board and levelling this point, and adding it to the corresponding staff gauge reading. In Figure 24 above, if the staff was placed on the nail, the staff reading would be added to 12.320.

6.3.4 Inclined External Staff Gauge

Inclined staff gauges are permanent structures that are installed at about the same slope as the stream bank. The scale along the incline is set to represent the water-surface elevation.

The slope of these gauges minimises damage caused by debris. The permanence of the inclined staff gauges makes them very difficult to adjust if they disagree with the site datum. Readings are taken on several marks throughout the staff gauge's range. If the inclined staff gauge is a composite of multiple slopes, at least two readings must be taken on each inclined staff to adequately cover the range.

6.3.5 Electric Plumb Bob (EPB)

Electric plumb bobs (EPBs) are used in stilling wells to measure the water surface inside the well.

Installation of electric plumb bobs

Electric plumb bobs need a reference point from which to read the level. This can be either the floor of a recorder hut, or preferably, a pointer attached to the EPB itself.

Figure 25 – Electric plumb bob with hut floor as the reference

Figure 26 – Electric plumb bob with electric pointer as the reference

The methods for installing an EPB are dependent on the type of reference point.

If the recorder hut floor is the reference, then you must level the floor (or the insulation ring in Figure 25 above). You may need to use a tape measure instead of the staff as it will not fit in the hut.

If the EPB has a pointer, then you must level this point; again, the use of a tape measure is a good idea.

The EPB tape length must equal the RL of the reference point. Lay out a length of EPB tape (it must be long enough to cover the expected range of the water level), and lay the EPB probe on top of it with the pointer sitting adjacent to the RL of the reference point. In Figure 27 below, the RL of the EPB reference point is 19.844 m so the end of the EPB probe is adjacent to this value on the tape.

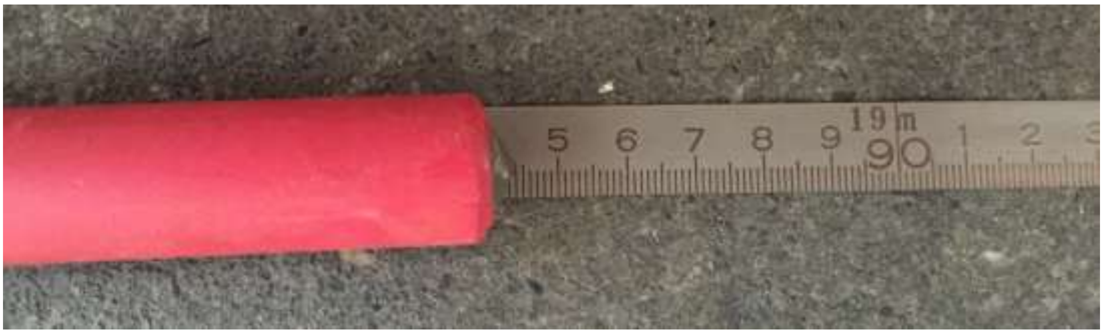


Figure 27 – Electric plumb bob at reference RL on tape

Cut the EPB tape so that it will be long enough to be attached to the end of the probe. In Figure 28 below, the tape should be cut at approximately 19.000m (the exact length is not critical as fine adjustment can be made using the threaded insert and lock nut).

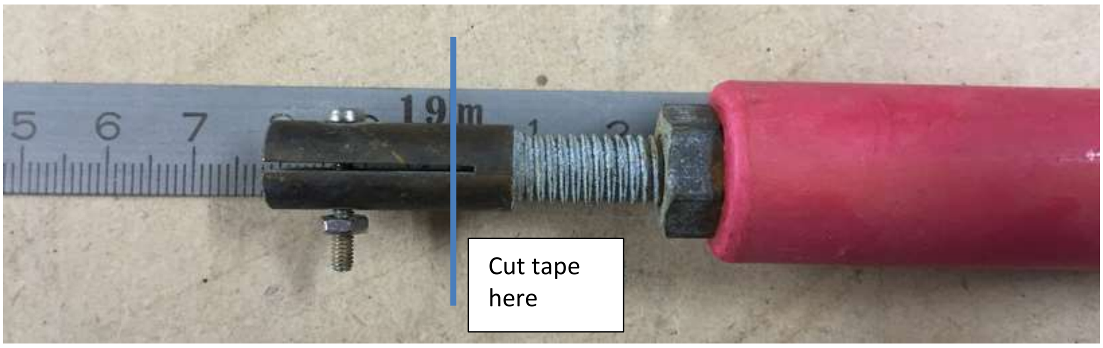


Figure 28 – Electric plumb bob tape cut point

Drill a hole in the EPB tape and attach it to the probe, then lay the probe and tape on top of a tape measure, align the two, and make any fine adjustments as necessary using the threaded insert, and tighten the lock nut.

Attach the other end of the tape to the EPB reel. The exact length at this end of the tape is not critical; however, it must be long enough for the EPB to be lowered to the lowest expected water level.

6.3.6 Checking Reduced Levels of Electric Plumb Bobs

The survey level should be set up so that its height of collimation allows the EPB to be read whilst freely hanging in the stilling well. The EPB weight/pointer should be lowered until the bottom of the pointer is at the cross hairs of the level. While the pointer is at this location, the EPB should be read. This is then reduced to determine the RL zero.

Observations taken on the bottom of the EPB weight should be taken with the weight as close to the water surface as possible. However, unless the stilling well is equipped with a clean-out door, the observation on the bottom of the weight will likely be taken with the weight located just below the instrument shelf.

In some cases the bottom of the EPB pointer cannot be directly read. Several alternate methods are possible including levelling the reference point directly and comparing this with the overall length of the EPB tape.

6.3.7 Water Surface

There are three techniques that can assist in taking precise and accurate observations of the water surface. For streams that are shallow along the banks, a stable object such as a rock, stake, or a screwdriver driven to the water surface can be used as a stable location to hold a survey staff.

A second technique that can be used, if stream conditions (including depth and velocity) allow, is to hold the rod on the stream bed, take an observation of the elevation of the stream bed, and manually read the depth of the water off the survey staff. To determine the elevation of the water surface, compute the elevation of the stream bed and add the water depth to it.

Finally, if the conditions of the stream do not allow both of these techniques, a reference point (either a temporary or a permanent one) can be established as close as possible to the water surface. From this reference point, a measuring tape can be used to measure down to the water surface.

6.4 Resetting External Staff Gauges and Electric Plumb Bobs

The main purpose of running levels at site is to verify that reference points, specifically the EPB and ESG, are properly set to read the stage at the site. The EPB or ESG should be reset if the absolute value of the differences between the elevation reading of the EPB/ESG and the site datum is greater than 3 mm. Before the EPB/ESG is reset, all elevations must have been computed and have been verified.

7 Practical Controls

7.1 Site Access

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

A long-term access agreement with any landowners whose land must be crossed to gain access to the site is recommended.

7.2 Safety

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

When working near high-voltage lines or equipment, even a near approach is dangerous, and the greatest care must be taken. Telephone lines sometimes carry quite high voltages and should be regarded as dangerous as any other power lines. It is advisable, in all cases where there is a risk of accident, to have the power cut off.

Take extra care when walking/climbing around structures whilst carrying equipment as usually only one hand is free for support.

Often a set-up is required on a stairway or steep slope to sight an EPB and care should be taken to avoid these where possible. If such a set-up is necessary, then set the instrument so that minimal movement by the surveyor is required to avoid tricky footwork and the possibility of knocking the instrument.

7.3 Hazard Review

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

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

7.4 Care and Maintenance of Instruments

7.4.1 Dust

Dust should not be allowed to accumulate on any survey instrument. Apart from damage made to foot screws and other surfaces, rain or moisture on dust will cause it to cake in corners and recesses from which it is difficult to remove.

7.4.2 Damp Instruments

A wet or damp instrument must not be cased up and put away for the night. If this is done, evaporation from the wet surfaces while in the box will raise the vapour pressure. Vapour seeping into the interior of the instrument becomes trapped and condensation follows, contaminating the optical surfaces and obstructing the passage of light.

Most survey instruments are supplied with a sachet of silica gel. As silica gel is hygroscopic, it will reduce the moisture content inside the instrument case and prevent the deposition of moisture on the optics and other internal parts of the instrument. Silica gel is only effective when it is active and this is indicated by the colour of the crystals.

A wet instrument should be wiped down and left standing in a safe place overnight to dry out. Artificial heating will promote vaporisation of any moisture inside the instrument which will reappear as condensation on the inner surfaces of the optics.

7.4.3 Optical Surfaces

The optical surfaces of modern instruments are coated with a non-reflecting film in order to improve light-transmission properties, and every effort must be made to preserve it.

A lens with a wet surface should be dabbed with absorbent cloth or paper and allowed to dry without rubbing. A lens with a smeared surface is best cleaned off with ether. To remove dust from the lens, use a camel hair or similar brush.

7.4.4 Metal-to-Metal Surfaces

Foot screws should be checked for slackness. Loose screws permit the instrument to move in relation to the tripod, and thus affect the stability and performance of the instrument in general. Exposed threads require lubrication with a little grease.

Wear in tangent screws is less obvious than in foot screws because the spring loading takes up the slackness. Tangent screws that are exposed will benefit from lubrication.

7.4.5 Handling

Although an instrument is reasonably safe when boxed, and even more so when inside a transport case, it must still be regarded as an object requiring care and handled accordingly. While it is common practice to carry an instrument on its tripod when on the job and moving between instrument stations, the instrument should desirably be boxed when being moved.

7.4.6 Transport

All instruments must be boxed or cased for transport from place to place.

8 Errors

8.1 Circuit Closure Error

The closure error of a levelling circuit is the difference between the RL for the origin benchmark and the RL for that same BM at survey completion/closure.

The random acquisition of error in a level circuit tends to vary with the square root of the number of instrument set-ups. Therefore, a vertical closure error limit for differential levels can be determined by multiplying an acceptable uncertainty constant by the square root of the total number of set-ups. This acceptable uncertainty depends on how the data will be used and should be amenable to the desired accuracy and precision requirements of the levels.

Closure Error

$$CE = \pm 3 \text{ mm or } \sqrt{n} \text{ (whichever is the lower)}$$

where: CE is closure error (mm), and

n is the number of instrument set-ups.

8.1.1 Types of Closure Error

8.1.1.1 Systematic Errors

- inclination of line of sight due to curvature of earth and refraction; generally very minimal due to short sights
- inclination due to maladjustment of instrument (collimation error); can be alleviated by equal length of BSs and FSs
- changes in scale of survey staff due to temperature (usually ignored except in very precise surveys).

8.1.1.2 Random Errors

- incorrect staff reading
- heat waves – limit shot lengths
- survey staff not held vertical (minimise this by using a staff bubble or 'rocking the staff' and taking the lowest reading)
- survey staff not extended correctly
- incorrect level reduction
- unstable change points
- incorrect booking of an observation
- misidentifying a reference point.

All these errors accumulate and it cannot be expected that a zero close is obtained each time.

8.1.1.3 Parallax

A sharply focused level is important for accurate readings of the survey staff. A properly focused instrument locates the graduations of the survey staff at the plane of the cross hairs. Parallax is the relative movement of the image of the survey staff with respect to the cross hairs as the observer's eye moves. This is caused by the objective lens not being focused on the survey staff.

To check for parallax, slightly move your eye up and down while sighting in a survey staff. If the survey staff appears to move with respect to the cross hair, parallax is present. Parallax usually can be eliminated by adjusting the objective focus. This can be achieved by focusing the cross hairs on either infinity or on a piece of white paper in front of the survey level. The setting will remain constant for a particular observer.

Diligence in refocusing the instrument for all readings and checking for parallax will eliminate erroneous measurements associated with improper focus.

8.2 Adjusting Circuit Closure Error

To check the calculations of a survey, the back sight, foresight, rise and fall columns should be summed. The following sums must agree for zero closure:

- the sums of the backsight and foresight columns, i.e. the difference will be zero
- the sums of the rise and fall columns, i.e. the difference will be zero, and
- the sums of the reduced levels at the start and end of the survey, i.e. the difference will be zero.

Calculate the closure error. This is the reduced level of the origin BM at the start minus the reduced level of the origin BM at the end.

Divide the closure error by the number of instrument set-ups you used (x).
Where for the first set-up $n = 1$, and for the second $n = 2$ (etc.), the adjustment for all the RLs from a single station is $n*x$.

In Figure 29, below, some errors have been introduced into the earlier example.

BS	IS	FS	Rise	Fall	RL	Corr	Adjusted RL	Remarks
1.526					10.000	0	10.000	Origin BM
	0.862		0.664		10.664	-0.001	10.663	A
	1.113			0.251	10.413	-0.001	10.412	B
1.304		0.888	0.225		10.638	-0.001	10.637	C
	0.652		0.652		11.290	-0.002	11.288	D
	2.339			1.687	9.603	-0.002	9.601	E
		1.940	0.399		10.002	-0.002	10.000	Origin BM
2.830		2.828	1.940	1.938	-0.002			Close

Figure 29 – Adjusting reduced level with closure error

In the example above (Figure 29), the closure is -2 mm and the number of instrument set-ups is 2, so the correction for the first station is −1 mm and the second is −2mm.

9 Preservation and Performance of Survey Records

9.1 Preservation

The following data shall be archived and retained indefinitely:

- final checked and verified survey data, and
- associated metadata, including:
  - benchmark and reference point datums
  - station history summaries (e.g. WS16), and
  - site maps.

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

9.2 Performance

Past level notes for the station where levels are to be run should be reviewed. These notes show the previous composition of the level circuit(s), which can assist in planning the new level circuit(s). The past level notes can be used to determine the maximum elevation difference between the origin and any point in the circuit. The historic level summary should be examined for any stability issues related to benchmarks and reference points.

Finally, copies of the past set of level notes and the site diagrams should be made and taken to the site (originals should not leave the office).

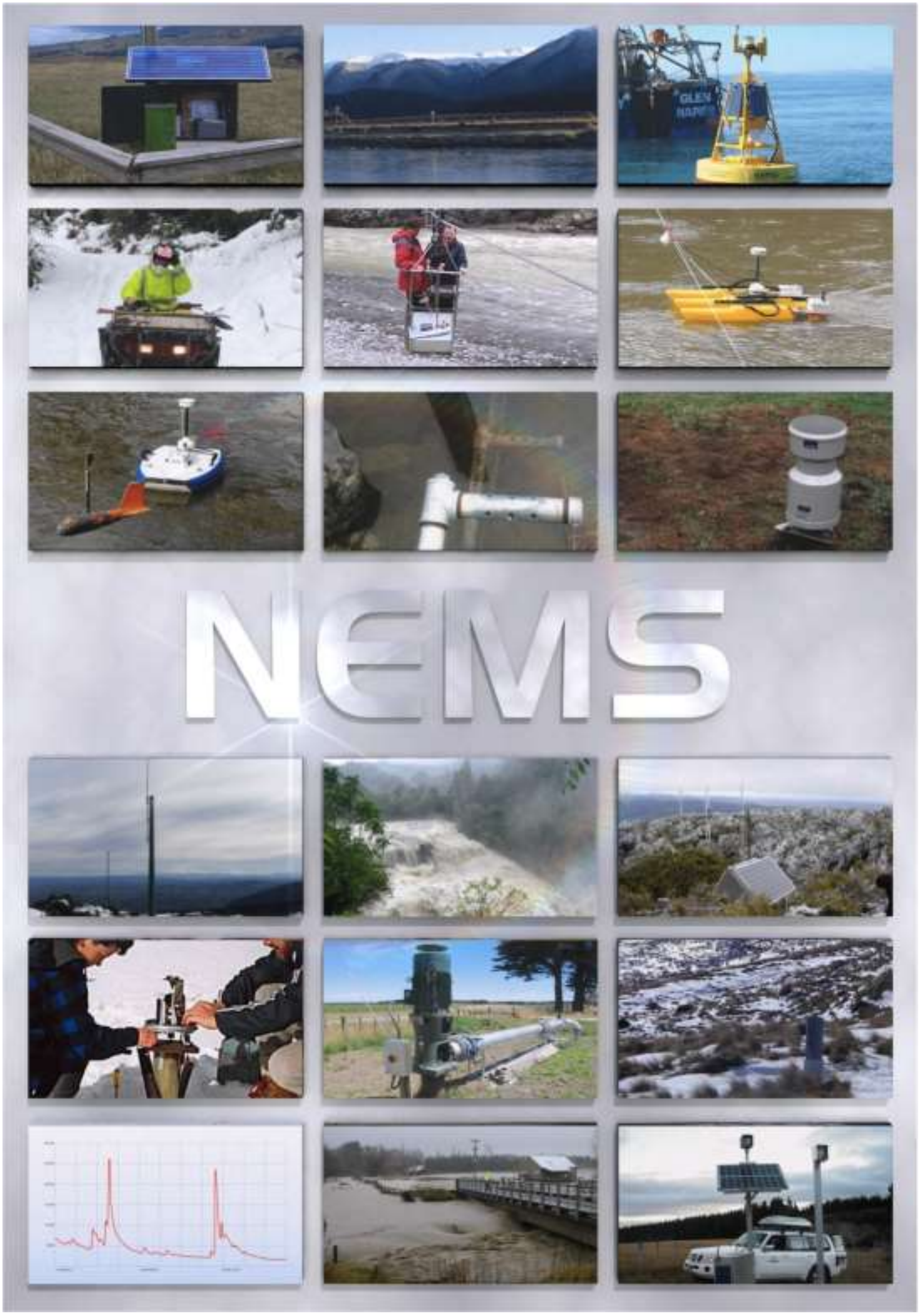
Annex A – Bibliography

APHA, AWWA, WEF (2005). *Standard methods for the examination of water and wastewater* (21st ed.). Alexandria, VA: Water Environment Federation.

Hach. (2007). *Hach LDO dissolved oxygen data sheet*. Retrieved from http://www.wastewatercanada.com/Products/Hach/Parameters_Process/LDO-Spec.pdf

Ministry of Works and Development (1981). *Survey Manual*. Wellington, New Zealand: Author.

US Geological Survey. (1990). Levels at streamflow gaging stations. In *Techniques of Water-Resources Investigations* (Book 3: *Applications of Hydraulics,* Section A-19*).* Reston, VA: US Geological Survey.


NEMS