# Non-Revenue Water and Large Water Meters Calibration

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# NON-REVENUE WATER AND LARGE METER CALIBRATION

***Summary***

*In the IWA standard water balance, it is clearly mentioned that Water Supplied to the system is equal to System Input Volume minus Treated Water Exported "corrected for known calibration and other errors". This point is very important but unfortunately, many utilities have no accredited or poor approach to calibrate their large bulk meters. It may lead to poor managerial decision.*

*This paper aims at providing basic information to the practitioners who want to apply such an accredited approach.*

## 1. Introduction

Large water meters are used to measure system input volumes and more generally bulk supply such as treated water and imported and exported volumes. The confidence in the data provided by these meters is of paramount importance. It can be considered as a prerequisite for the establishment of the water balance and for the quality of the decision-making resulting from the water balance.

Over registration of the water input volumes generates a fictitious increase in the water loss that is neither a real loss nor an apparent loss but that could erroneously be considered as such. Over registration of the volumes may generate an over estimate of real or apparent losses. Contradictorily, under registration of the water input would generate under valuation in the real loss volumes or in the apparent loss volume. In both cases, the errors may generate inappropriate decisions. The financial implications of these errors may be high. "Any programs, therefore which can determine and minimise the errors associated with these measurements on a sustainable basis will ultimately facilitate optimal decision-making and improve financial accountability" (Johnson, 2007)

There is, therefore, a need to include the regular and comprehensive calibration of large water meters as part of sustainable water management practice. A water utility should adopt an accredited approach to calibrate and check its large meters.

This paper aims at providing basic information to assist the practitioner in selecting an accredited approach founded on quality assurance.

## 2. Large water meters and calibration facilities

### Generic types of large water meters and flow meters

Various kinds of devices are used to measure flows in large diameter pipelines that can generally be categorised into those that extract energy and those that add energy to the flowing water.

Water Meters that extract energy from the flowing water include:

- Woltmann (velocity) meters.
- Volumetric (positive displacement) meters.
- Differential pressure flow meters (venture tubes, orifice plates).

Water meters that add energy to the flowing water include:

- electromagnetic flowmeters.
- ultrasonic flowmeters.

In these devices, there are two main components: the primary equipment that enables to measure the pressure or the flowrate and the secondary instrumentation that enables to transform the initial measure into flowrate and volumes. Modern secondary instrumentation are generally based on electronic systems.

### Verification, calibration and validation

The requirements of verification are generally defined by a country's metrological legislation. While verification is quite similar to calibration (in a practical sense), there are more stringent requirements as to who can verify an instrument. Only a verifying authority or utility meter verifier can verify a measuring instrument. Verification is a legal term and as such, there are strict legal requirements attached. The practitioner needs to be familiar with the requirements of the metrological legislation and the accreditation body of the country within which they operate.

Calibration relate to a set of operations that established, under specific conditions, the relationship between the quantities indicated by the water meter and the corresponding values realized by a reference standard of higher metrological quality. This process implies that the operations are undertaken in accordance with the requirements of an accreditation body, detailed in a quality manual and is peer reviewed on a regular basis. The implication of this definition is that it is an assessment of the meter as an integrated entity. The American Water Works Association (AWWA, 2016) provides an alternative definition for calibration that places emphasis on the proper functioning of the secondary instrumentation.

Validation relates to the evaluation and certification of a metering installation. While validation does require that the "validator" checks that the meter is suitably verified/calibrated, the focus is usually that a meter has been installed correctly.

### Calibration of the secondary instrumentation

Electromagnetic water meters have the capability to have the integrity of their original factory settings verified in the field by electronic equipment. This electronic verification of the electronic transmitter includes testing of the converter, sensor, signal outputs, system insulation, cables and magnetic circuitry. The assumption made is that if these tests indicate that the electronics are stable then the electromagnetic meter is also stable and accurate. However, this verification does not measure flow and if the meter was originally installed with an incorrectly set-up flow range then the electronic verification would not detect this problem (Paton, 2002). Electronic verification cannot establish the bias (e.g. systematic) error of the meter. An in situ calibration process is therefore, still required to assess the bias error together with a specified level of measurement uncertainty associated with its random error (e.g. by also quantifying its random or stochastic error range).

Calibration of differential pressure transmitters (transducers) alone assumes that the internal pipe conditions remain unchanged over time however, once encrustation is formed on the internal pipe walls this enhances swirl and introduces measurement errors in the primary equipment over time (Spitzer & Furness, 2008).

Therefore the general practice of many water utilities is to only calibrating secondary instrumentation and not the water meter as an integrated entity. The practitioner needs to be informed that the practice of only calibrating the second instrumentation is useful but is not enough: in fact, it may lead to incorrect decision making.

### Calibration facilities and laboratory

It is rare for water utilities have their own meter-testing laboratory to test and calibrate large water meters. In addition, such large facilities are not available in many countries.

Generally, the only available facilities are the manufacturer's facility and it is necessary to send the meters abroad to undertake the calibration. It is generally a very expensive solution and the metering device may be unavailable for a long period.

Such a solution should be envisaged in very special cases only. The recommendation is to set up regular in-situ calibration procedures of large in-line water meters.

The implementation of an accredited calibration exercise can involve expensive installation works and have an influence on bulk water supply operations. If calibrations are to be scheduled on a regular basis it is recommended that the design and construction of new meter installation allow access for future calibration or verification procedures.

**Check meters**

Additional check meters can be installed as a double metering system consisting of two similar types of flow meters in series. Typical applications are for custody transfer meters where a water distribution utility purchases water from a supply (production) utility. The first meter belongs to the production utility (that sells water in bulk) and the second meter belongs to the distribution utility (that purchases water in bulk). The contract generally specifies that water will be charged based on the average value provided by both flow meters provided that the volumetric difference between the two meters is lower than a limiting value specified in the contract. If the difference exceeds this limiting values both flowmeters will be calibrated based on the protocol specified in the contract (Djerrari & Vermersch, 2004).

## *3. In-Situ and In-Line Calibration*

**Requirements for an in situ approach**

A water meter requires on-going recalibration, as on installation and over its operational life, the water meter’s performance will differ from that of its original off-site laboratory calibration as well as the manufacturer’s generic measurement error specifications.

There is, therefore, a need to determine the uncertainty of flow measurements within large pipelines by means of a portable meter so those in-line meters that cannot be easily removed for testing can be evaluated. Previously calibrated water meters also need to be calibrated in situ to take into account particular site conditions as well as all facets of flow measurement relative to a site-specific flow standard.

The calibration of large in-line water meters in the field is also required because of the expense of testing on off-site facilities and the practical problems associated with the removal and testing of some types of large water meters. The calibration process should not - and cannot - be simplified as only a comparison between the reference and permanent meters’ error specifications.

To be sustainable, any in situ calibration approach developed should be based on best practices in the field of flow metrology. These best practices should also have a foundation in applied research, sound experience and Quality Systems. Verification procedures based on a Quality System such as AS/ISO 17025 (1999) are an essential component of a calibration approach as it provides confidence in the results obtained.

The errors associated with large meter errors can be allocated a cost whether the meter is used for custody transfer purposes or to establish water balances as part of estimating real and apparent losses. The benefit of reducing these errors can be established as part of a financial analysis process to determine whether the expense of applying a particular in situ calibration is justified.

**Types of measurement errors**

All measurements are estimates of the true value being measured and the true value can never be known without some level of uncertainty. All process measurements are adversely influenced by errors during measurement, processing and transmission of the measurement signal. The total error in the measurement is the difference between the measured value and the true value. Generally, this is the sum of two contributing types of error, random and systematic errors (Johnson, 2012).

Random errors are associated with inherent random (e.g. stochastic) fluctuation associated with any measurement device resulting from signal noise, ambient conditions, environmental changes, etc. Systematic (e.g. bias) errors are caused by non-random events such as calibration anomalies, degradation of performance, degradation of internal pipe conditions, extreme mechanical shock/vibration, velocity profile distortion due to close proximity of hydraulic disturbance devices, etc.

A simplified example of the meter error that takes into account a bias error of -2.5% and a random error of ±2% is illustrated in Figure 1 for various numbers of meters. This indicates that the uncertainty in the measurement of apparent losses (in % volume) decreases as the number of meters increase but the bias error is independent of meter numbers. The assumptions used are that all the meters are the same type, size, have the same volumetric amounts registered and are monitoring the demands for same type of homogeneous users. Also note that the results are reported in terms of weighted error which is the relative error of indication weighted in accordance with an expected usage (demand) pattern.

It is important to note that although the uncertainty 'range' is smaller with multiple meters supplying into a system, the bias error is independent of the number of meters.

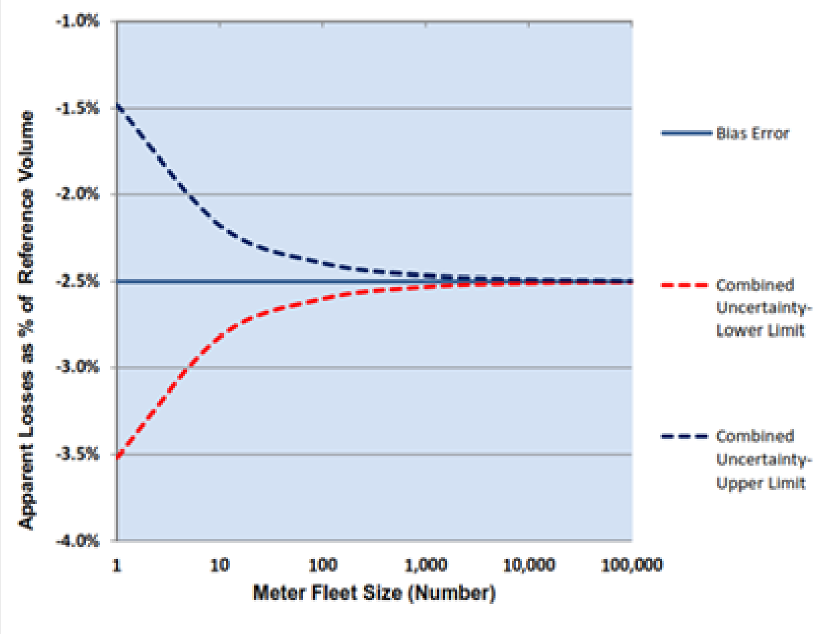


**Figure 1 Combined meter measurement errors (Johnson, 2012)**

In practice, Utility distribution systems can have multiple source meters and import meters, and sometimes also export meters, all with significantly different volumetric amounts due to bias errors and varying over a range due to random errors. This also complicates the assessment of the overall random error of Water Supplied by bulk metering into a distribution system. Lambert (2016) outlines a practical approach to assessing this combined uncertainty, not only for combinations of bulk meters but also for the complete Water Balance, to assist in prioritising actions which will have the greatest influence on reducing uncertainty in calculated volumes of Non-Revenue Water, Apparent Losses and Real Losses.

## *4. Principal Calibration Methods*

### REFERENCE STANDARD

A flow reference standard is generally used as the benchmark to be compared against when establishing errors in flow measurement. A water meter of a higher metrological quality or a technique utilising weighing methods or volumetric methods is the most common form of reference standard. To be credible this standard should also be traceable to a national or international flow standard. Traceability is therefore a property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations.

Methods used to establish a reference standard for flow rate in closed conduits are determined by either measuring the mass of liquid delivered into a weighing tank or collected in a volumetric tank in known time intervals.

Flow reference standards that could be applied in the field include the following:

**i. Portable prover testing device**

On-site calibration can be undertaken with a meter prover that is a portable testing device using a dynamic volume method. The water is diverted from the installed meter through the prover under pressure wherein sensors measure the movement of a displacer as it travels through a known volume.
A comparison of the prover's measured volume with that registered by the installed meter establishes the error of measurement. The range of flows of a portable meter prover is limited by the size of its measuring pipe, which generally restricts the maximum size of water meter that can be calibrated in situ to 150 mm diameter.

**ii. Reservoir Drop Tests**

A common volumetric in situ calibration technique used is the monitoring of the change in water level in a service reservoir or pump sump that has been previously been isolated for the test of a large in line water meter. However, without an accredited quality system, flows derived from these tests, known as 'drop' tests, cannot be certified as sufficiently stable to be replicated for different tests. The main assumption generally used with the use of drop tests is that the reference flow rates derived from measurement of changes in water level in the reservoir and time are error free. This assumption ignores the following potential errors that could occur during drop tests:

- Imperfect knowledge of the level volume relationship due to changes in temperature, tank dimensions, the calibration rating relationship, etc.;
- Errors due to measurements with a level gauge;
- Errors due to measurements by the timing device;
- Errors due to density and temperature measurements; and
- Errors in volume due to isolation valves not achieving watertight closure.

**iii. Tracer Methods**

Tracer methods involve the injection of different types of tracers into the water flowing in a pipe and after adequate mixing either the tracer's dilution (ratio) or its mean transit time is measured to determine the flow rate. This flow rate is measured because the tracer's dilution is proportional to the flow rate or the time taken by the tracer to travel a specified distance within the pipe.

Examples of non-radioactive tracers include sodium dichromate, sodium chloride and sodium nitrite. Although the British Standard BS5857 (1980) indicates that an advantage of the dilution methods is that it is not necessary to know the geometrical characteristics of the pipe, application of the transit time method does require an accurate determination of the volume of the pipe between the two detection points.

**iv. Laser Doppler Velocimetry**

Laser Doppler Velocimetry (LDV) have been successfully used to carry out accredited in situ calibration of large water meters of up to 1,000 mm in diameter with flow velocities from 0.01 to 6.0 m/s (Drysdale et al, 2005). Using multiple windows in the pipe to gain optical access to the flowing water, the LDV achieved an uncertainty of 0.9% when calibrating large district heating meters.

Successful application of LDV technology in assessing flow rates in large diameter potable water pipelines was demonstrated in an Australian pilot study (Johnson, et al, 2016).

## *5. Practical on-site calibration methods*

When undertaking a calibration exercise it is important to recognise that influence quantities of a water meter are departures from the reference conditions that are used to define its accuracy. Miller (1989) considers that velocity-profile deviations, non-homogeneous flow, pulsating flow, and cavitation are the four major influence quantities affecting all water meters. Miller is of the opinion that the velocity profile is probably the most important (and least understood) influence quantity.

The general criteria for an in-situ calibration approach that minimises or eliminates departures from those reference conditions defining a water meter's accuracy are as follows:

- Development of an axis symmetric velocity profile at the measuring section of the pipeline. If conditions within the pipe at the measurement section have been adequately addressed to ensure achievement of an axis symmetric velocity profile then, the adverse effects of swirl and turbulence will most likely also be minimised. Ensuring that the conditions within the pipe at the measuring section encourage development of a stable profile enhances confidence that they are repeatable when used for calibration purposes. The recommended lengths of straight pipe that are required before a meter installation to eliminate swirl (rotational distortion) are provided in literature (e.g. AWWA, 2016) and manuals. However, these recommendations generally relate to small pipe diameters as it has been found that swirl in large diameter pipes require considerable lengths of straight pipe to eliminate profile distortion (Spitzer & Furness, 2008). The distortion to a velocity profile in a 1,050 mm diameter pipeline situated 10 diameters downstream of a 15-degree bend is illustrated in Figure 2.
- Ensuring homogeneous flow and for water this means that the density and hence temperature must be constant or known during the test. Establishing a relationship that defines the velocity profile from point measurements that is independent of temperature changes will contribute to reducing the effect of this influence quantity.
- Ensuring steady state flow at reference conditions also minimises errors of measurement. Using a single traverse of an insertion meter reduces the measurement time and potential for large flow variations.
- Siting of the measurement section within a pipeline with properly operating air valves reduces the effects of cavitation, which is the "boiling" of water caused by decreasing pressure due to friction, flow separation, or restrictors and the subsequent entrapment of air.

There are a limited number of practical *in situ* calibration techniques that have evidence that their particular technique is traceable to a national or international flow standard. Techniques that have demonstrated this traceability were those that applied an insertion velocity probe (Johnson, 2007) and more recently, the LDV systems (Johnson, et al, 2016). The LDV technique is currently the only method that can achieve overall combined uncertainties in the field of smaller than ±1% that is verified by an independent and recognised accreditation organisation.

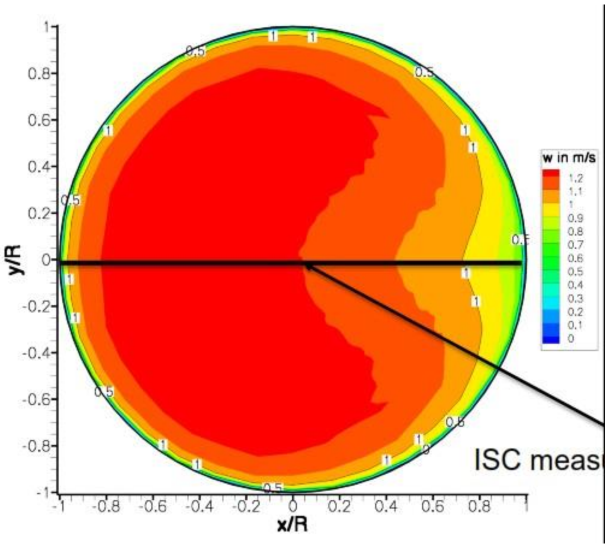


**Figure 2** **Velocity profile distortion due to an upstream 15º bend (source : Optolution)**

## *6. In Situ calibration research and investigations*

**Velocity Profiling using Insertion Meters**

Original research conducted in Europe into the various velocity-area methods of flow determination assumed that the insertion meters were error-free and emphasised the relative accuracy of these methods. A subsequent applied research project in South Africa combined the various components of uncertainty of measurement through a direct comparison of the velocity profiles measured with an insertion meter and the flow measured by an accredited off-site laboratory. A pilot study investigation was carried out to establish the practicality of applying the findings of this applied research. These previous studies are reviewed by Johnson (2007) and summarised as follows.

- The log-linear velocity-area method is the most efficient to use as it required fewer measuring points across the pipe to achieve smaller flow measurement errors than other velocity-area methods with a greater number of measuring points.
- The combined errors of all the factors influencing the measurement of flow by means of the in situ calibration method developed generally fall within the error limits adopted for meters in use.
- The correct assessment of future calibration sites as well as the ability of the hydraulic system to achieve specified flow rates required establishing from reconnaissance surveys and data collection exercises.
- An approach that excluded the application of a Quality System had limitations, although tentative results from initial tests indicated that the error in measurement of some permanent water meters were outside the limits specified by international standards.
- The calibration sites required the installation of new sections of in-line piping to ensure stability and consistency of velocity profile measurements.
- Establishing the in-line meter’s overall (uncalibrated) weighted error of measurement determined whether they were correctly specified for the current operating conditions.
- The water utility’s organisational capacity and respective skills base required strengthening before it could implement its own Quality System and a program for the on-going in situ calibration of its large water meters.

**Velocity Profiling using LDV technology**

The LDV technology is currently the only credible technique with traceability back to a national flow reference standard. The LDV flow reference standard is currently traceable to the German National Metrology Institute PTB (Physikalisch-Tehnische Bundesanstalt) national flow standard. ILA GmbH has certification of their LDV method with both PTB and TUVRheinland (Guntermann et al, 2011). An example of LDV installation for in situ calibrations is illustrated in Figure 3.

**Figure 3 LDV Installation for In situ Calibrations (Johnson, et al , 2016)**

A LDV pilot project involved flow comparisons with seven electromagnetic flow meters with diameters from 600 mm to 1,000 mm identified an overall (net) average over-reading of 583 ML with an equivalent value of approximately US$1.1 million per year based on the value of water (Johnson, et al, 2016).

## *7. Quality system and manual*

A Quality System for an in situ calibration laboratory includes applicable procedures, methods, competent personnel, portable water meters and water engineering infrastructure. The code of practice AS/ISO 17025 (1999) provides the general guidance to establish a Quality System for a calibration laboratory. A Quality System is outlined in a Quality Manual that sets out the quality policy and objectives as well as identifies management functions and responsibilities. Technical requirements that include the procedure to estimate uncertainty of flow measurements and validation of the calibration method are also detailed in a Quality Manual. An example of the technical requirements for an in situ calibration laboratory are provided by Johnson (2009).

The aim of a Quality System is to have routine activities standardised for the benefit of all concerned and then to ensure that every individual and activity involved becomes part of the process. This Quality System facilitates confidence by stakeholders in the uncertainty of flow measurement statements of a water authority’s large water meters.

The Quality Manual is the core document used for the purposes of obtaining accreditation of a calibration laboratory in terms of AS/ISO 17025 (2005). A laboratory obtains its accreditation from the National Accreditation Body of a country. National Accreditation Bodies for various countries are linked via international Mutual Recognition Agreements through the International Laboratory Accreditation Co-operation (ILAC) to ensure consistency amongst accreditation bodies.

## *8. Estimate uncertainty of flow measurement*

A statement of the uncertainty associated with the result of a measurement is preferred because it is more specific than the general term accuracy, which is often open to misinterpretation. To express correctly the 'accuracy' of a standard or a calibration it is the 'uncertainty', which must be stated (Paton, 2002).

A reference standard must be related to a national and international standard through an unbroken chain of comparisons.

The uncertainty assumed for a bulk meter which has been checked by an in situ flow reference standard cannot be assumed to be less than the uncertainty of that in situ flow reference standard. (e.g. if the uncertainty associated with flow reference standard is ± 2.0% and during in situ tests the error of the bulk metered volume falls within this ±2.0% the bulk meter should not be adjusted).

Selected examples of the sources of uncertainty that should be considered when preparing an uncertainty budget for a closed conduit flow meter system include the following:

**Primary device**

- The installation effects on the flow meter due to factors such as the internal condition of the pipe wall, fouling, deposits, distortion in roundness of the pipe (e.g. ovality), gauging sensor misplacement and internal diameter.
- Hydraulic effects such as potential distortion to the velocity profiles upstream and downstream of the meter installation due to the proximity of valves, bends and other fittings (e.g. asymmetry velocity profile, turbulence, swirl, and so on).
- Unsteady flow (e.g. excessive flow surges/pulses) as well as asymmetric velocity profiles due to pipe bends, valves and other flow disturbance devices in close proximity to the meter.
- Environmental factors such as temperature and humidity.

**Secondary device**

- The meter's electronics and equipment such as the current, inductance, inductance shift, loop resistance, transmitter data (e.g. gain), magnetic circuitry, sensors, pulse output, etc.
- Sampling frequency and set point.
- The resolution of the meter display (if manually read) or truncation of digits at electronic interfaces.
- 4-20mA flow range and pulse volume relationship.
- Signal conversion such as potential for analogue to digital (A-to-D) converter errors (e.g. negative flow rates, continuous periods of maximum flow and unexpected drop in flow rate).

**Data collection**

- Uncertainties in the data due to the flow meter operating outside of its operating range with higher measurement errors.
- Data conversion errors due to potential analogue to digital (A-to-D) converter errors at the transmitter, outstation or central base station.
- Incorrect scaling of electronic pulses (e.g. litres per pulse) and incorrect or insufficient resolution of data time recording (e.g. time stamp).

## 9. Concluding remarks

An accredited calibration approach provides the necessary confidence in the data on a more frequent basis than the original off-site manufacturer's calibration as well as takes into account specific on-site conditions (Johnson, 2007).

A water utility should adopt an accredited calibration approach based on the principles stated in this paper. It should be the first recommendation of any water audit resulting from the establishment of a water balance.

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