
**Manual methods for the measurement
of a groundwater level in a well**

*Méthodes manuelles pour le mesurage du niveau de l'eau souterraine
dans un puits*



Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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Introduction

The measurement of a water level in a well constitutes a data-collection process that provides fundamental information about the status of a groundwater system. Accordingly, measured water levels should be sufficiently accurate and reproducible to meet the needs of most data-collection and monitoring programs. Several manual methods commonly used to collect water-level data in wells employ relatively simple measuring devices such as graduated steel tapes, electric tapes, and air lines. In some cases, water-level measurements are required in flowing wells. The procedures associated with each of these methods are intrinsically different and subject to varying limitations and accuracies. Standardization of these methods would ensure that the procedures and associated equipment used by the international community to collect water-level data in a well are consistent, and that the results can be compared with minimal concern about the relative accuracies and/or the procedures use in collecting the data.

Manual methods for the measurement of a groundwater level in a well

1 Scope

This International Standard develops procedures and prescribes the minimum accuracy required of water-level measurements made in wells using graduated steel tapes, electric tapes and air lines. Procedures and accuracy requirements for measuring water levels in a flowing well are also included, as are procedures required to establish a permanent measuring point. This International Standard discusses the advantages and limitations of each method and requirements for recording the data. This International Standard does not include methods that use automated electrical or mechanical means to measure and record water levels.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply:

2.1

air line

water-level measuring device consisting of a small diameter open-ended tube fixed in position that is accessible from the top of the casing and extends to below the water level in a well where pressurized air measurements can be used to determine the depth to water

2.2

casing (well casing)

tubular retaining structure, which is installed in a drilled borehole or excavated well, to maintain the borehole opening. Plain (unscreened) casing prevents the entry of water and fine material into the well, while open (screened) casing allows water ingress but should exclude fines

2.3

electric tape

water-level measuring device that uses an electrical signal, sent through a cable with fixed distance marks, to determine the water level relative to a fixed reference point. The electrical signal, which is induced when the sensor makes contact with the water surface, activates an indicator (typically a light, buzzer or needle)

2.4

flowing well (or overflowing well)

well from which groundwater is discharged at the ground surface without the aid of pumping

NOTE A deprecated term for this definition is an artesian well.

2.5

graduated steel tape

water-level measuring device consisting of a flat measuring tape with permanently fixed distance marks that can be wound on a reel

2.6

groundwater

water within the saturated zone

- 2.7**
land surface datum
average altitude of land surface at a referenced well
- 2.8**
measuring point
permanent reference marked on well casing
- 2.9**
static water level (or static head)
height, relative to an arbitrary reference level, of a column of water that can be supported by the static pressure at a given point
- 2.10**
well
hole sunk into the ground for abstraction of water or for observation purposes

3 Water-level measurement using a graduated steel tape

3.1 Purpose

The purpose of this method is to measure the depth to the water surface (level) below a measuring point using the graduated steel tape (wetted-tape) method.

3.2 Materials and instruments

The following materials and instruments are required.

3.2.1 Steel tape graduated in metres and centimetres.

A black tape is preferred to a chromium-plated tape because the wetted chalk mark is easier to read against a black tape. A break-away weight should be attached to the ring on the end of the tape with wire strong enough to hold the weight, but not as strong as the tape, so that if the weight becomes lodged in the well, the tape can still be pulled free. The weight should be made of brass, stainless steel or iron.

3.2.2 Coloured chalk.

3.2.3 Clean cloth.

3.2.4 Pencil and eraser.

3.2.5 Steel tape calibration and maintenance equipment log book.

3.2.6 Water-level measurement field form (see the example in Figure 6).

3.2.7 Equipment to gain access to the well (wrenches, crow bars, manhole keys, etc.).

3.2.8 Common household chlorine bleach or other suitable disinfectant.

3.3 Data accuracy and limitations

The following data accuracy and limitations apply.

- a) Independent graduated steel tape measurements of static water levels should agree within $\pm 1,0$ cm for depths of less than 60 m;

- b) For depths between 60 m and 150 m, independent measurements using the same tape should agree within $\pm 2,0$ cm. When measuring deep water levels (i.e. greater than 300 m), errors due to the effects of thermal expansion and of stretch produced by the suspended weight of the tape and plumbing weight warrant consideration (see Reference [2], p. 3). An example of correcting a deep water level for thermal expansion and stretch of a steel tape is given in Annex A. However, because the equipment required to measure temperatures at land surface and down the well may not always be readily available, the corrections described in Annex A are not required for the purposes of this International Standard, though the practitioner shall note on the water-level field form (see the example in Figure 6) whether or not any such corrections were applied.
- c) At least once every twelve months, the steel tape should be calibrated against another steel tape that is dedicated as a calibration tape and is not used in the field. If the steel tape does not meet test criteria, then it must be removed from service. Records of these tests shall be kept.
- d) If the well casing is angled, instead of vertical, the depth to water will have to be corrected. If the casing angle is unknown and a correction is not feasible, this should be noted in water-level measurement field form (see the example in Figure 6).

3.4 Advantages and disadvantages

The graduated steel tape method is easy to use and is considered to be the most accurate method for measuring the water level in nonflowing wells of moderate depth. However, it may be impossible to get reliable results if water is dripping into the well or condensing on the well casing. Also, the method is not recommended for measuring pumping levels in wells.

3.5 Assumptions

The following assumptions apply in the use of the graduated steel tape method.

- a) An established measuring point (MP) exists and the distance from the MP to land-surface datum (LSD) is known (see the example in Figure 6). See the technical procedure described in Clause 7 for establishing a permanent MP.
- b) The MP is clearly marked and described so that all measurements will be taken from the same point.
- c) The results from previous water-level measurements made at the well are available for estimating the length of the required tape.
- d) The steel tape will retain the chalk.
- e) The well is free of obstructions. Well obstructions, if present, could cause errors in the measurement if the obstructions affect the plumbness of the steel tape.

3.6 Procedures

The following procedures for measuring water levels in a well with a graduated steel tape shall be observed.

- a) Apply the coloured chalk to the lower metre of the tape by pulling the tape across the chalk. The wetted chalk mark will identify that part of the tape that was submerged.
- b) Lower the weight and tape into the well until the lower end of the tape is submerged below the water (more than one attempted measurement may be needed to determine the length of tape required to submerge the weight). Once the end of the tape is submerged, continue to lower the tape into the well until the next whole metre graduation mark is opposite the MP. This whole number shall be recorded in the "MP HOLD" (Figure 1) column of the water-level measurements field form (see the example in Figure 6).

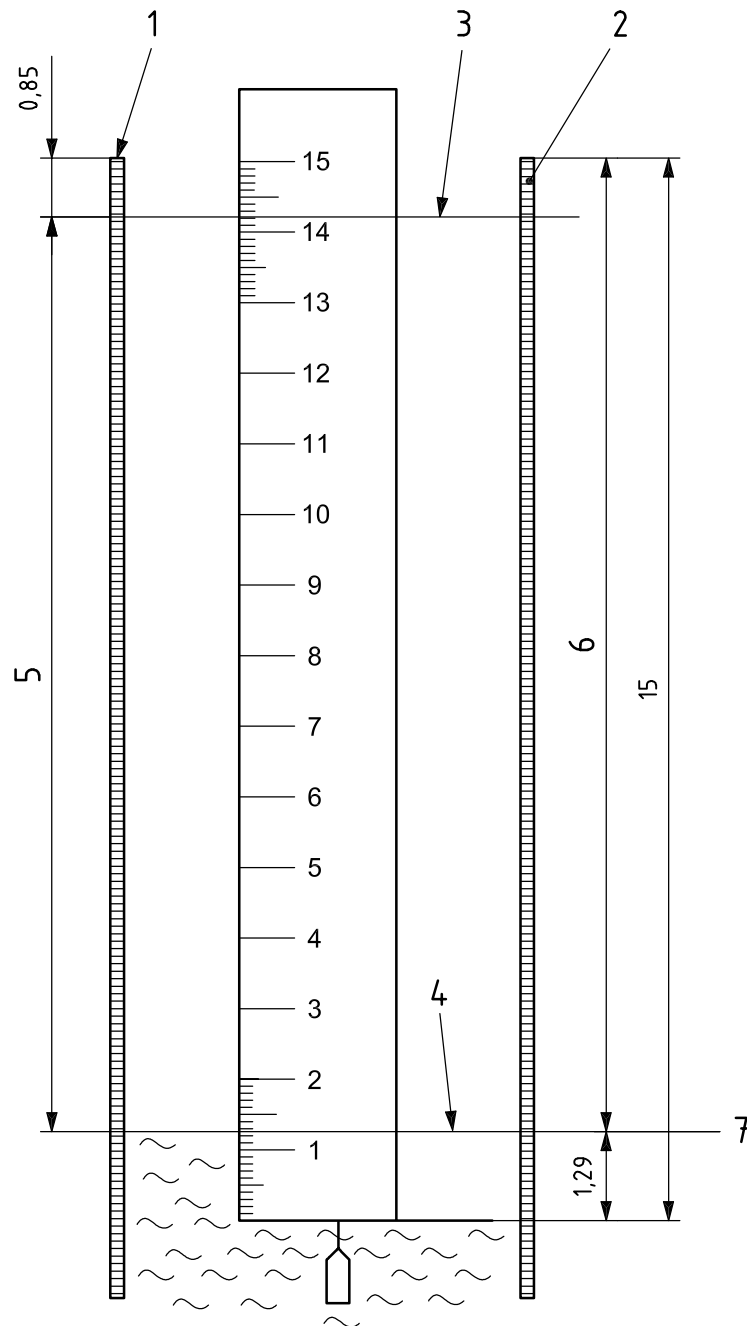
- c) Pull the tape back to the surface before the wetted chalk mark dries and becomes difficult to read. Record the number of the wetted chalk mark (sometimes referred to as the cut) in the “WETTED CHALK MARK” (Figure 1) column of the water-level measurements field form (see the example in Figure 6).
- d) Subtract the wetted chalk mark number from the number held to the MP, and record this number in the “DEPTH TO WATER FROM MP” (Figure 1) column of the water-level measurements field form (see the example in Figure 6). The difference between these two readings is the depth to water below the MP.
- e) Apply the MP correction to get the depth to water below or above land-surface datum (LSD). If the MP is above land surface (see the example in Figure 6), the distance between the MP and land surface datum is subtracted from the depth to water from the MP (see the example in Figure 6) to obtain the depth to water below land surface. If the MP is below land surface, precede the MP correction value with a minus (-) sign and subtract the distance between the MP and land surface datum from the depth to water from the MP to obtain the depth to water below land surface. Record this number in the “DEPTH TO WATER FROM LSD” (Figure 1) column of the water-level measurements field form (see the example in Figure 6). If the water level is above LSD, record the depth to water above land surface as a negative number.
- f) Make a check measurement by repeating steps a) through e). The check measurement shall be made using a different MP hold value (see the example in Figure 6) than that used for the original measurement. If the check measurement does not agree with the original measurement to the nearest centimetre, continue to make check measurements until the reason for the lack of agreement is determined or until the results are shown to be reliable. If more than two readings are taken, the observer shall select the reading considered the most reliable. This reading shall be recorded to the nearest centimetre.
- g) After completing the well measurements, disinfect the steel tape and weight by pouring a small amount of common household chlorine bleach or other suitable disinfectant on a clean cloth and wiping down the part of the tape that was submerged below the water surface. This will avoid possible contamination of other wells.
- h) The tape shall be maintained in good working condition by periodically checking the tape for rust, breaks, kinks and possible stretch due to the suspended weight of the tape and the tape weight.

All calibration and maintenance data associated with the steel tape being used shall be recorded in its calibration and maintenance equipment log book. All water-level data shall be recorded on the water-level measurements field form (see the example in Figure 6) to the nearest centimetre.

In some contaminated or pumped wells, a layer of oil may be floating on the surface of the water. In such cases, if the thickness of the oil layer is several centimetres or less, the tape reading made at the top of the oil mark can be used as the water-level measurement. The associated error in this case should be relatively small because the level of the oil surface would differ only slightly from the level of the water surface that would be measured if no oil were present. If a meter of more of oil is present, however, or if it is deemed necessary to ascertain the thickness of the oil layer, a commercially-available water-detection paste, originally developed to detect water in gasoline storage tanks, is available to do so. The paste can be applied to the end of the measuring tape that is lowered into the well. The top of the oil layer will be reflected as a wet line on the tape, while the top of the water will be shown by a distinct colour change. In either event, whether the oil layer is greater than or less than a few millimetres in thickness, its presence should be noted on the water-level measurements field form (see the example in Figure 6). A specialized interface probe is also commercially available for measuring the interface.

In the event no water is encountered in the well, this shall be duly noted under “REMARKS” on the field form, along with the distance between the MP and the bottom of the well.

Dimensions in metres



Key

- 1 measuring point (MP)
- 2 MP hold
- 3 land surface datum (LSD)
- 4 water level
- 5 depth to water from LSD = 12,86
- 6 depth to water from MP = 13,71
- 7 wetted chalk mark

Figure 1 — Water-level measurements using a graduated steel tape

4 Water-level measurement using an electric tape

4.1 Purpose

The purpose of this method is to measure the depth to the water surface below a measuring point using the electric tape method.

Electric tapes fall into two categories:

- Type 1 those that have fixed graduations lacking a suitable frequency (e.g. 1 m graduation) that would enable readings to be made at a sufficient accuracy without the use of additional graduated measures (e.g. tapes calibrated in centimetres). Type 1 tapes are referred to as “partially graduated” tapes in the rest of this clause; and
- Type 2 those with fixed graduations which are spaced at lengths equal to or smaller than the accuracy required for the readings. Type 2 tapes are referred to as “fully graduated” tapes in the rest of this clause.

4.2 Materials and instruments

The following materials and instruments are required.

4.2.1 Electric tape of various wiring arrangements or configurations, that would include flat parallel or co-axial conductive wires, graduated in metres and/or centimetres. Electric tapes are commonly mounted on a hand-cranked supply reel that contains space for the batteries and some device for signalling when the circuit is closed (Figure 2).

4.2.2 Electric tape calibration and maintenance equipment log book.

4.2.3 Pencil and eraser.

4.2.4 Water-level measurement field form (Tables 2 and 3).

4.2.5 Equipment to gain access to the well (wrenches, crow bars, manhole keys, etc.).

4.2.6 Common household chlorine bleach, and, for measurements made with Type 1, **electric tapes**.

4.2.7 Steel tape graduated in metres and centimetres.

4.2.8 Spare batteries.

4.3 Data accuracy and limitations

The following data accuracy and limitations apply.

- a) Independent electric tape measurements of static water levels using the same tape should agree within $\pm 1,0$ cm for depths of less than 60 m.
- b) For depths of about 150 m, the maximum difference of independent measurements using the same tape should agree within $\pm 3,0$ cm.
- c) For depths in the 500 m range, the repeatability of measurements using the same tape should agree within ± 15 cm (see Reference [2], p. 11).

4.4 Advantages and disadvantages

The electric tape method is superior to the graduated steel tape method when

- a) water is dripping into the well or condensing on the inside of casing walls which may make it very difficult to get a good water mark on the chalked tape,
- b) wells are being pumped and the splashing of the water surface makes chalked measurements virtually impossible, and
- c) a series of measurements are needed in quick succession, such as in aquifer tests, because the electric tape does not have to be removed from the well for each reading.

Also, the electric tape method is safer to use in pumping wells because the water is sensed as soon as the probe reaches the water surface and there is less danger of lowering the tape into the pump impellers.

Electric tape measurements are generally less accurate than are measurements made with graduated steel tapes. Electric tapes are also harder to keep calibrated than are steel tapes and electric connections need to be maintained in good order. Also, the insulation around the conductor cables may be severed when being drawn across sharp edges of metal pipes at the top of a borehole. In addition, the presence of hydrocarbons on the water surface that may result from oil leaks during drilling operations may coat the sonde, resulting in a failure to complete the electrical circuit. Finally, a stilling pipe may be required to avoid inaccurate readings where water is cascading down the borehole during pumping (aquifer) tests.

In general, fully graduated tapes are preferred to partially graduated tapes. Fully graduated tapes are easier to use and there are fewer opportunities for errors in measurement, particularly when the time intervals between measurements are small such as during pumping tests.

4.5 Assumptions

Application of the electric tape method assumes

- a) that an established measuring point (MP) exists; and
- b) if the water level is to be referenced to land surface, that the distance between the MP and land-surface datum (LSD) is known (see the example in Figure 7).

See the technical procedure described in Clause 7 for establishing a permanent MP.

Also, the MP should be clearly marked and described so that all measurements will be taken from the same point.

If the MP of record cannot be located, the use of data for assessing long-term trends may be compromised. In such cases, a new MP should be established and the date of change should be indicated on the record sheet.

4.6 Procedures

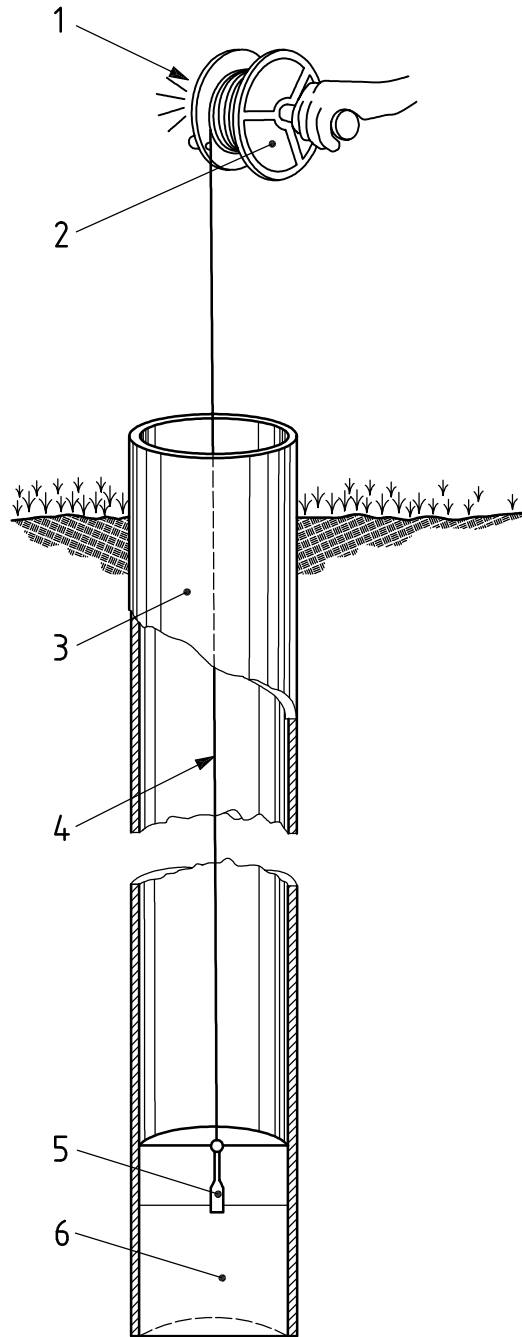
The following procedures for measuring water levels in a well with an electric tape shall be observed.

- a) Prior to using an electric tape in the field, calibrate it by comparing the total length of the electric tape against the length of an acceptable steel tape. An acceptable steel tape is one that has a fixed graduation of a centimetre (or less) and that is maintained in the office for the sole purpose of calibrating electric tapes. Also, check the accuracy of the position of each 1 m interval metal band to make sure that the bands have not moved. This is especially important if the electric tape has been used for a long time or after it has been pulled hard in attempting to free the line. If the field tape fails to meet test criteria, then it must be removed from service. Records of these tests shall be kept.

- b) Before lowering the probe into the well, check the circuitry of the electric tape by dipping the probe into water and observe if the indicator (needle, light, or buzzer) is operating correctly as the circuit closes. Note the position the indicator needle deflects during the circuitry check.
- c) Lower the electrode probe slowly into the well until contact with the water surface causes the circuit to close, activating the indicator (Figure 2). Slightly raise and then lower the electrode again to identify just where the electrode first comes into contact with the surface of the water. Once the indicator needle deflects to the point chosen during the circuitry check, place the nail of the index finger on the insulated wire at the MP.
- d) For fully graduated tapes, partly withdraw the electric tape from the well and record the depth to water to the nearest centimetre or less if, in the opinion of the observer, the instrumentation is capable of greater precision. Record in the "DEPTH TO WATER FROM MP" column of the water-level measurements field form (see the example in Figure 7).

For partially graduated tapes, partly withdraw the electric tape from the well and record the metre mark of the nearest 1-metre tape band below the MP in the "NEAREST 1-metre TAPE BAND BELOW MP" column of the water-level measurements field form (see the example in Figure 8). Then measure the distance from the MP mark on the insulated wire to the nearest 1-metre tape band that is below the MP mark with a graduated steel tape and record that distance, to the nearest centimetre, in the "DIFFERENCE BETWEEN MP MARK AND NEAREST 1-metre TAPE BAND BELOW MP" column of the water-level measurements field form (see the example in Figure 8). The depth to water below MP is then obtained by adding the distance between the MP mark and the next lowest 1-metre tape band to the value of the next lowest tape band. Record this number in the "DEPTH TO WATER FROM MP" column of the water-level measurements field form (see the example in Figure 8).

- e) Apply the MP correction to get the depth to water below or above LSD. If the MP is above land surface, its height is subtracted from the water level to obtain the depth to water below land surface. If the MP is below land surface, precede the MP correction value with a minus (-) sign and subtract its height from the water level to obtain the depth to water below land surface. Subtract the MP correction (Table 2 or Table 3) from the depth to water from MP (Table 2 or Table 3) and record this number in the "DEPTH TO WATER CORRECTED FOR LSD" column of the water-level measurements field form (Table 2 or Table 3). If the water level is above LSD, enter the water level in centimetres above land surface preceded by a minus sign (-).
- f) Make a check measurement by repeating steps d) through f). If the check measurement does not agree within the accuracy given in 4.3 under "Data accuracy and limitations", continue to make check measurements until the reason for the lack of agreement is determined. If more than two measurements are taken, the observer shall select the reading considered the most reliable. This reading shall be recorded to the nearest centimetre.
- g) After completing the well measurement, disinfect the electric tape by pouring a small amount of common household chlorine bleach or other suitable disinfectant on a clean cloth and then wipe down that part of the tape that was submerged below the water surface. This will avoid possible contamination of other wells.
- h) Maintain the tape in good working condition by periodically checking the tape for breaks, kinks, and possible stretch due to the suspended weight of the tape and the tape weight. Do not let the tape rub across the top of the casing because the 1-metre metal bands can become displaced; consequently, placement of the bands should be checked frequently with a steel tape.



Key

- 1 light indicator
- 2 reel
- 3 casing
- 4 electric cable
- 5 electrode(s)
- 6 water

Figure 2 — Water-level measurements using an electric tape (adapted from Reference [1], Figure 16.12)

Because an electric tape will not respond to oil floating on water in a well, the liquid level determined by an electric tape will be different than that determined by a steel tape, with the difference depending on the thickness of the oil layer. In cases where this is of concern, a miniature float-driven switch can be put on a two-conductor electric tape that will allow detection of the oil surface.

All calibration and maintenance data associated with the electric tape being used shall be recorded in its calibration and maintenance equipment log book. All data shall be recorded in the water-level measurements field form (see the example in Figure 6) to the appropriate accuracy (4.3) for the depth being measured.

In the event no water is encountered in the well, this shall be duly noted under "REMARKS" on the field form, along with the distance between the MP and the bottom of the well.

5 Water-level measurement using an air line

5.1 Purpose

The purpose of this method is to measure the depth to the water surface below a measuring point using a submerged air line.

5.2 Materials and instruments

The following materials and instruments are required.

5.2.1 Seamless copper tubing, brass tubing, or galvanized pipe, preferably 3 mm to 6 mm in diameter with a suitable pipe tee for connecting an altitude or pressure gauge.

Flexible plastic tubing can also be used, but is less desirable.

5.2.2 Altitude or pressure gauge.

5.2.3 Tyre valve stem and tyre pump.

5.2.4 Small open end wrench.

5.2.5 Wire or electrician's tape.

5.2.6 Steel tape graduated in metres and centimetres.

5.2.7 Blue carpenter's chalk.

5.2.8 Clean rag.

5.2.9 Field notebook, pencil and eraser.

5.2.10 Water-level measurements field form (see the example in Figure 9).

5.3 Data accuracy and limitations

The following data accuracy and limitations apply.

- a) Water-level measurements using an altitude gauge should be accurate to within 3 cm.
- b) Water-level measurements using a pressure gauge are more approximate and should not be considered accurate to more than 30 cm.

- c) As in all pressure-dependent methods, fluid density should be considered when measuring water levels by the air-line method, because the conversion constant of 0,102 m of water per kilopascal (referenced later in 5.6) is valid only for distilled water at 20 °C. Fluid density is affected primarily by the temperature and dissolved solids content of the water. An example of correcting a water level measured by an air line for temperature and dissolved solids content is given in Annex B. However, because the equipment required to measure the temperature and/or dissolved solids content of the groundwater is not always readily available, the corrections described in Annex B are not required for the purposes of this International Standard, though the practitioner shall note on the water-level field form (see the example in Figure 10) whether or not any such corrections were applied.

5.4 Advantages and disadvantages

The air-line method is especially useful in pumped wells where water turbulence may preclude using a more precise method. The method can be used while the well is being pumped, when splashing of water renders the wetted tape method useless. Bends or spirals in the air line do not influence the accuracy of this method as long as the position of the tubing is not appreciably changed. However, the method is less accurate than the wetted tape or the electric tape methods and requires time to install the air line and equipment.

5.5 Assumptions

The following assumptions apply in the use of the air-line method.

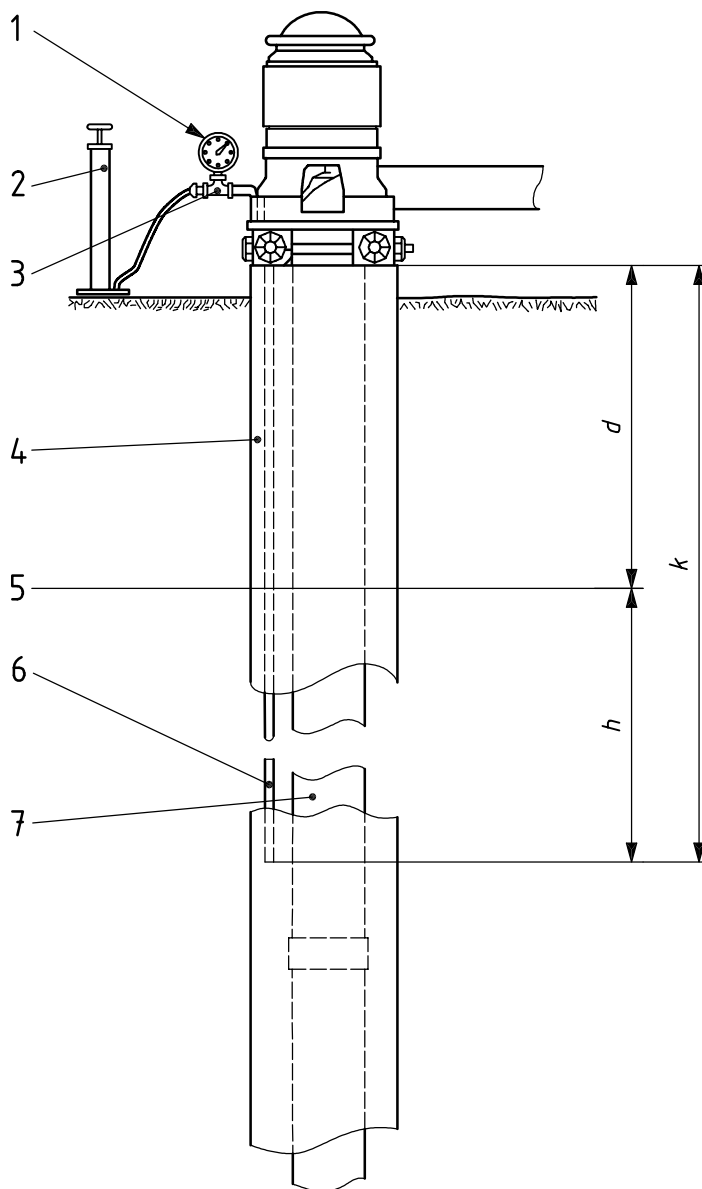
- a) An established measuring point (MP) exists. See the technical procedure described in Clause 7 for establishing an MP.
- b) The MP is clearly marked and described so that all measurements will be taken from the same point.

5.6 Procedures

Figure 3 shows a typical installation for measuring water levels by the air-line method.

The following procedures for measuring water levels in a well with an air line shall be observed.

- a) Install an air-line pipe or tube in the well. The air line can be installed by either lowering it into the annular space between the pump column and casing after the pump has been installed in the well, or by securing it to sections of the pump and pump column with wire or tape as it is lowered into the well.
- b) The air line shall be extended far enough below the water level such that the lower end remains submerged during pumping of the well.
- c) Attach a pipe tee to the top end of the air line. On the opposite end of the pipe tee, attach a tyre valve stem.
- d) Connect an altitude gauge that reads in meters, or a pressure gauge that reads pressure in kilopascals (kPa), to the fitting on top of the pipe tee with a wrench. If an altitude gauge is used, read the gauge to the nearest centimetre. For pressure gauges with kilopascal (kPa) units, read the gauge to the nearest kilopascal (kPa) and multiply by 0,102 m/kPa to convert to meters of water.
- e) Connect a tyre pump to the tyre valve stem fitting on the pipe tee.
- f) As the water level in the well changes, h and d (Figure 3) must change in a manner such that their sum remains the same. Their sum is a constant (k), which is determined at the same time as a simultaneous wetted-steel tape and air gauge measurement is made.



Key

- 1 altitude ^a or pressure gauge ^b
- 2 tyre pump
- 3 pipe tee
- 4 well casing
- 5 water level
- 6 air line
- 7 pump line or column

^a For the altitude gauge:

$$d = k \cdot h,$$

where

d is the measured depth to water level, in metres;

h is the height of water displaced from the air line, in metres; and

^b For the pressure gauge:

$$d = k \cdot (1,04p) \text{ and } h = 0,104p,$$

where

p is the pressure reading in kilopascals; and

d , h and k are in metres.

Figure 3 — Typical installation for measuring water levels by the air-line method and relation of measured depth to water level, height of water displaced from air line, and depth to bottom of air line

- g) To calibrate the air line and gauge, make an initial depth to water-level measurement (d) with a wetted-steel tape, and an initial air gauge reading (h). Add d and h to determine the constant value for k . Use a tyre pump to pump compressed air into the air line until all the water is expelled from the line. Once all water is displaced from the air line, record the maximum gauge reading.

EXAMPLE 1 Using an altitude gauge. The initial measured depth to the water level, d , is 7,88 m; the initial altitude gauge reading, h , is 23,02 m. Then the constant $k = 7,88 \text{ m} + 23,02 \text{ m} = 30,90 \text{ m}$ (see the example in Figure 9).

EXAMPLE 2 Using a pressure gauge. The initial measured depth to the water level, d , is 26,17 m; the initial pressure gauge reading, h , is 190 kPa. Then the constant $k = 26,17 \text{ m} + (190 \text{ kPa} \times 0,102 \text{ m/kPa}) = 26,17 \text{ m} + 19,38 \text{ m} = 45,55 \text{ m}$ (see the example in Figure 10).

- h) Calibrate the air line and gauge as indicated in g) above.
- i) To measure the water-level depth in a well with an air line, subsequent air line readings are subtracted from the constant k to determine the depth to the water level below the MP. Use a tyre pump to pump compressed air into the air line until all the water is expelled from the line, and record the maximum gauge reading.

EXAMPLE 3 Depth to the water level in a well using an altitude gauge with a constant k of 30,90 m. During a later pumping period, the maximum altitude gauge h reads 15,24 m; therefore, the water level,

$$d = 30,90 \text{ m} - 15,24 \text{ m} = 15,66 \text{ m} \quad (\text{see the example in Figure 9}).$$

EXAMPLE 4 Depth to the water level in a well using a pressure gauge with a constant k of 45,55 m. During a later pumping period, the maximum pressure gauge h reads 122 kPa; therefore, the water level,

$$d = 45,55 \text{ m} - (122 \text{ kPa} \times 0,102 \text{ m/kPa}) = 45,55 \text{ m} - 12,44 \text{ m} = 33,11 \text{ m} \quad (\text{see the example in Figure 10}).$$

- j) Measure the water-level depth as indicated in i) above.
- k) Apply the MP correction to get the depth to water below or above land-surface datum.
- l) Record water-level data in the field notebook and on the water-level measurements field form (Table 4 or Table 5).

6 Water-level measurement in a flowing well

6.1 Purpose

The purpose of this method is to measure low-pressure or high-pressure water-level heads in flowing wells.

6.2 Materials and instruments

The following materials and instruments are required.

6.2.1 Low-pressure head measurements

- 6.2.1.1 **Transparent plastic tubing**, of suitable length and diameter.
- 6.2.1.2 **Ladder**, if pressure head is more than 2 m to 3 m.
- 6.2.1.3 **Hose clamps**.
- 6.2.1.4 **Measuring scale**.
- 6.2.1.5 **Pencil and eraser**.

6.2.1.6 Calibration and maintenance log book.

6.2.1.7 Water-level measurements field form (see the example in Figure 11).

6.2.2 High-pressure head measurements

6.2.2.1 Flexible hose with a 3-way valve.

6.2.2.2 Hose clamps.

6.2.2.3 Altitude or pressure gauge.

6.2.2.4 Small open-end wrench.

6.2.2.5 Soil-pipe test plug, also known as a sanitary seal, available from most plumbing-supply stores in sizes that will fit 5 cm to 25 cm diameter pipes.

Soil-pipe test plugs consist of a length of small-diameter pipe, generally less than 3 cm, surrounded by a rubber packer. The packer can be expanded by an attached wing nut to fit tightly against the inside of the well casing or discharge pipe. The small-diameter pipe is threaded so that it can be attached to a valve, hose, or altitude/pressure gauge.

6.2.2.6 Pencil and eraser.

6.2.2.7 Calibration and maintenance log book.

6.2.2.8 Water-level measurement field form (see the example in Figure 11).

6.3 Data accuracy and limitations

The following data accuracy and limitations apply.

- a) Low-pressure head measurements can be measured to an accuracy of 3,0 cm.
- b) High-pressure head measurements using a pressure-gauge are probably not accurate to within less than 3,0 cm, although the measurements themselves can be read at finer resolutions.
- c) The pressure in the well shall not exceed the limit of the altitude/pressure gauge. Pressure gauges are generally most accurate in the middle third of the gauge range.
- d) The measuring gauge shall not be connected to a well that uses a booster pump in the system, because the pump could start automatically and the resulting pressure surge may ruin the gauge.
- e) When a flowing well is closed or opened by a valve or test plug, it should be done gradually. If pressure is applied or released suddenly, the well could be permanently damaged by the “water-hammer effect” with subsequent caving of the aquifer material, breakage of the well casing, or damage to the distribution lines or gauges. To reduce the possibility of a water-hammer effect, a pressure-snubber should be installed ahead of the altitude/pressure gauge.
- f) Ideally, all flow from the well should be shut down so that a static water-level measurement can be made. However, because of well owner objections or system leaks, this is not always possible. If the well does not have a shut-down valve, it can be shut-in by installing a soil-pipe test plug on the well or discharge line.
- g) If a well has to be shut down, the time required to reach static pressure after shut down may range from hours to days. Since it may be impractical or impossible to reach true static conditions, record the shut-down time for each gauge reading. During return visits to a particular well, it is desirable to duplicate the previously used shut-in time before making an altitude/pressure gauge reading.

6.4 Advantages and disadvantages

Low-pressure head measurements are simpler, faster, safer, and are more accurate than high-pressure head measurements, but are impractical for wells with heads greater than 2 m above land surface.

High-pressure head measurements can be made at wells with heads greater than 2 m above land surface, but the altitude/pressure gauges required for such measurements are delicate, easily broken, and subject to erroneous readings if dropped or mistreated.

SAFETY PRECAUTIONS — The soil-test plugs used in high-pressure head measurements may present a safety risk, as these devices could slip from the casing and become projectiles.

6.5 Assumptions

The following assumptions apply when measuring water levels in a flowing well.

- a) An established measuring point (MP) exists. See the technical procedure in Clause 7 for establishing an MP.
- b) The altitude/pressure gauges have been calibrated with a dead-weight tester.
- c) A log book, containing all the calibration and maintenance records, is available for each altitude/pressure gauge.

6.6 Procedures

6.6.1 Low-pressure head measurement (direct measurement)

Use the following procedure.

- a) Connect a short length of transparent plastic tubing tightly to the well with hose clamps.
- b) Raise the free end of the tubing until the flow stops.
- c) Rest the measuring scale on the measuring point (MP).
- d) Read the water level directly by placing the hose against the measuring scale.
- e) Apply the MP correction to get the depth to water above land-surface datum (LSD).
- f) Repeat steps b) through e) for a second check reading. If the check measurement does not agree within the accuracy given in 6.3 under "Data accuracy and limitations" continue to make check measurements until the reason for the lack of agreement is determined. If more than two measurements are taken, the observer shall select the reading considered the most reliable.

6.6.2 High-pressure head measurement (indirect measurement)

Use the following procedure.

- a) Make sure that all well valves are closed except the one to the altitude/pressure gauge. This will prevent use of the well during the measurement period and assure an accurate water-level reading. Record the original position of each valve that is closed (full open, half open, closed, etc.), so that the well can be restored to its original operating condition.
- b) Connect a flexible hose with a 3-way valve to the well with hose clamps using the soil-pipe test plug or appropriate plumbing fittings.

- c) Select a gauge where the water pressure in the well will fall in the middle third of the gauge range. It is suggested that, if in doubt, use a pressure gauge with at least a 500 kPa range to make an initial measurement, then select the gauge with the proper range for more accurate measurements.
- d) Attach the altitude/pressure gauge to one of the two "open" valve positions using a wrench. Do not tighten or loosen the gauge by twisting the case because the strain will disturb the calibration and give erroneous readings.
- e) Bleed air from the hose, using the other "open" valve position.
- f) Open the altitude/pressure gauge valve slowly to reduce the risk of damage by the "water-hammer effect" to the well, distribution lines and gauges. Once the needle stops moving, tap the glass face of the gauge lightly with a finger to make sure that the needle is not stuck.
- g) Make sure that the well is not being used by checking to see that there are no fluctuations in pressure.
- h) Hold the altitude/pressure gauge in a vertical position, with the centre of the gauge at the exact height of the MP. If using an altitude gauge, read the gauge to the nearest centimetre. For pressure gauges with kilopascal (kPa) units, read the gauge to the nearest kilopascal (kPa) and multiply by 0,102 to convert to metres of water.
- i) Apply the MP correction to get the depth to water above LSD.
- j) Shut off the well pressure and repeat steps e) through i) for a second check reading. If the check measurement does not agree within the accuracy given in 6.3 under "Data accuracy and limitations" continue to make check measurements until the reason for the lack of agreement is determined. If more than two measurements are taken, the observer shall select the reading considered the most reliable.
- k) Record the identification number of the altitude/pressure gauge with each water-level measurement so that the reading can be back referenced to the calibration record, if necessary.

All calibration and maintenance data for the well shall be recorded in the log book. All water-level data shall be recorded on the water-level measurements field form (see the example in Figure 11).

7 Establishing a permanent measuring point

7.1 Purpose

The purpose of this method is to establish a permanent reference point from which all water levels are measured in a particular well.

7.2 Materials and instruments

The following materials and instruments are required.

7.2.1 Form for recording the information required to locate and document the establishment of a permanent measuring point (see Reference [8] as an example).

7.2.2 Steel tape graduated in metres and centimetres.

7.2.3 Steel tape calibration and maintenance equipment log book.

7.2.4 Field notebook.

7.2.5 Pencil and eraser.

7.2.6 Spray paint or road chalk, bright colour.

7.2.7 Two wrenches with adjustable jaws, for removing the well cap.

7.3 Data accuracy and limitations

The accuracy with which the measuring point (MP) measurement is established should be the same as that established for the water-level measurement; that is, if water levels are measured to the nearest centimetre, then the MP should be established to an accuracy of 0,01 m.

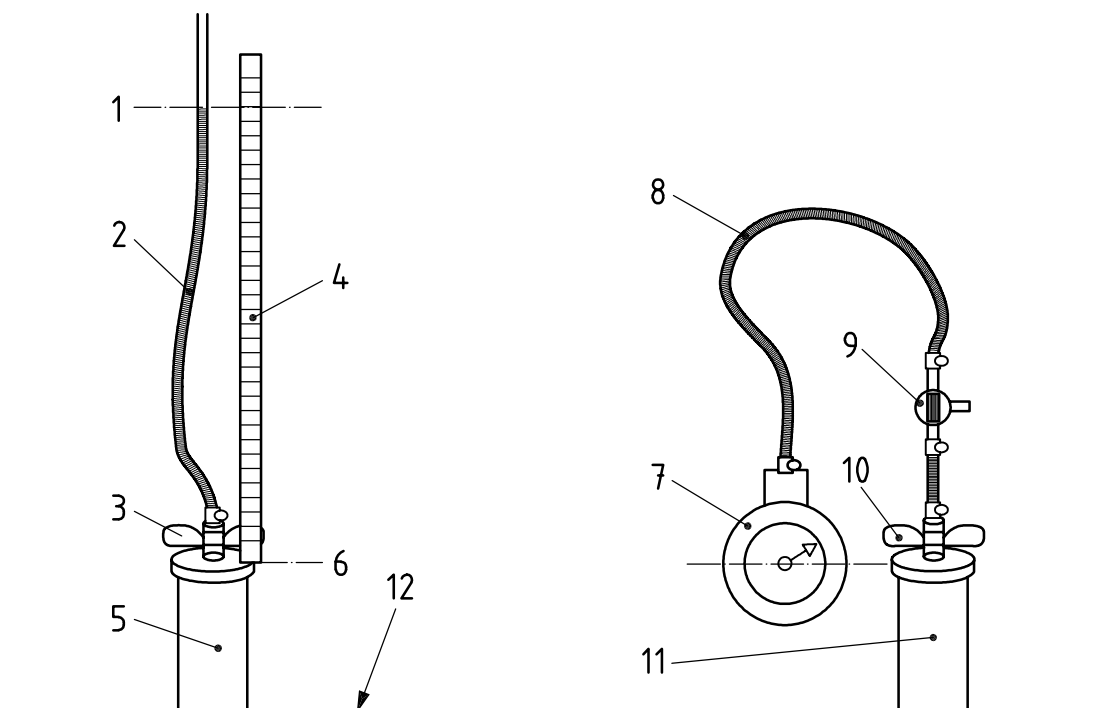
7.4 Assumptions

For comparability, water-level measurements shall be referenced to the same datum (elevation). Land surface datum (LSD) at the well is an arbitrary plane chosen to be approximately equivalent to the average altitude of the ground around the well. Because the LSD around a well may change over time, the distance between the MP and the LSD should be checked periodically. Also, measuring points change from time to time, especially on private wells.

7.5 Procedure

Use the following procedure

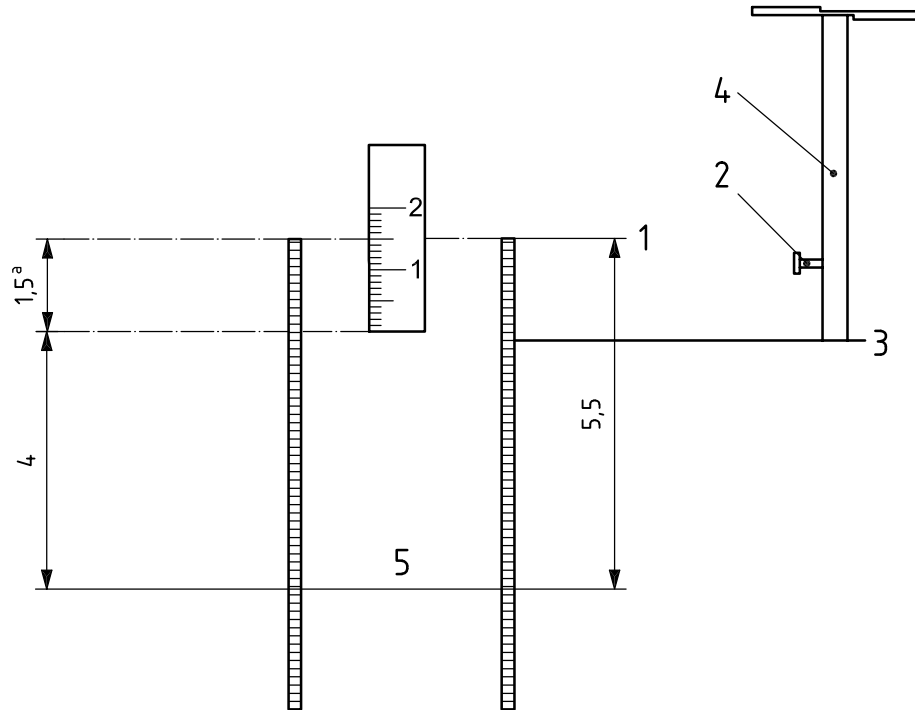
- a) The MP shall be as permanent as possible, clearly defined, marked, and easily located.
- b) The top of the well casing, which provides the most convenient location for measuring a water level in a well, should be designated as the MP and should be measured in reference to land surface datum (LSD).
- c) The MP should be measured in reference to land surface datum (LSD) and at a point on the well convenient for measuring water levels (most often at the top of the well casing).
- d) Clearly mark the MP with an arrow sprayed with a bright coloured paint or chalk.
- e) Measure the height of the MP above or below LSD (Figure 5) and record it on the ground-water site inventory form. Values for measuring points below land surface [Figure 5 b)] shall be preceded by a minus sign (–). Also record the date the MP was established and a detailed description of the MP. It is highly recommended that the MP and LSD be “surveyed-in” to a national geodesic reference point. If so, then the accuracy of the surveyed altitude should be estimated and recorded in the well file.
- f) Establish at least one clearly marked reference point (RP) somewhere near the well. For example, a lag bolt set in a telephone pole (Figure 5). The RP is an arbitrary datum established by permanent marks, and is used to check the MP or to re-establish a measuring point should the original MP be destroyed or changed.
- g) Make a detailed sketch of the MP and the RP on the groundwater site inventory form and, if possible, take a photograph. Clearly identify the MP and RP on the developed photograph. Also, all calibration and maintenance data associated with the steel tape being used are recorded in its calibration and maintenance equipment log book. MP data are recorded in a field notebook and on the ground-water site inventory form.



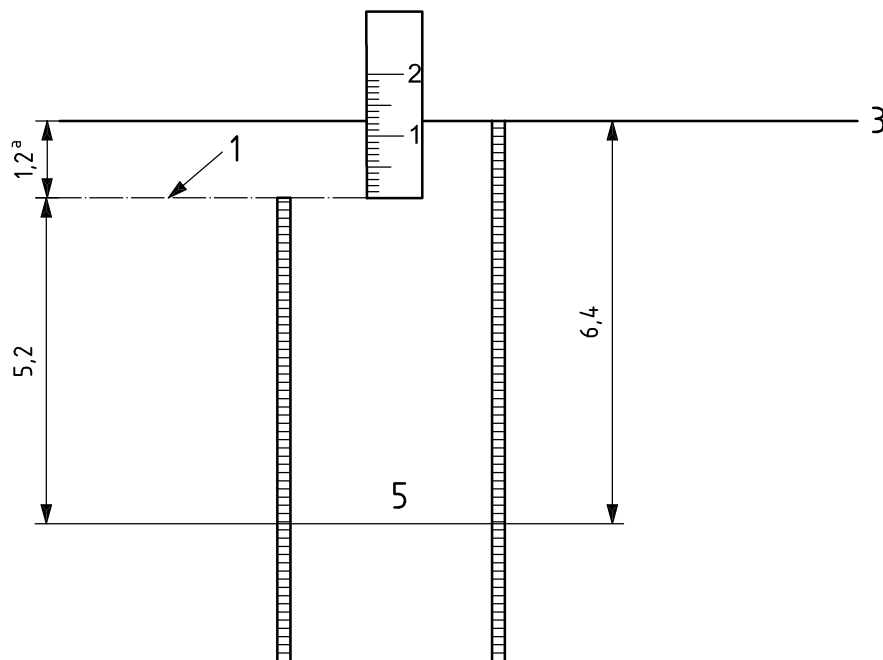
Key

- 1 water level
- 2 transparent flexible tubing
- 3 soil pipe test plug
- 4 measuring scale
- 5 well casing
- 6 measuring point (MP)
- 7 pressure gauge
- 8 flexible tubing
- 9 3-way valve
- 10 soil pipe test plug
- 11 well casing
- 12 land surface

Figure 4 — Water-level measurement in a flowing well



a) **MP above LSD** — Subtract MP correction to correct this water level to LSD ($5,50 - 1,50 = 4,0$)



b) **MP below LSD** — Subtract MP correction to correct this water level to LSD [$5,20 - (-1,20) = 6,40$]

Key

- 1 measuring point (MP)
- 2 reference point (RP)
- 3 land-surface datum (LSD)
- 4 lag bolt
- 5 water level
- a MP correction.

Figure 5 — Relation of measuring point, above or below the land surface datum, reference point, and water level

WATER-LEVEL MEASUREMENTS (Field)						
						WELL NO. <u>NHW 258</u>
SITE NAME AND LOCATION (include latitude/longitude if feasible)		Town of New Shoreham, Block Island, Rhode Island				
MP DESCRIPTION		Top inside edge of stainless steel casing, 0,85 m above land surface datum				
MISCELLANEOUS NOTES		No adjustment made for several centimetres of oil floating on water surface				
DATE	TIME OF MEASUREMENT	MP HOLD	WETTED CHALK MARK	DEPTH TO WATER FROM MP	DEPTH TO WATER FROM LSD	REMARKS (include name of observer)
YYYY-MM-DD	Local time (GMT)	m	m	m	m	
2002-08-29	14:45 (18:45)	15,00	1,29	13,71	12,86	Measured by Lansen Ramsbey

Figure 6 — Example of field data sheet for measurement of water levels with a graduated steel tape

WATER-LEVEL MEASUREMENTS (Field)				
				WELL NO. _____
SITE NAME AND LOCATION (include latitude/longitude if feasible)				
MP DESCRIPTION		Top inside edge of stainless steel casing, 1,50 m above land surface datum		
DATE YYYY-MM-DD	TIME OF MEASUREMENT Local time (GMT)	DEPTH TO WATER FROM MP m	DEPTH TO WATER FROM LSD m	REMARKS (include name of observer)
2002-04-16	12:31 (17:31)	8,15	6,65	Measured by Mary Smith

Figure 7 — Example of field data sheet for measurement of water levels with a fully graduated electric tape

WATER-LEVEL MEASUREMENTS (Field)						
						WELL NO. _____
SITE NAME AND LOCATION (include latitude/longitude if feasible)						
MP DESCRIPTION			Top inside edge of stainless steel casing, 1,50 m above land surface datum			
DATE	TIME OF MEASUREMENT	NEAREST 1-metre TAPE BAND BELOW MP	DIFFERENCE BETWEEN MP MARK AND NEAREST 1-metre TAPE BAND BELOW MP	DEPTH TO WATER FROM MP	DEPTH TO WATER FROM LSD	REMARKS (include name of observer)
YYYY-MM-DD	Local time (GMT)	m	m	m	m	
2002-04-16	11:09 (16:09)	9,00	0,85	8,15	6,65	Measured by Mary Smith

Figure 8 — Example of field data sheet for measurement of water levels with a partially graduated electric tape

WATER-LEVEL MEASUREMENTS (Field)						
						WELL NO. _____
SITE NAME / LOCATION (include latitude/longitude if feasible)						
MP DESCRIPTION		Top inside edge of steel casing, red arrow, north side, 0,50 m above land surface datum. Altitude gauge calibration data: Initial wetted steel tape water level, d , is 7,88 m; initial altitude gauge reading, h , is 23,02 m; constant $k = d + h = 7,88 \text{ m} + 23,02 \text{ m} = 30,90 \text{ m}$.				
DATE	TIME OF MEASUREMENT	ALTITUDE GAUGE CONSTANT (k)	ALTITUDE GAUGE READING (h)	DEPTH TO WATER FROM MP (d)	DEPTH TO WATER FROM LSD ($d - MP$)	REMARKS (include name of observer)
YYYY-MM-DD	Local time (GMT)	m	m	m	m	
2002-05-31	12:02 (17:02)	30,90	23,02	7,88	7,38	Altitude gauge calibrated by John Smith
2002-06-01	12:12 (17:12)	30,90	15,24	15,66	15,16	First air line water measurement, John Smith

Figure 9 — Example of field data sheet for measurement of water levels with an air line using an altitude gauge

WATER-LEVEL MEASUREMENTS (Field)						
						WELL NO. _____
SITE NAME / LOCATION (include latitude/longitude if feasible)						
MP DESCRIPTION		Top inside edge of steel casing, red arrow, south side, 1,00 m above land surface datum. Pressure gauge calibration data: Initial wetted steel tape water level, d , is 26,17 m; initial pressure gauge reading, h , is 190 kilopascals (kPa); constant $k = d + h = 26,17 \text{ m} + 19,38 \text{ m} = 45,55 \text{ m}$. Pressure gauge reading h (in metres) is calculated as pressure gauge reading (in kPa) $\times 0,102 \text{ (kPa/m)}$.				
DATE	TIME OF MEASUREMENT	PRESSURE GAUGE CONSTANT	PRESSURE GAUGE READING	DEPTH TO WATER FROM MP	DEPTH TO WATER FROM LSD	REMARKS
YYYY-MM-DD	Local time (GMT)	(k) m	(h) m	(d) m	($d - \text{MP}$) m	(include name of observer)
2002-05-31	14:50 (19:50)	45,55	19,38 (190 kPa)	26,17	25,17	Pressure gauge calibrated by John Smith
2002-06-01	14:47 (19:47)	45,55	12,44 (122 kPa)	33,11	32,11	First air line water-level measurement, John Smith

Figure 10 — Example of field data sheet for measurement of water levels with an air line using a pressure gauge

WATER-LEVEL MEASUREMENTS (Field)				
				WELL NO. _____
SITE NAME / LOCATION <small>(include latitude/longitude if feasible)</small>		Crescent Lake, Flagler Co., Florida		
MP DESCRIPTION		Top of casing at chiselled mark; 1,12 m above land surface datum. Pressure head (water level) reading (in metres) is calculated as pressure gauge reading (in kPa) × 0,410 2.		
DATE	TIME OF MEASUREMENT	PRESSURE HEAD (WATER LEVEL) ABOVE MP	PRESSURE HEAD (WATER LEVEL) ABOVE LSD	REMARKS <small>(include name of observer)</small>
YYYY-MM-DD	Local time (GMT)	m	m	
2001-06-09	10:34 (14:34)	1,06	2,18	Pressure gauge # 7, measured by GB Smith

Figure 11 — Example of field data sheet for measurement of pressure head (water level) in a flowing well

Annex A (informative)

Corrections for water levels measured in deep wells by steel tapes subject to temperature changes and tape stretch

In measuring water levels in deep wells, practitioners may wish to consider errors introduced from the effects of thermal expansion and/or stretch of the metal tape produced by the suspended weight of the tape and attached plumb bob. While such errors are negligible for many water-level measurements, they may become appreciable for measurements in deep wells, that is, for wells exceeding 300 m in depth (see Reference [2], p. 3). The corrections described below are not required for the purposes of this International Standard, but rather to provide the practitioner a means of evaluating the potential magnitude of such errors.

The equations used to estimate the changes in length of a metal tape resulting from thermal expansion and stretch are given in Equations (A.1) and (A.2), respectively, from Reference [2] as

$$C_T = L \cdot E (T_a - 20 \text{ }^\circ\text{C}) \quad (\text{A.1})$$

and

$$C_S = (L_e^2 m S / 2) + P \cdot L_e S \quad (\text{A.2})$$

where

C_T is the thermal correction, in metres (m);

C_S is the stretch correction, in metres (m);

L is the measured depth to water, in metres (m);

E is the coefficient of thermal expansion of the steel tape, in metres per metre per degree Celsius difference between the average temperature in the well and 20 °C (m/m per °C);

T_a is the average temperature in the well from land surface to water level, in degrees Celsius (°C);

L_e is the length of suspended tape corrected for thermal expansion, in metres (m);

m is the mass of tape, in kilograms (kg), per metre of tape;

S is the coefficient of stretch, in metres per metre per kilogram (m/m per kg); and

P is the mass of plumb bob, in kilograms (usually 0,10 kg to 0,30 kg).

EXAMPLE The following example illustrates the effects of thermal expansion and stretch on a steel tape used to measure water levels in a deep well.

Given:

$$L = 515,00 \text{ m}$$

$$E = 1,13 \times 10^{-5} \text{ m/m per } ^\circ\text{C} \quad (\text{from Reference [2]})$$

$$T_a = 30 \text{ } ^\circ\text{C}$$

$$m = 0,003 \text{ 6 kg} \quad (\text{from Reference [2]})$$

$$S = 3,85 \times 10^{-5} \text{ m/m per kg} \quad (\text{from Reference [2]})$$

$$P = 0,20 \text{ kg}$$

Correction for thermal expansion:

$$C_T = LE(T_a - 20 \text{ } ^\circ\text{C}) = (515,00 \text{ m})(1,13 \times 10^{-5} \text{ m/m per } ^\circ\text{C})(30 \text{ } ^\circ\text{C} - 20 \text{ } ^\circ\text{C}) = 0,06 \text{ m}$$

then

$$L_e = 515,00 \text{ m} - 0,06 \text{ m} = 514,94 \text{ m (rounded to the nearest centimetre)}$$

Correction for stretch:

$$\begin{aligned} C_S &= (L_e^2 m S / 2) + P L_e S \\ &= [(514,94 \text{ m})^2 (0,003 \text{ 6 kg})(3,85 \times 10^{-5} \text{ m/m per kg}) / 2] + [(0,20 \text{ kg})(514,94 \text{ m})(3,85 \times 10^{-5} \text{ m/m per kg})] \\ &= 0,02 \text{ m (rounded to the nearest centimetre)} \end{aligned}$$

then

$$\text{corrected depth} = L_e - \text{stretch correction} = 514,94 \text{ m} - 0,02 \text{ m} = 514,92 \text{ m}$$

Annex B (informative)

Corrections for water levels measured in wells with the air-line method

As in all pressure-dependent methods, fluid density should be considered when measuring water levels by the air-line method. Fluid density is affected primarily by temperature and, to a lesser extent, by the concentration of dissolved solids. The density of water at 20 °C is 0,998 23 g/ml. At this density, 0,102 m of water can be associated with each kilopascal of measured pressure. However, water with temperatures greater than or less than 20 °C would have proportionately smaller or greater densities, respectively, with proportionately greater or smaller conversion factors. A table (Table B.1), quantifying the change in density of distilled water over a wide temperature range, is shown below.

Table B.1 — Density of pure water, free from air

Temperature <i>T</i> °C	Density of pure water, free from air g/ml	Temperature <i>T</i> °C	Density of pure water, free from air g/ml
0	0,999 87	45	0,990 25
3,98	1,000 00	50	0,988 07
5	0,999 99	55	0,985 73
10	0,999 73	60	0,983 24
15	0,999 13	65	0,980 59
18	0,998 62	70	0,977 81
20	0,998 23	75	0,974 89
25	0,997 07	80	0,971 83
30	0,995 67	85	0,968 65
35	0,994 06	90	0,965 34
38	0,992 99	95	0,961 92
40	0,992 24	100	0,958 38

Table modified from Reference [4].

To illustrate the use of the Table B.1 in correcting water-level measurements for temperature in air lines, consider Example 2, which was previously described in 5.6 and shown in Table 5. If, in that example, the water in the air line had some temperature other than 20 °C, say 60 °C, then the conversion factor, C_c , used to convert the pressure reading in kilopascals to metres of water would be recalculated as

$$C_c = 0,102 \text{ m/kPa} \times (0,998 \text{ 23 g/ml}) / (0,983 \text{ 24 g/ml}) = 0,103 \text{ 6 m/kPa}$$

and

$$\text{initial } h = 0,103 \text{ 6 m/kPa} \times 190 \text{ kPa} = 19,68 \text{ m,}$$

and (from Table 5),

$$k = 19,68 + 26,17 = 45,85 \text{ m}$$

then, the corrected depth to water would be calculated as

$$\begin{aligned} d &= k - h \\ &= 45,85 \text{ m} - (0,103 \text{ 6 m/kPa} \times 122 \text{ kPa}) \\ &= 33,21 \text{ m (versus an uncorrected depth of 33,11 m from Table 5).} \end{aligned}$$

In moderate concentrations, the effect of dissolved solids on fluid density is at least one order of magnitude less than that of temperature. For example, for dissolved solids having a specific gravity of 2,5 (water taken as unity), calculations show that the density of water having a dissolved solids concentration of 100 mg/l would be 1,000 06; water having a dissolved solids concentration of 200 mg/l would have a density of 1,000 12; and water having a dissolved solids concentration of 1 000 mg/l would have a density of 1,000 6.

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