

3 LEVELLING & SURVEYING

3.1 General

The primary reference at water-level recording stations is a set of stable bench-marks, installed in locations where their level should not change. Upon initial set-up of a station, the levels of the relevant parts of the installation are established and recorded by means of accurate levelling.

At least every two years, the levels of the staff gauges, sensor level, internal gauge, tower structure and benchmarks should be measured relative to each other as a check that records are not in error due to bank subsidence or other movement.

Accurate levelling is thus a particularly important part of site establishment, installation and quality assurance. All staff shall be thoroughly familiar with its theory and practice.

Levelling and surveying methods are also used for measurements of river channel and lake configurations. Often, less accurate methods can be used for this work than for water-level recording stations, although the techniques are common.

3.2 Definitions

Differential levelling is the term applied to any method of measuring directly with a graduated staff the difference in elevation between two or more points.

Precise levelling is a particularly accurate method of differential levelling which uses highly accurate levels and with a more rigorous observing procedure than general engineering levelling. It aims to achieve high orders of accuracy such as 1 mm per 1 km traverse.

A level surface is a surface which is everywhere perpendicular to the direction of the force of gravity. An example is the surface of a completely still lake. For ordinary levelling, level surfaces at different elevations can be considered to be parallel.

A level datum is an arbitrary level surface to which elevations are referred. The most common surveying datum is mean sea-level (MSL), but as hydrological work is usually just concerned with levels in a local area, we often use:

An assumed datum, which is established by giving a benchmark an assumed value (e.g. 100.000 m) to which all levels in the local area will be reduced. It is not good practice to assume a level which is close to the actual MSL value, as it creates potential for confusion.

A reduced level is the vertical distance between a survey point and the adopted level datum.

A bench mark (BM) is the term given to a definite, permanent accessible point of known height above a datum to which the height of other points can be referred.

It is usually a stainless steel pin embedded in a substantial concrete block cast into the ground. At hydrological stations rock bolts driven into bedrock or concrete structures can be used, but structures should be used warily as they themselves are subject to settlement. The locations of benchmarks shall be marked with BM marker posts and/or paint, and recorded on the Station History Form.

A set-up refers the position of a level or other instrument at the time in which a number of observations are made without mooring the instrument. The first observation is made to the known point and is termed a backsight; the last observation is to the final point or the next to be measured on the run, and all other points are intermediates.

A run is the levelling between two or more points measured in one direction only. The outward run is from known to unknown points and the return run is the check levelling in the opposite direction.

A close is the difference between the starting level of the initial point for the outward run and that determined at the end of the return run. If the levels have been reduced correctly this value should be the same as the difference between the sum of the rises and falls and also the difference between the sum of the backsights and foresights.

Height of Collimation is the elevation of the optical axis of the telescope at the time of the setup. The line of collimation is the imaginary line at the elevation.

Orders of levelling refer to the quality of the levelling, usually being defined by the expected maximum closing error. These are given in Table 6.1

Order	Purpose	Maximum close (m)
Precision order	Deformation surveys	0.001 x km
First order	Major levelling control	0.003 x km
Second order	Minor levelling control	0.007 x km
Third order	Levelling for construction	0.012 x km

Table 1 *Levelling closes*

The accuracy requirements for water-level stations relate to the standards; for further information refer to section 6.1.5.

Change points are points of measurement which are used to carry the measurements forward in a run. Each one will be read first as a foresight, the instrument position is changed, and then it will be read as a backsight.

3.3 Equipment

The level, its tripod, the staff and the staff bubble are all precision items of equipment upon which the accuracy of the work is highly dependent. They shall be kept correctly calibrated, and be used and stored with care.

Levels shall be carried in vehicles in a padded box, case or shelf in addition to the normal case, and staves shall be kept in a canvas or plastic sleeve to prevent damage to the face and entry of dirt.

3.3.1 Levels

A level is basically a telescope attached to an accurate levelling device, set upon a tripod so that it can rotate horizontally through 360°. Normally the levelling device is a bubble, but modern ones incorporate a pendulum. There are three basic types of level, shown in figure 6.1 (from MWD, 1981) and described below:

(a) Dumpy levels

These are more basic levels often used in construction work. The telescope is rigidly attached to a single bubble and the assembly is adjusted either by means of a screwed ball-joint or by footscrews which are adjusted first in one direction, then at 90°.

(b) Tilting levels

This type of level is fitted with a circular bubble for preliminary approximate levelling and a main bubble which is attached to the telescope. For each observation (not setup) the main bubble is viewed through an eyepiece and the telescope tilted by a fine screw to bring the two ends of the bubble into coincidence.

(c) Automatic levels

This more modern type of level is now in general use. It has a compensator which consists of an arrangement of three prisms. The two outer ones are attached to the barrel of the telescope. The middle prism is suspended by fine wiring and reacts to gravity. The instrument is first levelled approximately with a circular bubble; the compensator will then deviate the line of sight by the amount that the telescope is out of level.

3.3.2 Staves

The levelling staff is a box section of aluminium or wood, which will extend to 3 or 5 m in height by telescoping, hinging or addition of sections. One face has a graduated scale attached for reading with the cross-hairs of the level telescope. These faces can vary in pattern and graduation; 5mm graduations should be the maximum for accurate levelling of gauging stations.

Many staves used these days are of aluminium because of its durability. However aluminium has a co-efficient of thermal expansion of :

$$0.000023\text{m/metre of length}/^{\circ}\text{C}$$

and this can cause some potential inaccuracies. For instance, "Survey Chief" and "Brookeades" staves are standardised at 27°C, and in very cold weather these staves could be as much as 3mm too short over their full length. For low temperature work consult the temperature table for each staff which should be with its "instruction manual" or printed on the staff itself.

3.3.3 Staff bubbles

These are generally a small circular bubble on an angle plate which is held against one corner of the staff to ensure that the staff is held in a vertical position. If the staff is not held vertical, the reading will be too large and may be significantly in error.

A staff bubble shall be used at all times. If one is not available, the "chainman" (staff operator) shall rock the staff slowly back and forth about the vertical in a line towards the instrument. The observer notes the smallest reading which will occur when the staff is vertical.

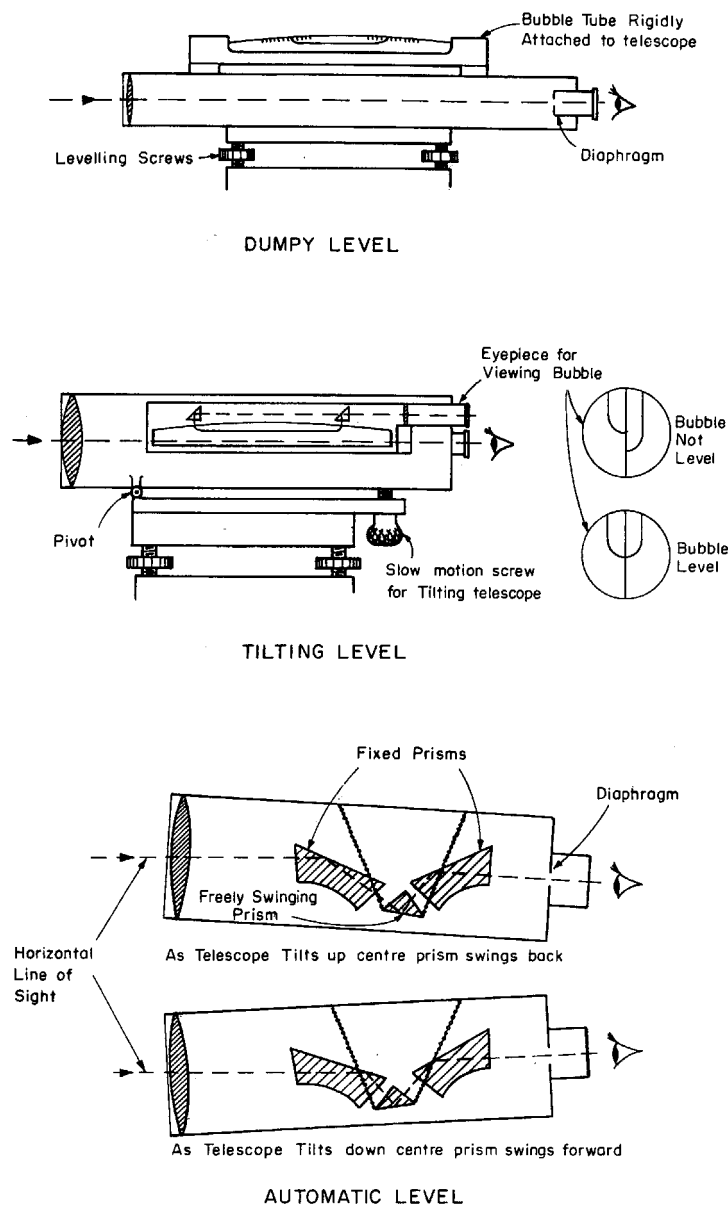


Figure 1 *The three main types of levels.*

3.4 Care of equipment

- ensure that tripod screws and hinges are kept tight.
- always transport the level in a padded box.
- when removing from the box lift it by the centre and not by the eyepiece or objective end of the telescope.
- screw it firmly onto the tripod, whilst holding it in one hand (make certain that it is not cross-threaded and that threads are compatible).
- when carrying the level tripod assembly in the field, support it over the shoulder or, in bush, crooked over an arm with the telescope unclamped (i.e. free to rotate).
- automatic levels should not be carried in a vertical or near-vertical position, as the compensator will swing about and be prone to damage.

- staves are too much of a precision item of equipment to be used in place of a slasher, vaulting pole, etc.
- staves shall be transported in their protective cases to protect the face from damage.
- wooden staves which become wet should be dismantled and dried out before storing away.
- any moisture which is evident in an instrument must be allowed to disperse by storing the level out of its case in a warm room. Should it persist after several days the instrument may require specialist servicing.

3.5 Checking the level's accuracy

Levels can move out of adjustment so that their line of sight (line of collimation) is not truly horizontal. This will cause errors in readings which become greater as the viewing distance increases. However if a backsight and a foresight are exactly equi-distant from the instrument, the error in each sighting will cancel each other out. This feature can be used to check the accuracy of a level by the following simple method which is depicted in figure 6.2 (from MWD, 1981):

- install three pegs or marks firmly in the ground at distances of 30 m apart in a straight line; the centre peg is only to mark the distance, but the outside two shall be firm enough for reliable change points
- set up the level over the centre peg and read the staff on each of the outside pegs in turn. Book these values and calculate the height difference. This will be a true height difference, as the distances are equal and any errors will be self-compensating
- set up the level about 4 m to the far side of one of the outside pegs. Read the staff on the peg 4 m away and then on the one 64 m away. Book these values and calculate the apparent height difference
- compare the two height differences; if the instrument is in adjustment (i.e. its collimation is true) they will be within 5 mm.

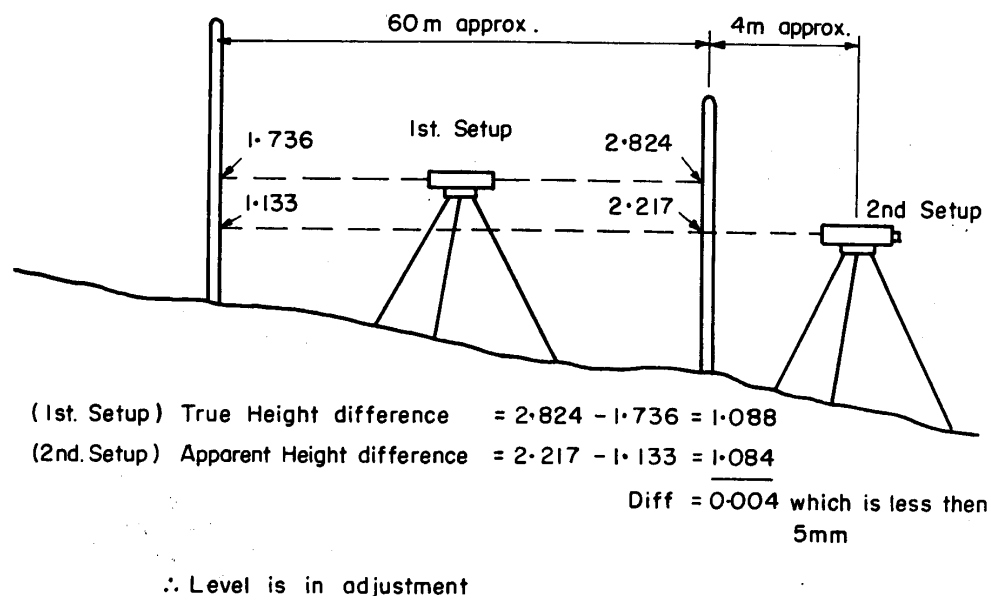


Figure 2 A method for checking the level accuracy

If the instrument's collimation appears to be out, recheck by repeating the process. Then, whilst setup at one of the outside locations, adjust the instrument (according to the manufacturer's

instructions) so that it reads the correct value on the far staff, checking it against the near one. Two staves are useful for this.

This type of level check shall be carried out at least once per year, preferably just prior to carrying out a round of station inspections. The details and results of the checks shall be recorded in a numbered level book and be readily retrievable as a quality record, and the date of this calibration check shall also be recorded in the instrument inventory.

3.6 Levelling procedures

(a) Setting up

- Backsight and foresight distances should be approximately equal to avoid any errors due to collimation, refraction or earth curvature.
- Distances must not be so great as to not be able to read the graduations accurately.
- The points to be observed must be below the level of the instrument, but not lower than the height of the staff.

(b) Elimination of parallax

Parallax is the apparent movement of the image produced by movement of the observer's eye at the eyepiece.

It is eliminated by focusing the telescope on infinity and then adjusting the eyepiece until the cross-hairs appear in sharp focus. The setting will remain constant for a particular observer's eye.

(c) Booking

- level books or loose-leaf levelling sheets shall be numbered and indexed in a register.
- details of the site, work, date, observer, chainman, booker, weather, wind, instrument and any other relevant items shall be entered.
- enter the first observation (which is on a known point) in the Backsight column, and sufficient detail in the Remarks column to identify it. Enter the point's R.L. zero from the site register or plate on the BM, etc.
- enter all other points on subsequent lines as intermediates except the point chosen as the foresight. Identify them in the Remarks column as above. Enter the foresight on a further line in the Foresight column.
- change the instrument to the next setup. Enter the following backsight on the same line as the previous foresight but in the Backsight column.
- repeat the above procedure at each setup on the outward run then reverse it to work back to the starting point on the return run. The furthest point out is treated as for all other change points.

3.7 Reducing the levels

Two methods are in general use; the "rise and fall" method and the "height of collimation" method. The latter reduces levels relative to the instrument height. As it has inferior in-built checks it should not be used and will not be covered here.

The "rise and fall" methods shall be used for reduction of all site levelling. Reduction shall be carried out on site before packing up to ensure that the levelling has been done correctly.

- calculate the rises and fall between successive points and book them in the appropriate column (one can determine whether each shot is a rise or fall by the following rule of thumb: a higher value on top denotes a rise; a higher value on the bottom denotes a fall)
- add up the backsight and foresight columns for the entire traverse and note the difference between them; this is the close
- add up the rises and falls for the entire traverse, and compare the difference between them with the difference between the backsights and foresights; they should be the same
- carry the reduced levels in the R.L. column down the page by adding or subtracting the appropriate rise and fall values to the successive values of R.L. The final value of the original starting point will differ from the original value by the amount of the close.

If the levelling has been done correctly and all arithmetic reductions are correct, the differences between total backsights and foresights, total rises and falls, and starting and finishing R.L.'s should be the same. This difference is the close; and for site inspection purposes it should be within $\pm 2\text{mm}$ or $\pm 6\text{mm}$, depending upon which water-level standard is being followed, $\pm 3\text{mm}$ or $\pm 10\text{mm}$.

3.8 Level books

All levelling shall be booked in either level books or levelling sheets which shall be retained as permanent records.

Level books shall be numbered so that they can be referenced on station history and inspection forms. They should be stored in fire-proof storage as for original record. They should also include an index.

Levelling sheets shall be filed in time-sequential order in site files, and also need to be in fire-proof storage as for level books.