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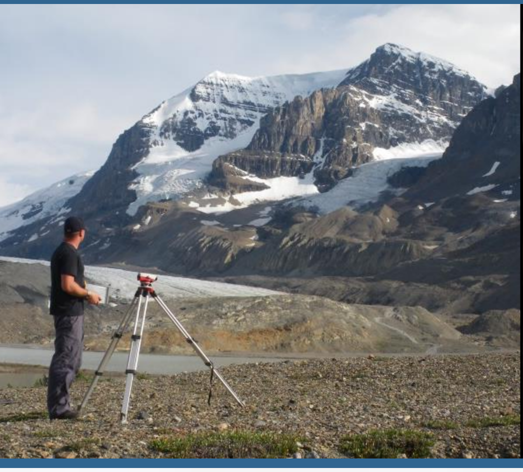
Hydrometric Field Manual

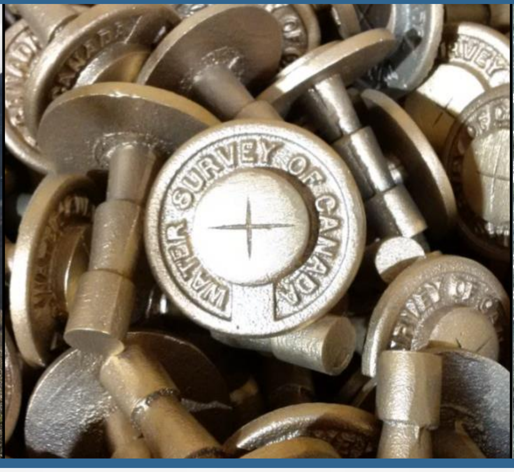
Levelling

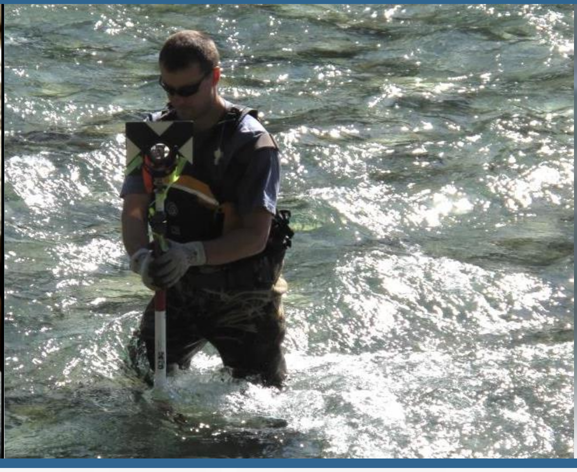
Water Survey of Canada

Environment and Climate Change Canada

qSOP-NA005-04-2019







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Authors: Stephanie Moore, François Rainville, James Wilcox

Version aussi disponible en français.

Front Cover
Left: Sean O'Connor taking levels at Sunwapta River at Athabasca Glacier (photo by Dave Moncur)
Middle: Benchmark brass cap inventory in Gatineau (photo by Paul Campbell)
Right: Kyle Page taking levels for an indirect measurement on the Red Deer River, AB (photo by Jerry Wagner-Watchel)

Back Cover
Left: Curtis Waiting levelling at Elbow River below Sarcee Bridge, AB (photo by Curtis Waiting)
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Right: Staff plate used as reference gauge

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Version Control

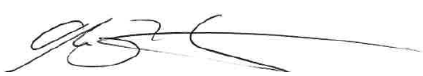
Version	Date	Source	Description/Rationale for Change
3.0	June 2017	SAM, FR, JAW, CT	Overhaul of qSOP-NA005-02 to clarify and update requirements
4.0	May 2019	SAM	Corrected two incorrect sentences and clarified one diagram.

Foreword

The Water Survey of Canada (WSC) is the federal agency responsible for the collection, interpretation and dissemination of standardized hydrometric data and information in Canada. It is a well-respected organization, proud of its traditions and accomplishments spanning over 100 years but also progressive in its attitudes. The Water Survey of Canada is an International Organization for Standardization 9001 certified organization committed to the principle of continuous improvement.

Adopting standard practices for levelling is essential to our mandate. This document outlines the field methods used by the Water Survey of Canada for all levelling activities, including the assessment of benchmark stability, gauge stability and site geometry. The procedures presented in the previous version of this document (qSOP-NA005-02-2005) have been modified in order to clarify and update national requirements. In addition to the material covered in the previous version of this Standard Operating Procedure, this document includes a discussion of thresholds for assessing the quality of results, giving guidance on what to do when these criteria are not met. It also includes detailed procedures for levelling circuit scenarios, with guidelines for how, under any condition, levels should be performed. Inconsistencies in guidance regarding the thresholds for survey tolerance and corrections have been eliminated. Office activities related to levelling are documented in other procedures such as those related to Data Computation (e.g. qSOP-NA037-00-2012).

Many of our employees offered support which enabled the development of this document. In particular we thank the following people in alphabetical order: Dwayne Akerman, Tom Arsenault, Steven Baxter, Crystal Beaton, Nicole Ferguson, Dennis Lazowski, Theodore Mlynowski and Julie Thérien for their detailed review of the document. We thank everyone for their effort in contributing to these procedures and are confident that it will help maintain our reputation of excellence for years to come.



Al Pietroniro
Director, National Hydrological Services
July 2017

Glossary

Backsight (BS): A sight taken on a benchmark or point of known elevation in order to determine the instrument height.

Benchmark (BM): A permanent, fixed reference point of known elevation.

Benchmark History: The record of surveyed elevations of all benchmarks and reference gauges used throughout a station's history.

Closed circuit: A line of levels that ends at the point of origin.

Closure error: The difference between the starting elevation and the surveyed elevation at the end of the circuit.

Collimation error: The deviation or inclination of a level's line of sight from horizontal, often given as a vertical deviation per horizontal distance, such as *x* millimeters per *y* meters.

Differential levelling: The process of measuring the height difference between a point of known elevation and a point of unknown elevation in order to determine the unknown elevation.

Established elevation: The documented elevation of a benchmark or reference gauge to which subsequent surveyed elevations are compared.

Foresight (FS): A sight taken on a point for which an elevation is to be determined.

Full tie-in: Levelling of all benchmarks and reference gauges at a gauging station, beginning on the primary benchmark.

Gauge correction (GC): A correction that is applied to recorded water levels to account for vertical movement of the reference gauge.

Gauge datum: The surface to which gauge heights are referred. It may be an assumed datum or a standard datum. Note: there is no connection between assumed datum at different sites, they are independent.

Gauge height: The height of the water surface above the gauge datum. This term is used interchangeably with stage and water level.

Gauging station: A location where systematic records of stage or stage and discharge are obtained, synonym of hydrometric station.

Height of Instrument (HI): The elevation of the line of sight through a levelled telescope of a levelling instrument.

Intermediate foresight: A foresight obtained using the same instrument setup used for another objective point.

Level circuit: A line of levels that ends at the point of origin or at another previously established benchmark.

Level run: Levelling between two or more points measured in one direction. The outward run is from known to unknown points and the return run is in the opposite direction.

Levelling rod: A graduated rod used in measuring the vertical distance between a point on the ground and the line of sight of a surveyor's level.

Local reference network: The assemblage of benchmarks at a site.

Objective point: A point for which the elevation is to be determined. This is the point on which the levelling rod is placed and the levelling instrument's line of sight is focused.

Primary benchmark: The benchmark considered to be the most stable.

Reference gauge: The gauge to which the readings from the stage sensor are compared. This can include many things such as an electric contact gauge, a "measuring point", or benchmark from which direct water level measurements are taken.

Reference point: A stable, accessible point (for example on a bridge, pier, or abutment) from which the distance to the water surface may be measured; also known as measuring point.

Returning point: The objective point that is the last point surveyed on the forward run of a level circuit and the first point surveyed on the return run. It is the turning point that is used to establish a new instrument height from which second elevations of previously shot points are determined.

Rod level: A circular level mounted on an angle bracket which is held against the levelling rod and is used to align the rod in a vertical position.

Sighting: A reading of the levelling rod through the level.

Staff gauge: A graduated plate or rod which is set vertically in a streambed or attached to a solid structure.

Station Analysis: The document describing all interpretive details and decisions that were used in data production.

Surveyed elevation: The elevation of a point that is obtained via surveying.

Survey tolerance: The maximum closure error allowed for a given levelling circuit. It depends on the number of instrument setups and the circuit length.

Turning point: A fixed point on which a foresight rod reading is taken, then the instrument is moved and a backsight rod reading is taken in order to establish a new instrument height.

1. Introduction

The function of a hydrometric gauge on a river, stream or lake is to provide the means by which reliable and accurate water levels can be obtained for most conditions. Since these water levels are commonly used as input to discharge models, a lack of permanent datum or instability of the stage sensor, benchmarks or reference gauge can contribute to unreliability or inaccuracy of water level and discharge records. Although some problems can be overcome by careful and proper positioning of benchmarks and installations, periodic levelling must be carried out to assess their stability.

Levelling is the process by which elevations of points of interest are determined. Levelling for hydrometric operations serves four main purposes:

1) Monitoring stability of a system of benchmarks as an indicator of site stability;
2) Monitoring vertical displacement of a reference gauge to determine gauge corrections;
3) Performing direct water level measurements to determine sensor reset corrections;
4) Obtaining elevations of other points such as a high water mark or the elevation of the river bed.

The timelines and frequency of each activity differ: item 1 relates to long term monitoring, item 2 relates to medium term monitoring (months to years), item 3 is visit to visit monitoring and item 4 is event based monitoring. All levelling activities hinge on the results of the benchmark stability monitoring since the elevation of the primary benchmark is used to determine the elevations of all other surveyed points.

2. Reference Gauge and Gauge Datum

Readings from the stage sensor are routinely compared to readings from the reference gauge at each station. The reference gauge may be a staff gauge, a wire-weight gauge installed on a bridge or an electric contact gauge (ECG) inside the station shelter. The reference gauge may also be a permanent point from which direct water level measurements are taken, such as a benchmark. It is best to only have one reference gauge per station as this will reduce the chance of making errors when applying gauge corrections.

In order to obtain accurate and reliable stage data at a station, the reference gauge and benchmarks must be referred to a fixed datum, known as the gauge datum (Figure 1). This level surface above which all elevations are expressed is often an assumed datum that is generally specified by assigning an arbitrary elevation to a particular benchmark. Alternatively, the gauge datum may be a reference plane dictated by operational requirements, including the Geodetic Survey of Canada (GSC) datum or the Prairie Farm Rehabilitation Administration datum, among many others. For the purpose of discharge computations there is no advantage in using one datum over another. However, the gauge datum should be well below the elevation at which zero flow is likely to occur in order to ensure that stage readings are only ever positive values even if the channel is scoured.

To ensure the quality of records, each station's gauge datum must be documented in HYDEX. Using a common datum for all hydrometric stations in a drainage basin provides data users with the average slope of the water surface between sites in a watershed. An example of a common gauge datum is the Canadian Geodetic Vertical Datum of 2013 which approximates the shape of the surface of the oceans that would result from Earth's gravity. If additional datum references are required, they must be listed in HYDEX along with their associated datum transformation and information on how the transformations were obtained.

Every reasonable effort should be made to express elevations at a given gauging station relative to the same datum throughout the station's period of record. This is particularly important when a station is reactivated. Continued use of the same datum at a site leads to consistency in the stage record, greatly enhancing the value of hydrometric data for numerous hydrologic and engineering studies.

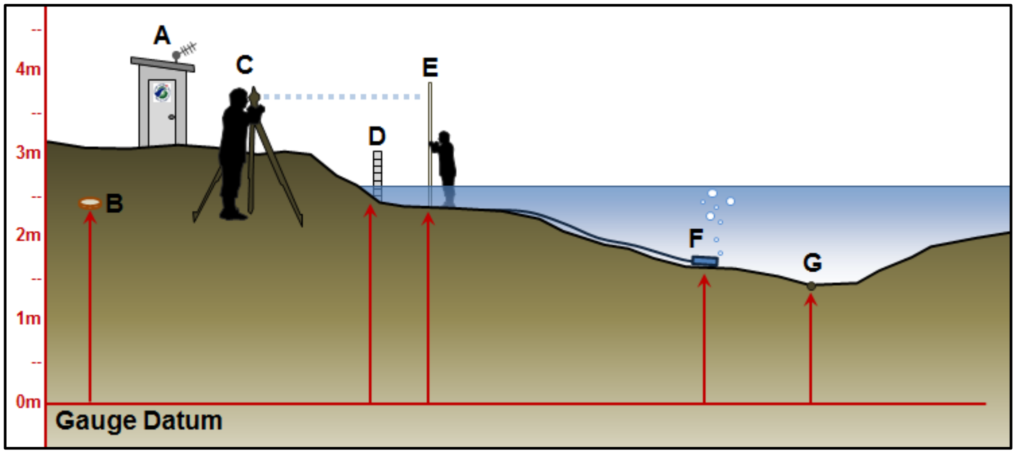


Figure 1: Sketch illustrating (A) gauge house, (B) benchmark, (C,E) direct water level reading, (D) reference gauge, (F) stage sensor or orifice, (G) point of zero flow.

3. Benchmarks

Knowing the elevation of the reference gauge relative to the gauge datum at all times ensures continuity and consistency in the stage record. To allow reliable monitoring of its position, there must be a system of at least _**three**_ permanent and stable markers (benchmarks) that are independent of each other and independent of the gauging structure. If a site has only two benchmarks, no decisions can be reached about their movement. On the other hand, there is no benefit to having more than four benchmarks. Throughout the remainder of this document, the assemblage of benchmarks at a site is referred to as the local reference network.

In addition to being used as a reference system for the elevation of the gauge datum, benchmarks are used to monitor site stability. Benchmarks may sometimes be disturbed or destroyed by natural processes such as erosion, tremors, structural settling or human activities such as construction work or snow plowing. Therefore, to reduce the risk of losing the reference to the gauge datum and to best assess site stability, the benchmarks should be spread apart and well away from the river bank and/or areas of destructive human activity. At least one benchmark must be above the floodplain. If possible, all stations should have at least one benchmark that offers a large unobstructed view of the sky to enable sampling of GPS data from that marker.

3.1 Benchmark Types

There are two styles of official benchmark presently used by the WSC. One is a brass plug which can be mounted vertically or horizontally in a rock or concrete surface (see subsections on benchmark placement below), the other is a brass cap which is meant to be screwed onto coupled threaded rods that have been excessively pounded to the point of refusal with a power drill (i.e. a pneumatic hammer drill). In this case, the brass cap and any rod couplers should be coated with thread locking adhesive to ensure longevity.

When installing a new benchmark, if it is impractical to install a WSC benchmark, the use of another agency's permanent benchmark is acceptable if it is considered stable. This may alleviate any concerns about putting a WSC benchmark in an engineered facility like a bridge or dam. All benchmarks must have a unique identifier (ID) that is controlled by each office and assigned when the benchmark is installed, with the exception of benchmarks from other agencies that have their own unique identifiers. The identifier is placed on the crowned surface of official benchmarks (Figure 2). These serial numbers must be recorded in the station description and in the Benchmark History. The serial number should indicate by the first one or two letters the province or territory in which the benchmark is located, by the following two or four digits, the year in which it was established, and by the last digits, the numerical sequence in which the ID was assigned in a particular calendar year. The abbreviations for the provinces and territories are as follows:

A: Alberta	NO: Northern Ontario	PE: Prince Edward Island
BC: British Columbia	NS: Nova Scotia	Q: Quebec
M: Manitoba	NT: Northwest Territories	S: Saskatchewan
N: Newfoundland	NU: Nunavut	YT: Yukon Territory
NB: New Brunswick	O: Ontario	

Figure 2: An image of a horizontally-mounted WSC benchmark complete with a benchmark identifier.

When establishing a new benchmark at a site, if no other benchmarks pre-exist in the area and if, in rare circumstances, there is an operational need to use unmarked components of an engineered facility such as a bridge bolt, every effort must be taken to permanently identify it with the WSC ID. This can be done using a stamp, plaque or witness sign nearby that point to the benchmark location and displays its ID (e.g. A2016-118).

Many sites currently have benchmarks without brass caps. These may include carriage bolts and lug nuts, or steel ledges on bridges. While these benchmarks do not need to be replaced, every effort must be made to permanently mark them as detailed above. Unidentified markers are not considered permanent benchmarks.

Benchmarks must be adequately described in the data computation system (e.g. Aquarius in 2017) and in any other relevant station records. These descriptions must enable them to be easily located at any time of the year. As such, there must be an explicit physical description of each benchmark, including reference to any stamped ID or other markings. The descriptions should also include their location relative to permanent features, using distance and heading. An example of a suitable description would be, "BM S2017-129: Brass cap on threaded rod driven 8 m deep, located 0.8 m NW of NW corner of shelter."

Temporary benchmarks, such as those that may be installed in a flood situation, do not need brass caps. Temporary benchmarks are used for newly constructed stations and for existing stations where permanent benchmarks have recently been destroyed. They should only be used for relatively short periods until permanent benchmarks can be established.

3.2 Horizontally-mounted Benchmarks

Horizontally-mounted benchmarks are often set in rock, soil or cement. It may sometimes be difficult to install a benchmark on a perfectly horizontal plane, as can be seen in Figure 3b where the benchmark cap is slightly slanted. When obtaining the elevation of these benchmarks, the level rod must be placed on the highest point for the reading.

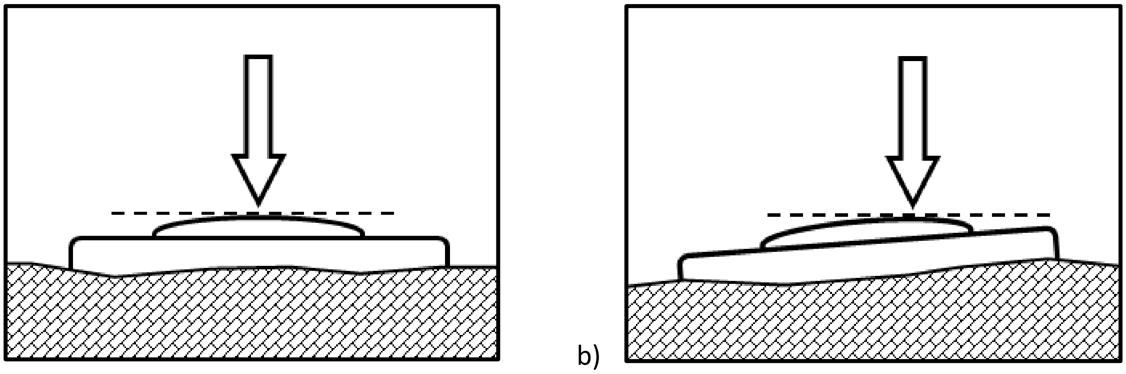


Figure 3: Benchmark caps mounted horizontally. The arrows show where the rod should be positioned when reading elevations.

3.3 Vertically-mounted Benchmarks

Vertically mounted benchmarks are often set into a concrete building or bridge facility. For benchmarks mounted on a vertical surface, the raised centre section protrudes far enough to allow a level rod to be placed on the edge of the crown as shown in Figure 4a. In this case, neither cross limb should be in the horizontal position. If the top of the benchmark is mounted under a ledge so that the edge of the crown is not accessible, a benchmark chisel or knife blade can be placed in the groove of the horizontal limb and the level rod can be held on the chisel as in Figure 4b. In either case, an arrow stamped on the crowned surface is required to indicate the point to which the elevation applies and the point of elevation must be stated in the benchmark description.

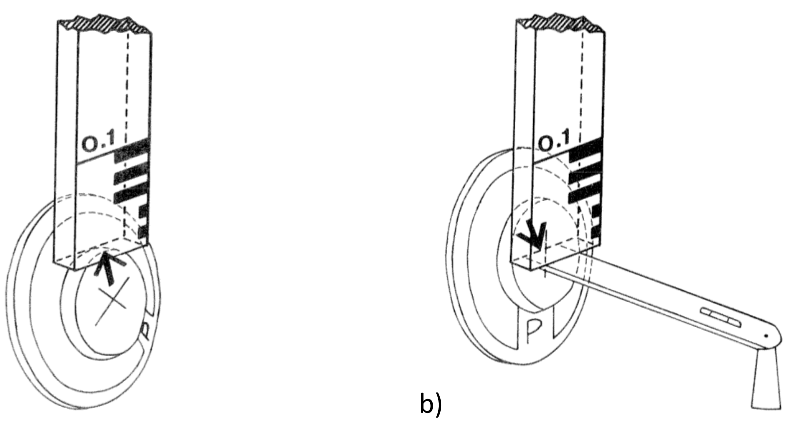


Figure 4: Demonstration of the use of benchmarks mounted in a vertical plane. Engraved arrows indicate where to place the leveling rod: (a) Place the leveling rod on the edge of the raised center section. (b) Place the benchmark chisel in the long horizontal groove, and the rod on top.

4. Monitoring Stability – Benchmark History Analysis

The record of surveyed elevations of all benchmarks and reference gauges used throughout a station's history is referred to as the Benchmark History. Depending on the site, this record may be a paper document, an entry within the data computation system, or some combination of the two. Analysis of this record is performed to determine if:

(a) The designated primary benchmark is appropriate, i.e. if it is indeed the most stable.
(b) The established elevation of a benchmark or reference gauge needs to be adjusted.
(c) A new benchmark should be added to the local reference network to replace a benchmark that is unstable or has been destroyed.

Benchmark History Analysis should be done after each full tie-in. When done consistently, examining the last 5-10 years of levelling data should be more than sufficient to draw meaningful conclusions (see Figure 5). These conclusions must be documented on the Benchmark History and in the Station Analysis.

4.1 Defining Stability

A benchmark is classified as stable if:

- Its surveyed elevation has fluctuated about a consistent value throughout the last five years and the deviation from the mean surveyed elevation has not exceeded the survey tolerance (concept introduced in Section 6.2) as shown in Figure 5a.

A reference gauge is classified as stable if:

- Its surveyed elevation has fluctuated about a consistent value throughout the last three years and the deviation from the mean surveyed elevation has not exceeded the survey tolerance.

A station's local reference network is classified as stable if all benchmarks in that network are stable. Having a stable local reference network will ensure that the continuity of the gauge datum is maintained. A station is classified as stable if all benchmarks and reference gauges at that station are classified as stable.

A benchmark or reference gauge may be classified as unstable if:

- Its surveyed elevation differs from its established elevation by more than the survey tolerance as shown in Figure 5b. This indicates that the point was unstable in the past but does not indicate whether it will continue to be so. An event could have caused a change in elevation.
- There is a trend in the deviation of the surveyed elevation from the established elevation as shown in Figure 5c. Note that a point may be unstable even if the deviation is within the survey tolerance.

Any benchmark or reference gauge that is found to be unstable will have to be carefully monitored in future visits. Unstable benchmarks or reference gauges require more frequent levelling, and when used for water level measurements they regularly result in the application of gauge corrections (see Section 8.2). Operationally, it is more important to have a stable reference network than a stable reference gauge because gauge corrections can account for reference gauge instabilities, but these can only be defined with a stable network.

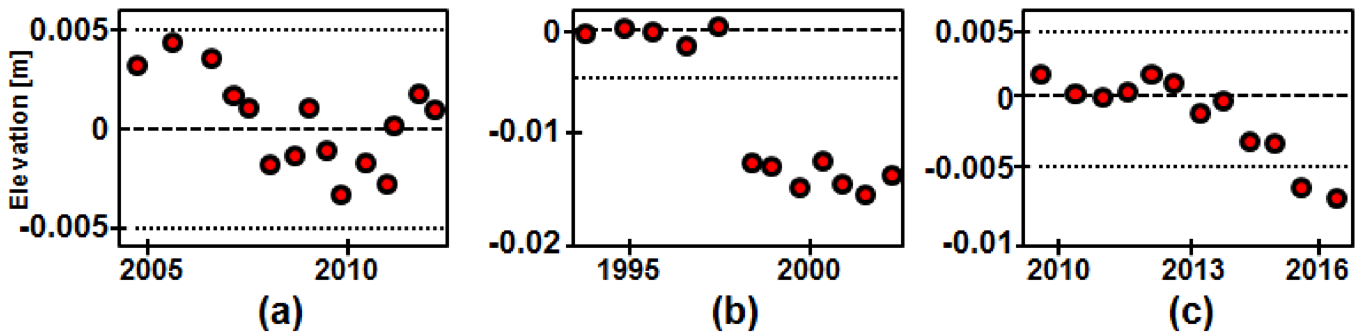


Figure 5: Surveyed elevations for three benchmarks that each have an established elevation of 0.000 m (dashed line) and a local survey tolerance of ±0.005m (dotted line, see Section 6.2): (a) stable benchmark; (b) benchmark whose elevation changed suddenly and appears to have stabilized; (c) currently unstable benchmark.

The following should also be considered while performing a Benchmark History Analysis:

- If the surveyed elevations of all secondary benchmarks indicate the same trend (i.e. evolve in the same direction by the same amount), it is likely the primary benchmark that moved, not the secondary benchmarks.
- If all points in the local reference network move to the same extent in the same direction, as may be the case with isostatic rebound, this movement will go undetected.

4.2 Frequency of Levelling

Levels should be run between all benchmarks and reference gauges once a year at stable sites, preferably after the spring thaw, and twice a year at unstable sites. This is referred to as a full tie-in. In addition, the elevation of the reference gauge may have to be monitored more frequently depending on its documented stability.

4.3 Benchmark Replacement or Adjustment of Established Elevation

If Benchmark History Analysis reveals that:

1. A benchmark has moved but then stabilized (i.e. the surveyed elevation has fluctuated about a consistent value throughout the last 5 years and the deviation from the mean surveyed elevation has not exceeded the survey tolerance), then its established elevation must be changed.
    a. The new established elevation should reflect the most repeatable surveyed elevation.
2. A benchmark is unstable,
    a. If it is the primary benchmark, the role of primary should be assigned to the next most stable benchmark.
    b. A new benchmark should be installed and the elevations of both benchmarks should be monitored until the new one proves to be the more stable of the two based on results from at least 3 full tie-ins obtained over a period of at least 18 months. This should ensure that any seasonal variation is observed.
    c. Once stability of the new benchmark has been demonstrated, the old one must be removed or destroyed to avoid future confusion.

If unstable benchmarks are unavoidable at a station, consider absolute referencing with satellite positioning (discuss with your supervisor and contact National Headquarters for details). All decisions about benchmark replacement or adjustment of established elevation must be documented in the Station Analysis and on the Benchmark History.

5. Instrumentation

Four types of height measurement equipment are currently used by the WSC. The requirements and scenarios for their use are outlined in the following sections, along with the pros and cons of each device. All height measurement devices are mounted on tripods, and all tripods must have legs whose length can be easily adjusted and fixed.

5.1 Spirit Levels (Optical)

The levelling traditionally performed by the WSC is known as differential levelling. Differential levelling involves measuring the vertical difference between a point of known elevation (the backsight) and a point of unknown elevation (the foresight) in order to determine the unknown elevation (Figure 6). A telescope with suitable magnification is used to read a graduated rod held on a point where the elevation is to be determined (the objective point). Measurements of horizontal distance and angle are not required.

Levelling with optical spirit levels requires graduated rods with numerical scales from which elevations are read by eye. Older spirit levels have a manual precise levelling adjustment, whereas modern spirit levels use automatic compensators located within the instrument to level the line of sight precisely after they have been levelled manually. Spirit levels are accepted for use in all aspects of height measurement. They have time tested procedures and a low equipment cost.

The following should be noted about their use:

- The distance at which readings can be obtained depends on the operator's eyesight.
- They are more susceptible to human error than are digital spirit levels.
- They are sensitive to atmospheric refraction, so best results are obtained under uniform atmospheric conditions, for example on an overcast day. Even sighting over a water body can cause atmospheric refraction.
- The condition of the level and rod is critical for accuracy.
- The recommended instrumentation specification for 1 km double run levelling is 2 mm accuracy.

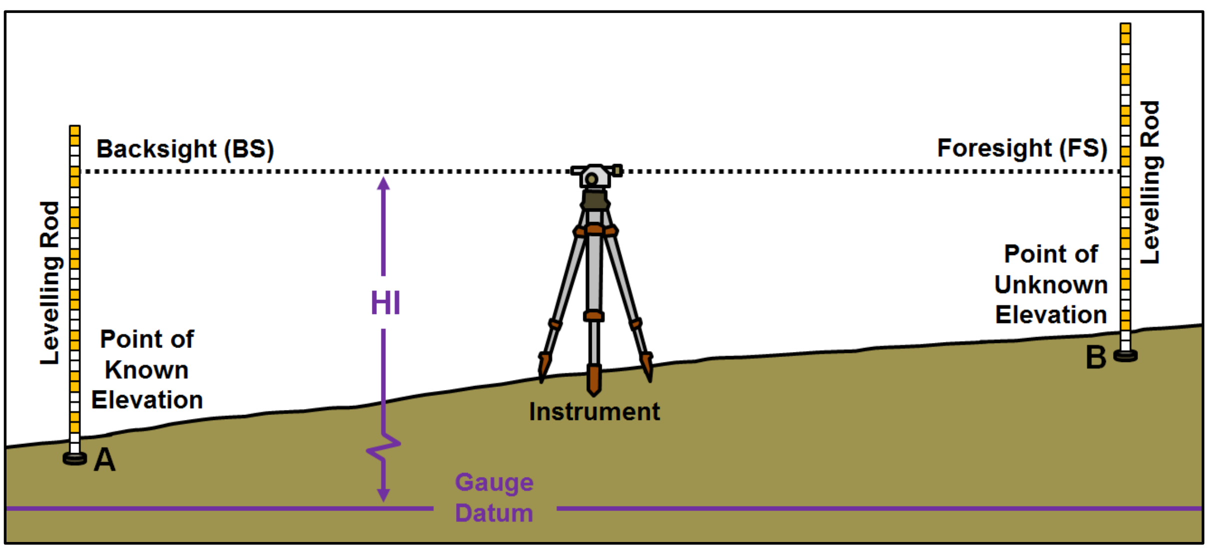


Figure 6: Diagram illustrating instrument setup, foresight (FS) and backsight (BS) for spirit leveling.

5.2 Spirit Levels (Digital)

Digital spirit levels are operated following the same procedures as optical spirit levels (Figure 6), but they are battery operated and require bar-coded rods which are read automatically by the level. The use of digital spirit levels is acceptable in all aspects of height measurement and may be preferable to optical spirit levels, since they are less prone to human error in estimating and reading and measurements are quicker to perform.

The following should be noted about their use:

- Digital files can be exported and stored for proper record keeping.
- The condition of the bar code on the rod is critical for accuracy.
- Construction grade laser levels are not acceptable.
- They are sensitive to atmospheric refraction, as such best results are obtained under uniform atmospheric conditions and they are not effective in extreme heat.
- As with all electronics they have the potential for failure, but most models can be used as optical levels when necessary.
- Electric contact gauges and wire weight gauge plummets cannot be levelled when operating in digital mode, therefore the level must be changed to optical mode in these situations.
- An entirely clear line of site is required.
- Extreme care should be taken not to knock them out of alignment.
- The recommended technical specification for 1 km double run levelling is 2 mm accuracy. It is 1.5 mm when 2nd order accuracy is required such as at the Great Lakes gauges.

5.3 Total Station (Trigonometric Levelling)

Total stations determine an elevation using vertical angles in conjunction with measurements of distance (Figure 7). They may be suitable for use over steep slopes or longer sight lines to reduce the number of instrument setups, subsequently reducing measurement times. The highest accuracy is obtained on lines of up to a few hundred meters.

The following should be noted about their use:

- The method used to measure distances is sensitive to atmospheric refraction; therefore total stations should be used under uniform atmospheric conditions. If there are non-uniform gradients in temperature or humidity, follow manufacturer instructions.
- It is not possible to accurately level an electric contact gauge or a wire weight gauge plummet.
- To perform the recommended procedures (Appendix A), the prism target height must be maintained to correctly calculate a height difference between the backsight and the foresight. Therefore, a fixed height rod should be used.
- Digital files can be exported and stored for proper record keeping.
- The recommended technical specification is 1.5 mm +2 ppm accuracy for horizontal distance and 1” angular accuracy.

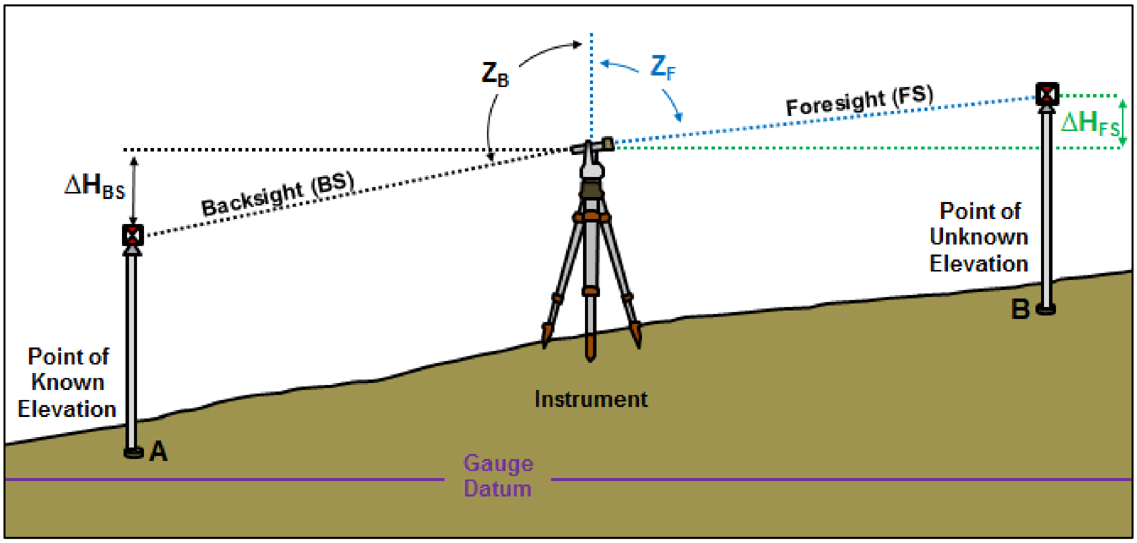


Figure 7: Example of the direct sightings with a total station to prisms at points A and B.

5.4 Use of Global Navigation Satellite System (GNSS)

Where appropriate, Global Navigation Satellite Systems (GNSS) such as GPS can be used for differential levelling (Figure 8). This method requires two static receivers and can provide more accurate height differencing than spirit levelling for sighting distances that are between 500 m and 5 km. For shorter distances under ideal conditions, spirit levelling is more accurate and should be used. The 5 km upper limit is imposed by the assumption that the height difference between the two receiver locations be the same in all height systems (i.e. CGVD2013, ellipsoid, and local datum). Absolute height referencing using geodetic systems (gravity-based height systems) is not covered in this document.

It is important to note that although this method can save time in the field, substantial time is required to process the data in the office and expert knowledge is required. After discussion with your supervisor, consult with National Headquarters on this subject. With this in mind, some basic requirements for differential levelling with GPS include:

- Two receivers operating in Real-Time Kinematic (RTK) or Post-Processed Kinematic (PPK) modes.
- Antenna with multipath technology, such as a choke ring or ground plane, and a known Phase Centre Offset for precise processing.
- Concurrent observations with the two receivers under an obstruction free sky.
- Two sets of observations for at least 2 hours each at different times of day to ensure repeatability of the measurements and to eliminate the impact of geometric or atmospheric anomalies.
- Processing by a subject matter expert (contact National Headquarters).
- Retention and archiving of all raw and processed data, including statistics for quality assurance.
- Recommended technical specification for GNSS Receiver: either 3.5 mm + 0.4 ppm RMS Vertical accuracy OR 1 mm L1/L2 carrier phase precision.

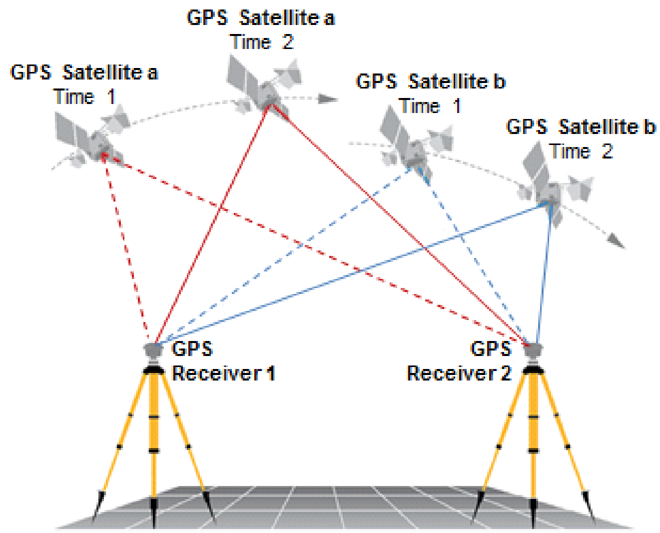


Figure 8: Concurrent GPS signal acquisition for differential levelling.

5.5 Routine Maintenance

All levelling equipment must be tested routinely to ensure proper adjustment and accuracy. The validation tests outlined in each instrument's operation manual must be conducted prior to full tie-ins. Therefore they should be done at least once a year and generally in the spring. They should also be performed after any accidental rough usage. Test and calibration results should be documented according to regional procedures.

The two-peg test is an example of a simple and common test for spirit levelling equipment (see Appendix B for details). If a two-peg test is not done prior to differential levelling, then backsight and foresight distances from a given instrument height <u>must</u> be the same. Typically, modern digital instrumentation requires annual servicing by an authorized agent for each type of instrument. These should be done to the specifications outlined by the manufacture.

When not in use, a rod should be stored in a solid case to prevent accidental scratching of the printed surface or damage to the socket ends. An untreated wooden rod should not continually be placed in water as this will cause the wood to swell and the painted surface will eventually flake off, thereby limiting the useful life of the rod. Levelling rods must be checked for accuracy when first purchased and they should be calibrated prior to any major levelling project.

6. Error

6.1 Sources of Error

The ability to determine the correct elevation (i.e. the accuracy of levelling) depends on the quality of the instrument used and the skill and care exercised in the application of the procedures. Awareness of the factors that contribute to error and of the steps necessary to limit them can help improve the quality of levelling data. The following is a list to which some errors can be attributed. Many of these examples apply only to spirit levelling.

1. <u>Improper Adjustment of Instrument</u> – This condition occurs when the line of sight is not parallel to the axis of the level tube. This error can be minimized by keeping backsight and foresight distances the same. Performing the two-peg test routinely will help detect this error.

2. Parallax – If there is an apparent movement of the cross-hairs on the target with a corresponding slight movement of the observer's eye, the condition of parallax exists. To reduce parallax, the eyepiece of the telescope must be adjusted until the cross-hairs appear sharp and distinct. The objective lens is then carefully focused on a target.
3. Inaccurate Reading of Rod with Optical Levels – These errors can be greatly reduced by using shorter sights and by checking each reading before recording it. The maximum sighting distance for optical levelling should be 90 meters, and ideally less than 30 m.
4. Level Bubble Not Centred – If the level bubble is not centred at the time of sighting, the magnitude of the error will be proportional to the distance between the instrument and the rod. It follows therefore, that the greater the distance to be sighted, the greater the care that should be exercised when levelling the instrument.
5. Settlement of Instrument Tripod – Some settlement of the tripod is likely to occur when levelling over soft, muddy, snowy, or thawing ground. In these instances, backsight and foresight observation should be made in quick succession to minimize any effects from the instrument settling and care should be taken not to jostle or bump the tripod when repositioning for the foresight and backsight.
6. Improper Turning Points – Turning points are fixed points on which a foresight rod reading and then a backsight rod reading are taken in order to establish a new instrument height. If a turning point is not well-defined, it may be hard to locate on the return run. If it is not stable or does not have a rounded or pointed top, the elevation reading may not be accurate. Therefore, turning points should be well-defined, stable and rounded or pointed on top. When no natural turning point exists, a screwdriver driven into the ground can be used.
7. Mistakes - Mistakes can be made due to miscalculation, carelessness or poor judgment. Survey results must be checked in the field before leaving the site in order to detect and eliminate errors.
8. Rod Not Plumb – A rod level can be used to keep the rod vertical. Alternatively, the rod can be waved towards and away from the objective lens while the person sighting the rod notes the smallest elevation seen, which occurs when the rod is vertical (Figure 9). When rocking the rod, it must continue to rest on the front edge of its base when tipped backwards, as can be done when the rod is on a rounded surface such as a brass cap.

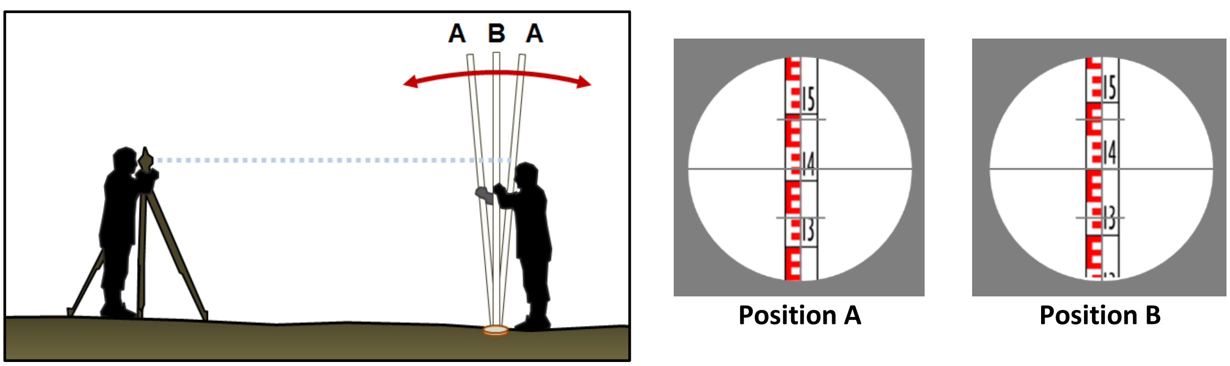


Figure 9: Depiction of waving the levelling rod, demonstrating that the smallest reading (1.400m) occurs when the rod is plumb (position B). When the rod is inclined (Position A), the reading is 1.420 m.

6.2 Closure Error and Survey Tolerance

When a level circuit is closed, the surveyed elevation of the last point (which is also the first point) may not equal the elevation used at the start of the circuit due to the error sources listed above. This difference in elevation is called the closure error, CE, or misclosure:

$$CE = E_{start} - E_{surveyed}$$

The maximum allowable closure error is referred to as the survey tolerance. Closure error must be within survey tolerance to be acceptable. If this is not the case, the level note must be examined for errors and the affected part of the circuit must be rerun. For this reason, the survey tolerance for all completed level circuits must be documented on the field note (Section 0) to enable proper quality checking of results. This value will also be used when assessing local reference network stability (Section 4.1).

For leveling circuits with three or less setups, the survey tolerance is ±0.003 m. Therefore:

- If $|CE| > 0.003$ m, the circuit should be rejected and redone until it is ≤ 0.003 m.
- If $|CE| \leq 0.003$ m, elevations of objective points should be recorded as surveyed on the forward run.

For leveling circuits with four or more setups, the survey tolerance is $\pm 0.01\sqrt{D}$ m, where *D* is the circuit length in kilometers. For example, if a circuit with 4 or more setups is 1 km long, the survey tolerance is ±0.01 m, if it is 400 m long, the tolerance is ±0.006 m. The circuit length is the sum of all sighting distances. A rough estimate of this value can be obtained using the documented information on benchmark location.

Therefore, for circuits with four or more setups:

- If $|CE| > 0.01\sqrt{D}$ m, the circuit should be rejected and redone until it is within tolerance.
- If $|CE| \leq 0.01\sqrt{D}$ m and it exceeds 0.003 m, the error should be distributed following the steps outlined below.
- If $|CE| \leq 0.003$ m, the elevations obtained on the forward run should be used as the surveyed elevations for the Benchmark History.

6.3 Distributing Closure Error

It is important to understand that error distribution **does not** compensate for errors, it simply produces a set of data for which the surveyed elevation of the last point in the circuit is the same as the elevation used at the start of the circuit. As indicated above, closure error is never distributed for circuits with three or less setups. For circuits with four or more setups, when the absolute value of the closure error is within tolerance and more than 0.003 m (i.e. when $0.003\, m < |CE| \leq 0.01\sqrt{D}\, m$ where *D* is the circuit length in kilometers), error is distributed. The following is the primary method accepted by the professional surveying community, and is recommended for use by the WSC, but if other regional methods are found to be sound and preferred, they may also be used. Closure error is distributed to all points in the circuit by adding the following to the surveyed elevation of each point:

$$\frac{CE * n}{x}$$

where *x* is the number of instrument setups used in the circuit and *n* is the setup number so that *n* = 1 for the first setup, *n* = 2 for the second, etc. An example of closure error distribution is shown in Table 1. The surveyed elevation to be noted on the Benchmark History for each objective point is the average of the corrected elevations.

Table 1: Demonstration of closure error distribution for a 4-setup circuit. The last column of the field note which is typically blank has been divided into columns for notes, correction, and adjusted elevation.

Station	Backsight	Height of Instrument	Foresight	Elevation	Notes	Correction	Adjusted Elevation
BM1	0.550 m	30.550 m		30.000 m	Brass Cap	0 m	
BM2	1.205 m	30.356 m	1.399 m	29.151 m	Brass Cap	-0.001 m	29.150 m
TP1	1.113 m	29.911 m	1.558 m	28.798 m	Bolt on Bridge	-0.002 m	28.796 m
BM2	1.239 m	30.388 m	0.762 m	29.149m	Brass Cap	-0.003 m	29.146 m
BM1			0.384 m	30.004 m	Brass Cap	-0.004 m	30.000 m
			Closure Error =	- 0.004 m	OK		

Four set ups and circuit length of 250 m. Survey tolerance based on distance is $\pm 0.01\sqrt{0.25} = \pm 0.005$ m **Established elevations** BM1 = 30.000 m BM2 = 29.150 m Average corrected surveyed elevation of BM2 = 29.148 m

7. Acceptable Levelling Circuits

A level circuit is a line of levels that starts at a point of known elevation and ends at the point of origin or at another point with a previously established elevation. A closed circuit or closed loop is a level circuit that starts and ends on the same point. A variety of closed loop scenarios are used by the WSC, and the choice of scenario is dictated by site characteristics such as horizontal and vertical distances between points to be surveyed (i.e. spatial extent of the local reference network), land cover and available technology. Three acceptable scenarios for spirit and total station levelling are detailed in this section. The examples are presented as they would be completed with a spirit level, but they can be adapted for use with total stations (see Appendix A).

For all scenarios:

- Level rods should not be extended beyond 3 m unless needed. If extended beyond 3 m and readings are being shot near the top of the rod, extra care must be taken to ensure it is plumb, i.e. use the rod waving technique.
- When assessing the stability of the local reference network, the starting point must be the primary benchmark. This means that if a series of smaller loops is used, the first loop must begin on the primary benchmark.
- In order to obtain two independent observations of the returning point (the last objective point surveyed on the forward run of a level circuit and the first point surveyed on the return run), there needs to be a new instrument setup. This will ensure an independent return run of the level circuit. This step can be validated by confirming a difference in instrument height, ideally by more than 1 cm.

When spirit levels are used:

- Sighting distances should not exceed 90 m, and ideally be less than 30 m to ensure more accurate rod readings.
- The instrument should be placed equal distance from all objective points to ensure that errors caused by the line of sight not being horizontal (collimation error) cancel out.

When a circuit has three or less setups, elevations of each objective point are assigned on the initial foresight, i.e. only the first surveyed elevation of an objective point is noted on the Benchmark History. The second elevation obtained for each point is used for validation.

7.1 Forward and Return Runs with Two Instrument Setups

This scenario consists of a forward run to the returning point (the turning point on which the direction of the level circuit changes), and a return run. On the return run the objective points from the forward run are levelled in the reverse order. There are two instrument setups, one in each direction (Figure 10 and Table 2). Multiple foresights are obtained for a given instrument set-up and the additional foresights are referred to as intermediate foresights. To ensure that the potential for error is minimized, shot distances must be less than 30 m.

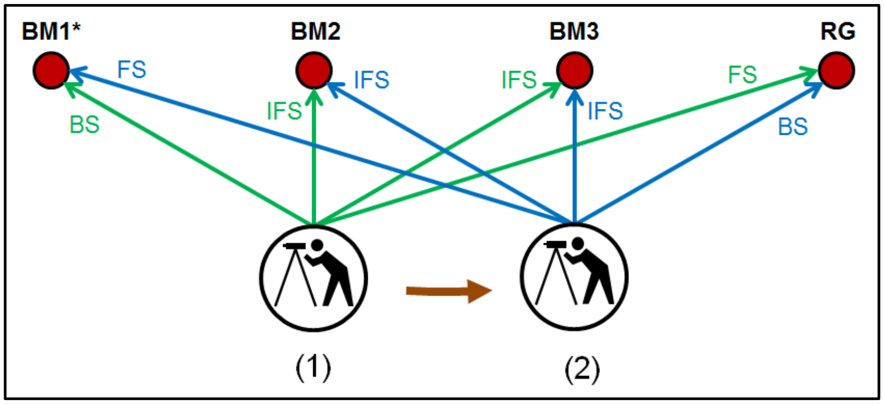


Figure 10 : Forward and return runs with two setups using intermediate foresights (IFS). The starting point is indicated with a star and each red circle indicates an objective point. BM stands for benchmark and RG for reference gauge.

Table 2 : Level note corresponding to the scenario shown in Figure 10, a forward and return run with two setups.

Station	Backsight	Height of Instrument	Foresight	Elevation	Notes
BM1	2.250 m	6.563 m		4.313 m	
BM2			2.258 m	4.305 m	
BM3			1.372 m	5.191 m	
RG	1.418 m	5.980 m	2.001 m	4.562 m	Electric contact gauge
BM3			0.789 m	5.191 m	
BM2			1.673 m	4.307 m	
BM1			1.666 m	4.314 m	
			Closure error =	**-0.001 m**	ok
Two set-ups, therefore survey tolerance is ± 0.003 m					

Application

This method is best suited to sites with small spatial extent (both horizontal and vertical) that have a clear line of sight from the primary benchmark to all points being tied-in. <u>For this method, it is especially important that the instrument be the same distance (i.e. equidistant) from all objective points measured from that position.</u>

Advantages:

- This method is relatively quick to perform since it only involves two instrument setups.
- Points in the circuit where errors occurred can be isolated by examining the level note. This is done by looking for discrepancies between the height difference of subsequent objective points on the forward and return runs. For example, in Table 2 the height difference between BM1 and BM2 is 0.008 m on the forward run and 0.007 m on the return run, so there does not appear to be any major error.

Limitations:

- If there is an error with the instrument (collimation error), the bias will not be detected on the intermediate foresights, it will only be detected once the loop is closed.
- The closure error does not account for errors in the reading of the intermediate foresights.

Survey tolerance

Since this method involves only two instrument setups, the absolute value of the closure error must be less than or equal to 0.003 m. If it exceeds 0.003 m, the circuit must be redone. Closure error is never distributed with this method. Additionally, the discrepancy between forward and return elevations for each point surveyed must be less than or equal to 0.003 m, if not the objective point in question must be re-surveyed as a circuit. Only the elevations obtained on the forward run should be documented in the Benchmark History, elevations obtained on the return run are only used for verification.

7.2 Forward and Return Runs with Four or More Setups

This method consists of a forward run and a return run, changing direction on the returning point, and moving the level after each foresight (Figure 11 and Table 3). If turning points are required, they should be the same on both legs of the circuit. This will allow for tracking of errors since the surveyed elevation of the turning points should be the same on the forward and return runs.

Application

This method is typically used when it is not possible to sight directly between the primary benchmark and all other objective points, either due to obstruction of the line of sight or due to the spatial extent of the network.

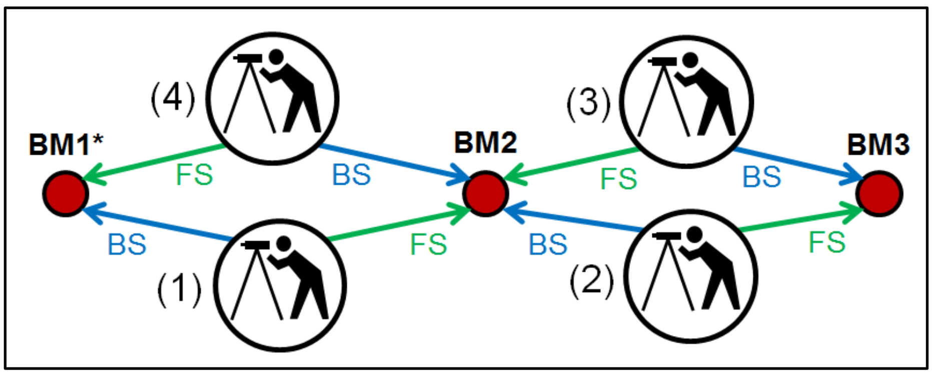


Figure 11: Forward and return runs with four setups. Red circles indicate objective points and setup numbers are given in brackets. The circuit starts and ends at BM1, as indicated by the star.

Table 3: Level note corresponding to the scenario in Figure 11, forward and return runs with four setups.

Station	Backsight	Height of Instrument	Foresight	Elevation	Notes
BM1	2.250 m	6.563 m		4.313 m	
BM2	2.192 m	6.497 m	2.258 m	4.305 m	
BM3	1.444 m	6.634 m	1.307 m	5.190 m	
BM2	2.892 m	7.196 m	2.330 m	4.304 m	
BM1			2.882 m	4.314 m	
			Closure Error =	-0.001 m	OK
Four setups, 240 m circuit length. Survey tolerance is $\pm 0.01\sqrt{0.24}$ = ±0.005 m					

Advantages:

- Ability to isolate points in the circuit where errors occurred by examining the level note. This is done by looking for discrepancies between the height difference of subsequent objective points on the forward and return runs. For example, in Table 3 the height difference of BM1 and BM2 is 0.008 m on the forward run and 0.010 m on the return run so does not appear to be any major error.

Limitations:

- This method can be time consuming due to the number of setups required.
- Errors due to instrument setup propagate throughout the loop. For example, an incorrect instrument height determined on the first setup will affect the reading from the second setup since the backsight will be wrong.

Survey tolerance

Since this circuit involves four or more setups, the survey tolerance is calculated using the circuit length (Section 6.2). When the closure error exceeds the survey tolerance, the appropriate part of the circuit must be rerun. If the error is within tolerance but the absolute value is more than 0.003 m, it is distributed.

Other considerations: a series of small loops

Depending on the spatial extent and visibility of the local reference network, this scenario may take the form of a series of sequentially closed small loops. When a circuit starts on a benchmark that is not the primary benchmark, its surveyed elevation from the previous run should be used as the starting elevation. For example, if the first circuit is from BM1 to BM2 and then back to BM1, and the second circuit is from BM2 to BM3 and then back, this second circuit should begin with the surveyed elevation of BM2. For this scenario, it is important to understand how error can propagate between loops. For example, if the closure error is 0.003 m on both loops, the total closure error is 0.006 m which may exceed the survey tolerance depending on the total distance surveyed. Since it can be tricky to track errors with a set of sequentially closed loops, this method should only be used if it has been approved by local supervisors as an acceptable solution to resolve an operational need. For this scenario, the simplest way to calculate the total closure error is to subtract the sum of the foresights from the sum of the backsights: $CE = \sum BS - \sum FS$.

7.3 Simple Loop

This method is a continuous forward run, starting and ending on the primary benchmark, moving the level after each foresight (Figure 12 and Table 4).

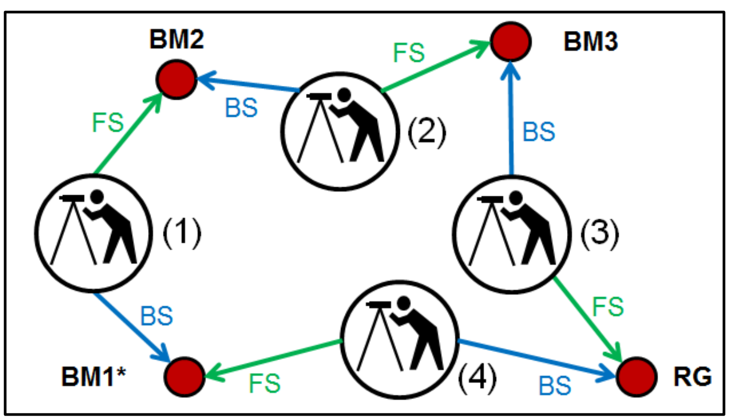


Figure 12: An example of a simple loop starting and ending on BM1, as indicated by the star. The instrument is moved after each foresight and the setup number is indicated in brackets.

Table 4: Level note corresponding to the simple loop example from Figure 12.

Station	Backsight	Height of Instrument	Foresight	Elevation	Notes
BM1	1.250 m	5.563 m		4.313 m	
BM2	1.205 m	5.509 m	1.259 m	4.304 m	

BM3	0.800 m	5.991 m	0.318 m	5.191 m	
RG	2.201 m	6.191 m	2.001 m	3.990 m	
BM1			1.880 m	4.311 m	
			Closure Error =	0.002 m	OK
Four set-ups, 450 m circuit length Survey tolerance is $\pm 0.01\sqrt{0.45}$ = ±0.007 m					

Application

Since this method involves only one leg between each pair of subsequent objective points, there is not the same quality control as with the methods presented in Sections 7.1 and 7.2. Therefore this scenario is not an acceptable method when obtaining the first elevation of a new benchmark or reference gauge.

Advantages:

- Relatively quick to perform as there is only one backsight and one foresight per objective point.

Limitations:

- When a closure error is found, it is not possible to know where in the circuit the error was introduced.

Survey tolerance

If there are three or less setups, the ±0.003 m rule applies. If there are four or more setups, the distance rule applies. Additionally, if any point in the circuit has a surveyed elevation that differs from its established elevation by more than ±0.003 m this difference must be confirmed by performing an additional simple loop from the primary benchmark to the point in question and back.

8. Monitoring Vertical Displacement of the Reference Gauge

The elevation of the reference gauge must be monitored in order to determine:

(1) Its overall stability (its movement should be minimal);
(2) If gauge corrections are required for stage records such as time series and gauge heights noted during discharge measurements.

The frequency with which the elevation of the reference gauge must be monitored depends on its documented stability (Section 4.1). At a minimum, it must be levelled once a year. Any benchmark classified as stable following the procedures outlined in Section 4.1 can be used to monitor the elevation of the reference gauge via levelling; however experience has shown that the process of reviewing of sites is simplified by starting all circuits from the primary benchmark.

8.1 Surveying the Reference Gauge Elevation

Figure 13 is a schematic demonstrating where to survey various types of reference gauges in order to obtain their elevations. These include wire weight gauges (B), staff gauges (C) and electric contact gauges (D). In each case, gauge corrections are determined by comparing the surveyed elevation to the established elevation of the reference gauge as explained in Section 8.2.

For wire weight gauges, the surveyor must determine the elevation of the bottom of the weight. To do so, the sighting should be taken within the lowest centimeter of the weight which is graduated with 2 mm markings, and the height z in

Figure 13 must be subtracted from the height of the instrument (HI). The reading output from the wire weight gauge, often on a digital screen, should correspond to this elevation. If not, a gauge correction should be considered.

For staff gauges, the surveyor must determine the elevation of the zero of the scale. To do so, a sighting can be taken on any part of the graduated plate. If the staff gauge is too far below the line of sight, a survey rod should be placed beside it, extending above it in order to obtain the elevation of the zero of the staff gauge. The height z in Figure 13 must be subtracted from the height of instrument (HI).

For electric contact gauges, the surveyor must determine the elevation at which the tape is read, this is the triangular marker in Figure 13D. This is typically done by sighting the bottom of the ECG and adding the height z. If the survey instrument is too high for a reading to be obtained on the ECG, a ruler or a survey rod can be placed beside the reel mounting to enable determination of the elevation of the reading/reference marker of the electric contact gauge.

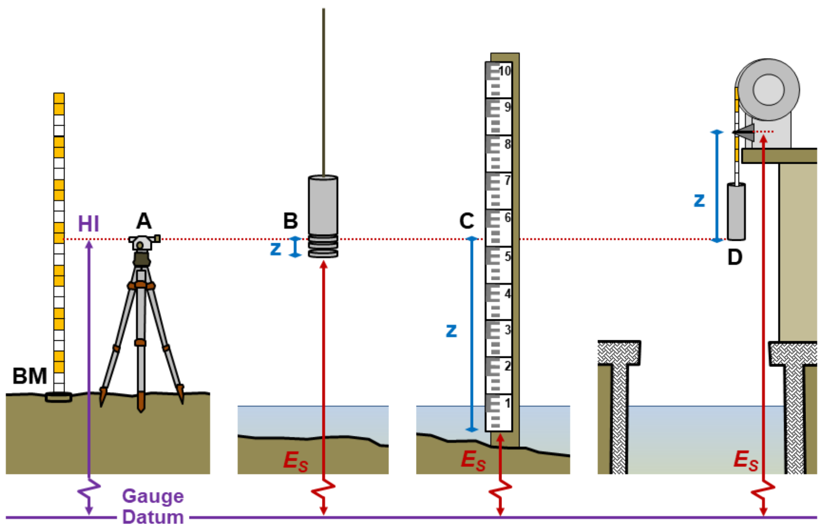


Figure 13: Demonstration of how to obtain elevations for the various reference gauges: a wire weight gauge (B), a staff gauge (C) and an electric contact gauge (D). The height of instrument (A) was obtained using the benchmark BM.

8.2 Gauge Corrections

Gauge corrections (GC) compensate for temporary vertical movement of the reference gauge (Figure 14). They are computed each time that the reference gauge is surveyed by subtracting the established elevation, E_e, of the reference gauge from its surveyed elevation, E_s recalling that elevations are always given relative to the gauge datum:

$$GC = E_s - E_e.$$

If the absolute value of GC is ≤ 0.003 m, no correction should be applied. If it exceeds 0.003 m, a gauge correction is applied to all stage data. Gauge corrections are applied until the elevation of the reference gauge returns to its (previously) established elevation, until a new gauge correction is determined via levelling, or until a new established elevation is determined via Benchmark History Analysis (see Section 4). Gauge corrections must only be entered in the data computation system. They must not be entered in the data logger onsite. This approach keeps gauge corrections separate from other corrections such as sensor resets which account for the difference in water levels read by the reference gauge and the sensor after having accounted for gauge corrections (Figure 14). See the standard operating procedure on data computations for details.

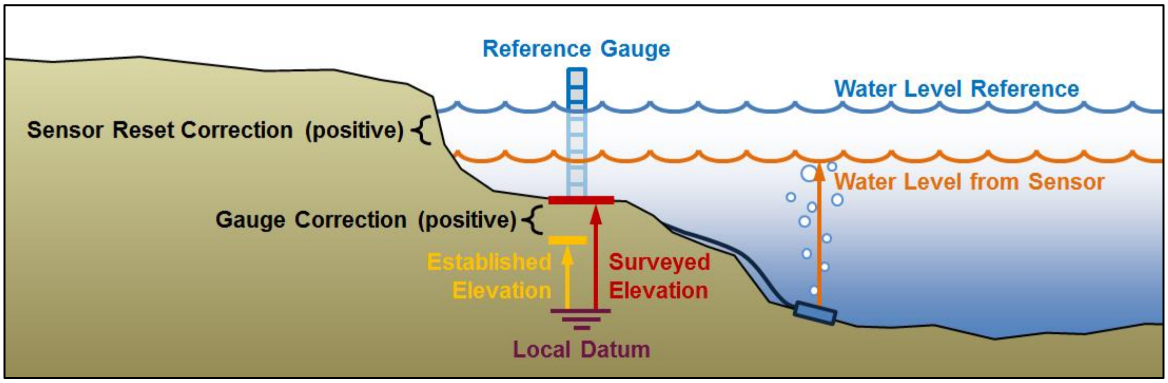


Figure 14: Information involved in the definition of Gauge and Sensor Reset Corrections.

8.3 Changing the established elevation of the reference gauge

Changing the established elevation of the reference gauge should reduce or even eliminate the need for future gauge corrections. Deciding to change the established elevation of the reference gauge must be based on Benchmark History Analysis (Section 4). When changing the established elevation of the reference gauge (Figure 15), the following steps are recommended to ensure that reliable and continuous water level data are recorded throughout the process:

Prior to the station visit:

1. Define a new established elevation for the reference gauge. This value should reflect the most repeatable surveyed elevation.

During the station visit:

2. Survey the elevation of the reference gauge and compare this elevation to the proposed new established elevation. If they agree within ±0.003 m, proceed with the change. If not, changing the established elevation should be postponed until further analysis.
3. Measure the water level using the reference gauge, noting the stage sensor value (HG) observed at this time. Apply a sensor reset correction if needed (see Data Computation SOP for details).
4. Apply the new established elevation to the reference gauge. This may require adjusting the instrument setup so that readings are easily compared with sensor outputs.
5. Measure the water level using the reference gauge, which is now set to its new established elevation. Note the stage sensor value observed at this time. Apply a sensor reset correction once again, if needed.

After the station visit, while back in office:

- The surveyed elevation of the reference gauge is used to define and terminate any gauge correction that was applied on data prior to the change of established elevation. Note that the terminated gauge correction was transferred to the change in established elevation.
- A sensor reset correction based on the water level measurement obtained before the change of established elevation is applied to data prior to the site visit (see Data Computation SOP for details).

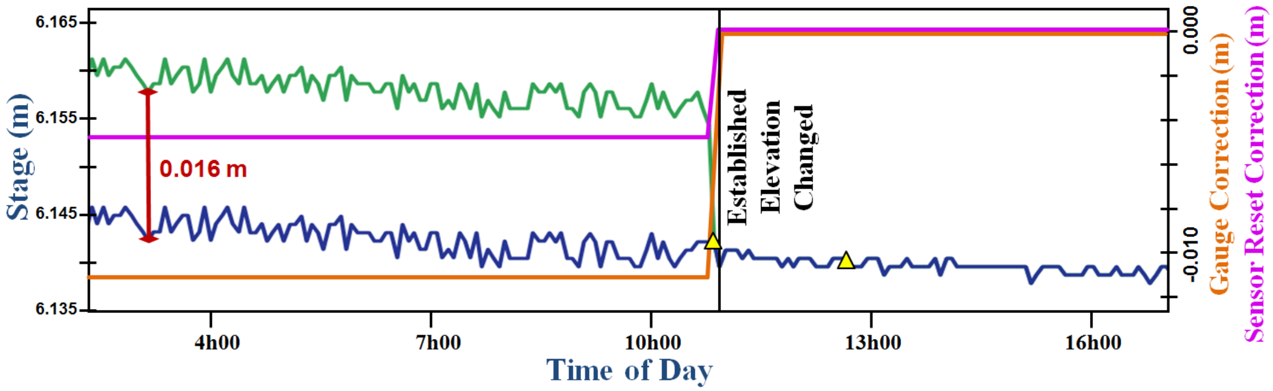


Figure 15: Example of corrections applied to stage data prior to and following a change of established elevation. The yellow triangles show reference gauge readings. Before the change of established elevation, there was a difference of 0.016 m between the raw (green) and corrected (blue) signals which corresponded to a gauge correction (GC) of -0.011 m and a sensor reset correction (SRC) of -0.005 m. The sensor was reset following the first gauge check, thus the established elevation was changed and the SRC (pink) and GC were set to zero. After this change of established elevation the raw and corrected signals match perfectly since there is zero correction (blue line is superimposed on green).

9. Surveying the water level and other landmarks

Performing a direct water level is the process of determining the water level using a combination of the surveyed elevation of a reference point and a measurement of the distance to the water surface either above or below it. In the example shown in Figure 16, the water level measured on the rod (B) is added to the surveyed elevation of point A.

When the surface of the water is choppy or surging, the height of the water surface may be difficult to measure. In this case, a temporary stilling well can be constructed from a bucket with holes at the bottom (see Figure 16). This bucket will stabilize the water surface at the point where the rod is to be read.

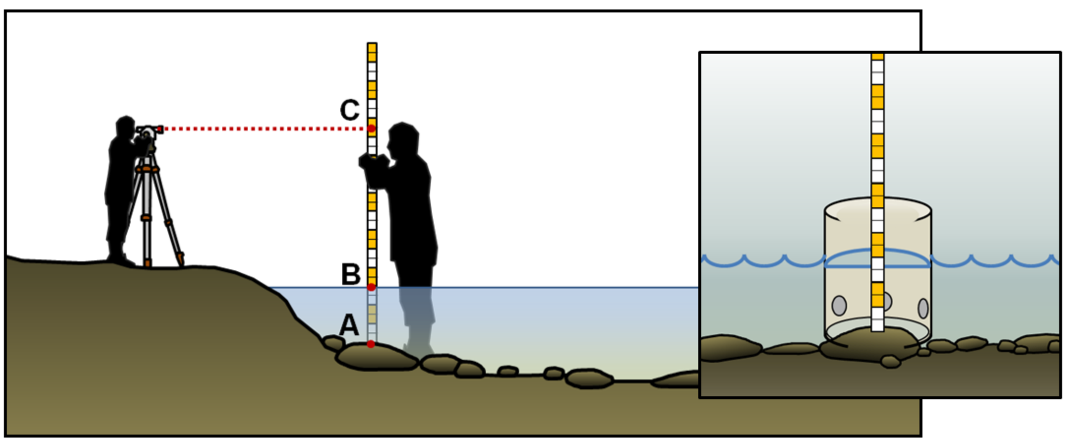


Figure 16: Demonstration of a direct water level measurement and an inset of a temporary stilling well (bucket with holes at the bottom).

Other useful information at a gauging station can be acquired from elevation surveys. Depending on its intended use, elevations can be obtained with a wide variety of tools, ranging from terrestrial levels, to GPS, to the bottom tracking function of Acoustic Doppler Current Profilers. In particular, the elevations of the following points can be valuable during data production:

- High water marks can be compared to recorded gauge heights.

- The elevation at which flow overtops any of the river bank features is useful for rating development, especially to define when the system might reach flood conditions.
- The elevation of zero flow is used to accurately define the lower end of a stage-discharge curve.
- The geometry of hydraulic controls (section and channel) can guide the development of stage-discharge ratings.
- The geometry of the cross section at which the mean velocity is determined for index-velocity sites.
- Elevations of various gauge components such as the end of an orifice line or a stilling well intake will help determine the stage at which the gauge is no longer connected with the stream. They will also assist in determining if the sensor has moved.

10. Documentation Requirements

10.1 Level Note

The level page of the hydrometric survey note is divided into columns for recording observations and computing elevations. The *Station* column is used to record the name of the objective point (e.g. benchmark identification number, turning point number, type of reference gauge) and the information on each horizontal line pertains to that objective point. There are columns for backsight, height of instrument, foresight and elevation. The electronic hydrometric survey note has columns for surveyed elevation and established elevation whereas the paper note has only one elevation column which can be used for either the established or the surveyed elevation, depending on the situation. Descriptive information can be entered in the space to the right of the elevation column. The lower part of the level sheet can be used for recording further descriptive notes. All errors on paper level notes are to be stroked out, not erased. An example of a completed level note for a closed circuit between BM3, BM6 and BM7 is shown in Table 5.

Table 5: Example of a completed level sheet.

Station	Backsight	Height of Instrument	Foresight	Elevation	Notes
BM3	2.103 m	3.804 m		1.701 m	Est. elevation
TP1	2.212 m	5.275 m	0.741 m	3.063 m	screwdriver
BM6			1.384 m	3.891 m	Brass cap
BM7			1.620 m	3.655 m	Screw anchor
TP2	2.444 m	5.919 m	1.800 m	3.475 m	Rock in river
BM7			2.265 m	3.654 m	
BM6			2.026 m	3.893 m	
TP1	1.310 m	4.379 m	2.850 m	3.069 m	
BM3			2.679 m	1.700 m	
4 setups and a circuit length of 150 m. Survey tolerance is $\pm 0.01\sqrt{0.15}$ m = ±0.004 m					

The identification number of the starting point, BM3, is entered on the first line, as is its established elevation (1.701 m). The reading acquired with the levelling rod held on BM3 is entered as the backsight (2.103 m). This value is added to the known elevation to obtain the current height of instrument (3.804 m). On the next line, the second objective point is listed. This is the first point for which the elevation must be determined, in this case turning point 1 (TP1). The reading acquired with the levelling rod held on TP1 is entered as a foresight (0.741 m). This value is then subtracted from the height of instrument from the previous line (the current height of instrument) to obtain the elevation of that objective point (3.063 m). The instrument is then repositioned. From this position a backsight is taken on TP1 and foresights are taken on BM6, BM7, and TP2. The instrument is then repositioned for the return run of the level circuit and a backsight is taken on TP2. The observations and notes are continued in the manner just described until the circuit is closed.

The remainder of section summarizes the requirements for documentation that were listed elsewhere in this SOP. For each station, the following information must be documented in the following locations.

In HYDEX:

- The gauge datum
- Any other datum used at the site, including the corresponding conversion and details on how it was obtained
- A description of all benchmarks and reference gauge locations, as part of the station sketch

In the Benchmark History, recalling that this record may be a combination of hard copy and digital documents:

- A complete listing of the reference gauge and benchmarks with descriptions and elevations, indicating the ones that are currently used.
- A chronological listing of all benchmark activity throughout the station's history

In the Hydrometric Workstation and in the Station Analysis:

- Decisions about benchmark replacement
- Decisions about adjustment of established elevation
- A complete listing of the current reference gauge and benchmarks

References

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Appendix A: Procedures Specific to Total Stations

For sightings exceeding 300 m, special procedures must be followed. See Natural Resources Canada (1978) for details. The following steps are recommended by the WSC for sightings under 300 m.

1. Set up and level the total station. Turn on the scope and orient it to the forward position.
2. Place the target over the backsight benchmark (A) and sight on target.
3. Record vertical distance including sign (+/-) in BS column.
4. Place target over the foresight benchmark (B) and sight on target.
5. Record vertical distance including sign (+/-) in FS column.
6. Reverse the scope to the reverse face position and check that the instrument is still level. This reversing of the scope eliminates vertical axis misalignment, including vertical collimation error.
7. Point on foresight benchmark (B) and record vertical distance in BS column.
8. Point on backsight benchmark (A) and record vertical distance in FS column.

Document the circuit on the field note in the same manner as a conventional level circuit, but execute the computations differently as shown in Table 6 by:

a) Subtracting the BS values from the elevation values to obtain the Height of Instrument value.
b) Adding the FS values to Height of Instrument values to obtain elevations, paying careful attention to signs (+/-).
c) Recalling that the value in the Height of Instrument column has no physical meaning. It is only used for computations.

Table 6: Note taking for total station levelling using the levelling page of the WSC hydrometric survey note.

Station	Backsight	Height of Instrument	Foresight	Elevation	Notes
A	+0.236 m	9.764 m		10.000 m	direct pointing backsight on A
B	-0.471 m	9.762 m	-0.473 m	9.291 m	direct pointing foresight on B (foresight column) reverse pointing backsight on B (backsight column)
A			+0.237 m	9.999 m	reverse pointing foresight on A

Appendix B: The Two-Peg Test

The two-peg test is used to ensure that the line of sight through the telescope of a level is on a horizontal plane. This is done by measuring the inclination of a level's line of sight which is known as the collimation error. It is often expressed as vertical deviation in millimeters over a horizontal distance in meters. The WSC requires that the collimation error not exceed 0.001 m over a sighting distance of 30 m. An excel spreadsheet of the two-peg test form which automatically calculates collimation error can be found on the WSC Operational Library.

To begin the test, set two stakes, A and B, 60 to 90 metres apart on reasonably level ground (Figure 17). Set up and level the instrument at a point midway between the two stakes and take rod reading **a** on stake A and reading **b** on stake B. These values are noted on the two-peg test form (Figure 18). Since the observations are made from a point that is equidistant from each stake, the difference in the reading, **b-a**, is the correct difference in elevation between the two stakes, regardless of any error in the instrument.

Next, set up and level the instrument as close as possible to stake A. Read **c** on the rod through the telescope. Move the rod to stake B and obtain reading **d**. If the instrument is in good adjustment, the difference in elevation of the two stakes as observed from stake A will be the same as when observed from midway between them, so that **d-c** will equal **b-a**. The correct reading of the rod at stake B (**e**) is equal to **b - a + c**. Therefore, the difference between this value and the actual reading at **d** is the error in the adjustment of the line of sight between the two stakes (the collimation error). The two-peg test form automatically calculates the collimation error.

$$Collimation\ error = b - a + c - d$$

<u>If the collimation error exceeds 0.001 m over a 30 m sighting distance, the instrument should be sent to a calibration facility for proper adjustment as per the manufacturer's instructions</u>. As can be seen from the completed form in Figure 18, the true difference in elevation between stakes A and B is 0.777 m and the collimation error is 0.015 m over 90 m. This exceeds the acceptable limit.

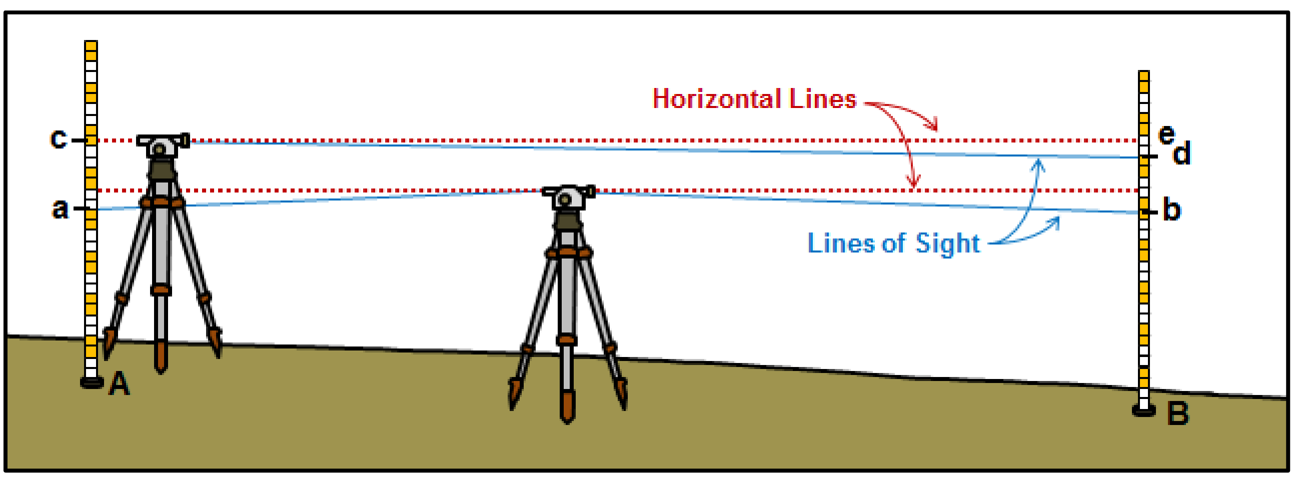
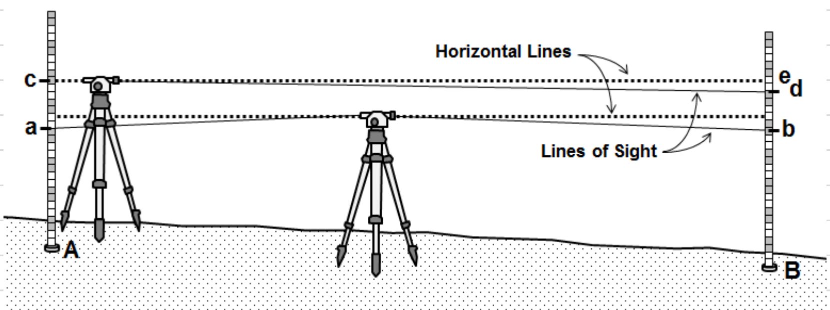


Figure 17: An illustration of the principles of the two-peg test.

Two Peg Test Form

Environment and Climate Change Canada
Water Survey of Canada

DATE:	2017/05/01		
INSPECTOR:	Inspector Name		
LEVEL MAKE:	Leica		
LEVEL MODEL:	DNA3		
LEVEL SERIAL #:	12345		
LEVEL ASSIGNMENT:	Tech name		
Distance between rods A and B	90 m		
Shot a	0.573 m	Shot c	1.161 m
Shot b	1.35 m	Shot d	1.923 m
Difference b-a	0.777 m	Difference d-c	0.762 m
(Difference b-a)-(Difference d-c)	0.015 m		
Collimation error	0.005 m / 30 m		
	less than or equal to 0.001m/30 m?	No	



Comments:

For Two Peg Test Procedure refer to Hydrometric Field Manual - Levelling Appendix A (qSOP-NA005-03-2017)

Figure 18: Example of a completed two-peg test excel template.

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