Metrology for Real-World Domestic Water Metering

Publishable Summary for 17IND13 Metrowamet
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Overview

Smart water meters are fast becoming a selling point, as they provide, for example, convenient access for consumers at any time to monitor water consumption or leakage. However, such real time metering requires adequate meter sensitivity and resolution, especially at low flow rates below 3 L/h, paired with pattern recognition. The aim of this project was to provide European water meter manufacturers and water suppliers with reliable and trustworthy measurement capabilities. This was achieved by realising a new measurement infrastructure which enables testing of domestic water meters in simulated conditions that closely resemble the real-world. Conditions include dynamic flow changes as seen in water consumption in households, water quality related aspects, and withdrawal of low amounts of water. Guidelines and publications were prepared which enable stakeholders to take up the project outputs.

Need

For European manufacturers of domestic water meters and water suppliers to meet present-day demands for accurate metering under real-world operation conditions, it is desirable to test meters under close to real-world and not only under laboratory conditions as was the case at the beginning of the project. In the last decades, the state of the art for water meters has progressed considerably. Materials and fabrications have changed, additionally meters based on new technologies have been deployed. At the same time, the consumption behaviour of consumers and the technical equipment in dwellings have also changed significantly.

Actual water consumption profiles represent dynamic load changes which therefore deviate strongly from the well-defined, constant and reproducible reference flows as prescribed in legal metrology documentation (such as OIML R49 and ISO 4064: Technical requirements for water meters for cold potable water and hot water). This means that the domestic water meters might meet requirements at the test points, excluding the required cumulative uncertainty. This issue had already become a work item for WELMEC WG13 (European Cooperation in Legal Metrology) and could develop as a work item for CEN/TC92/WG2 (European Committee for Standardisation - Water meters). There was no clear view on how different types of domestic water meters actually perform under dynamic load changes, as the metrology for this was missing.

The performance of domestic water meters under real-world operation conditions such as typical water qualities, age and wear is a further matter of concern, particularly for extending or shortening calibration periods. By undergoing sampling, the operation times of water meters could be extended. In order to do so, it is necessary to ensure that the meters remain within the maximum permissible error in the calibration period, otherwise they need to be replaced. Short calibration periods of a few years can result in significant effort and high costs of several million € per year for meter replacements, which make it unattractive for water suppliers to deploy high-quality flow meters. This ultimately may lead to the adoption of sub-optimal technologies with a reduced metering quality, which is not in the interest of consumer protection. Moreover, any costs related to replacements are passed on to consumers leading to increased costs for water supply. Furthermore, a systematic assessment of water meter performance for common operation conditions, combined with metrologically backed scenarios for standardised real-world test conditions related to water quality and a means to estimate meter performance for given conditions was needed.

While water meter manufacturers already offer devices with implemented leakage detection, the criterion by which a leak is defined, is commonly an economic one, based on the smallest flow rate that their domestic flow meter can easily identify. Given that leakage is frequently the cause for increased water consumption in a household and leakage related damage, claims have been rising significantly for several years. There was a clear need for more sophisticated leak detection based on leak signatures and quality assessment that could enable early action and thereby minimise the damage and repair costs caused due to undetected leakage.

Objectives

The overall aim of this project was to provide European manufacturers of water meters and water suppliers with needed trusted measurement capabilities to assess the measurement performance of domestic water meters close to real-world conditions.

The specific objectives of the project were:

1. To develop test rigs and provide protocols beyond the current methods of OIML R49 for the calibration/verification of domestic water meters under dynamic load changes; this includes the determination of typical consumption profiles and based on this the derivation of one or more pre-normative reference profiles. Furthermore, inter-comparisons and a rigorous uncertainty assessment will be carried out.
2. To assess the performance of domestic water meters under realistic operation conditions such as typical water qualities (hardness, pH and particles such as rust, sediments) as well as age and wear in general by experiments and where appropriate modelling including a determination of the related uncertainties. Scenarios for more real-world test conditions will be defined as basis for future standardised tests.
3. To foster smart metering by determining the requirements for a real-time monitoring of water consumption, the development and adaption of intelligent algorithms for the detection of leakage and by setting up a feasibility study about domestic water meters suitable for the detection of small flow rates (i.e. below 3 L/h).
4. To develop a virtual flow meter to simulate effects of the operation conditions on the performance of water meters, to estimate the uncertainty and to predict effects due to ageing or wear of water meters based on data of used devices.
5. To engage with water meter manufacturers and water suppliers to facilitate the take up of the technology and measurement infrastructure developed in the project by end users (e.g. water meter manufacturers and water suppliers), thereby enhancing the competitiveness of EU industry and to provide input into relevant organisations, e.g. WELMEC WG13, CEN/TC92/WG2 and ISO/TC 30/SC 7.

Progress beyond the state of the art

The project aimed at establishing a metrological infrastructure, which will enable an integral characterisation of domestic water meter performance under conditions as close to real-world as possible. Current test regimes for domestic water meters are prescribed to be run with well-defined, constant and reproducible reference flow rates. This project has developed essential metrological infrastructure and protocols required to assess the performance of domestic water meters under a dynamic test regime. Taking account of the variability in consumer behaviour, three pre-normative reference load profiles were derived, which can serve as input for the assessment of water meters under the novel test regime. Furthermore, test rigs operated with dynamic load changes, based on different principles were realised. A comprehensive inter-comparison of the rigs and rigorous uncertainty assessment of the systems has been carried out. (Objective 1)

Higher expectations on meter performance and progress in water meter manufacturing both require a reassessment of the influence of potentially adverse conditions and their effect on measurement uncertainties. Based on the analysis of historic and recent surveys as well as on a literature review, the project provided ranges of typical conditions regarding water hardness, pH, contents of relevant elements and suspended particles encountered at consumers' "doorstep". Effects of associated age and general wear on the performance of domestic water meters commonly deployed in Europe were investigated in a broad range of experiments and through the evaluation of surveys concerning used water meters. Protocols to test water meters close to real-world operation conditions were developed within the project. (Objective 2)

Leakage is frequently the cause for increased water consumption in a household therefore damages and claims related to leakages have been rising significantly for several years. Algorithms for leak detection were developed based on metrologically sound characterisation of background leakage. Furthermore, criteria on the monitoring side have been derived, which need to be fulfilled by meter and acquisition system for leak detection in a given order of magnitude. After the performance capabilities of commonly deployed water meters in the low flow range below 3 L/h were reviewed against these criteria, a hardware solution appropriate for leakage monitoring has been proposed. The detection reliability of algorithms and hardware performances were assessed by testing against experimental leakage data derived from the project. This enabled the quantitative performance validation of both the hardware and software. (Objective 3)

The knowledge gained in the project on water meter performance served as an input for the development of a virtual flow meter. This comprehensive tool provides a quantitative estimation of metering quality for given conditions, manufacturer and operating time, which was not available prior to the project. The data base and virtual flow meter are not in their final state as of the end of the project but will provide the framework for an extension according to future stakeholder needs and new technological developments. (Objective 4)

Results

To develop test rigs and provide protocols beyond the current methods of OIML R49 (Objective 1)

A joint analysis of consumption data, from surveys carried out both before and within this project that were targeted at various European countries, has shown that water consumption is fairly similar in this European region (excluding situations where a storage tank is used). So, a distinction according to country or season was not necessary for the flow profiles, which have been used to assess water meter performance under dynamic flow rate changes.

A Metering Site Identification Scheme was developed which includes guidelines on data acquisition as well as a minimum set of meta data required for carrying out water consumption measurements at households. AQUA (European Association of Water and Heat Meter Manufacturers) joined the project as a collaborator and provided input to the scheme which can be downloaded here. With WRC Ltd, a company active in research and consultancy in water, waste and the environment in the United Kingdom, the project gained another collaborator. They provided insights into aspects of water consumption in the UK.

Based on the consumption data, a set of requirements was derived which test rigs should fulfil to capably generate and measure dynamic flows associated with water consumption in Europe. Subsequently, seven test rigs were developed in the project based on different technologies. An official EURAMET pilot study (Project No. 1506) was launched in which an inter-comparison of the test rigs regarding the generation and measurement of dynamic flow changes was carried out. For the assessment and comparison of the test rigs, a validation module was developed which was tested extensively at the partners prior to the inter-comparison. A special test protocol was set up for the inter-comparison, in which experience gained during the test phase was entered. The pilot study was performed using three flow profiles with volumes of approximately 50 L, 80 L and 100 L simulating (representing) dynamic flow load changes in a flow rate range up to 1600 L/h. The flow profiles were chosen with respect to the laboratories' capabilities and so that they were statistically representative of the actual water consumption in European households. Each flow profile represented different starting/ending situations, which the participating laboratory had to demonstrate its capacity to handle. Eight partners participated in this inter-comparison. This was the first time worldwide that an inter-comparison of dynamic flow measurements was performed. To adequately realise the inter-comparison a dedicated transfer setup was developed. For a more comprehensive characterisation of the test rigs concerning their dynamic performance, additional criteria extending beyond those of a standard inter-comparison were derived. These new criteria will also be suitable for use in other inter-comparisons which deal with dynamic liquid flow changes. The novel measurement capabilities were used to exemplarily evaluate the measurement performance of several types of domestic water meters from different manufacturers. The results were compared with the measurement deviations obtained after tests using a set of constant flow rates as prescribed in normative documents. In general, no significant differences in the measurement performance of the water meters were found for the two test regimes. However, a few individual water meters showed differences. The further procedure must be discussed in the relevant normative committees.

All contents of Objective 1 have been entirely fulfilled. The test rigs for dynamic flow changes linked to household water consumption were realised. Statistically assured test profiles reflecting water consumption characteristics were derived.) The capabilities and quality of the newly developed metrological infrastructure were demonstrated in an inter-comparison. The applicability of the new regime to performance tests of domestic water meters was shown. By providing guidelines and publications, the uptake of the project outputs related to Objective 1 is facilitated.

To assess the performance of domestic water meters under realistic operation conditions (Objective 2)

Typical ranges of water qualities encountered in central Europe were derived from a literature review and were also confirmed by an analysis of a recent survey, carried out in Austria. The ranges were used in the performance tests with domestic water meters on rigs and in small-scale model networks. These performance tests focussed on meters of the types single jet, multi jet, ultrasound, electromagnetic and piston with size Q_3 2.5. All meters were installed at minimum horizontally with dial up. In addition, single jet and multi jet meters were also measured in vertical position. A protocol for the testing of water meters and potential deterioration of performance related to water quality was set up. A mixing recipe for a reference water were developed. This water can be prepared easily by any parties Its pH and hardness values can be systematically and reproducibly modified according to more recipes. For quality control, all partners monitored the pH and hardness values of the test waters used in their experiments. Altogether 196 water meters from nine manufacturers were measured. At a second stage, the measurement program was expanded in order to verify measurement results and also to gain insight into how critical experiment duration (i.e. the time span in which the meters were exposed to water of known quality) is for the measurement result. For this purpose, the trial period was extended once again by the same amount of time after the water meters had been checked for their measurement performance after the regular period had passed. The hardness tests were extended to include measurements for a significantly harder water. Also, using a combination of increased total hardness and particles it was exemplarily investigated whether a combination of effects has a greater impact on the measurement errors than the individual influences. Here, too, the experiment duration was doubled again after an intermediate measurement of the water meters. To round off the work, a comparison was made between the results of the continuous stress test according to OIML R 49:2013(E) and ISO 4064:2014 and the results after exposing the water meters to a defined test water.

On the basis of the experiments, various insights could be gained: Apparently, the type of test regime (test rig with a steady flow or a small-scale model network which is run with a dynamic flow profile) does not seem to play a relevant role. The test waters proved to be stable. The experiments showed that the greatest impact on the water meter performance does not necessarily occur with the poorest water quality or at the smallest flow rates. There are indications that tests with poorer water quality tend to have a stronger effect on the water meter performance than conventional stress testing (100 h at Q_4) as prescribed i.e. in OIML R49:2013(E). Moreover, mechanical water meters installed vertically are more affected than water meters installed horizontally. Water meters with an electronic measuring principle tend to be less affected by water quality than water meters with a mechanical measuring principle. However, there are obvious exceptions in this respect. The overall results are extremely heterogeneous with respect to the type, the manufacturer and the results of the project show that even to the batch.

Objective 2 has been fully achieved. The conditions which a domestic water meter is typically exposed to in Europe were derived. From surveys on consumption characteristics and tap water quality boundary conditions for a water quality-related test regime were identified. Based on these, mixing recipes for different water qualities (PH, total hardness, suspended particles) were developed, which ensure the comparability and repeatability of the test water properties. All of this has gone into the development of a new metrologically validated test regime for evaluating the measurement performance of domestic water meters depending on water quality. A comparison with the conventional endurance test as prescribed e.g. in OIML R49:2013(E) was carried out. By providing guidelines and publications the uptake of the project outputs related to Objective 2 is facilitated.

To foster smart metering by determining the requirements for a real-time monitoring of water consumption (Objective 3)

A survey among manufacturers and water utilities along with a literature review were carried out to get an overview of leak detection approaches and related infrastructure. AQUA provided manufacturers’ insights into the performance capabilities of different water meter technologies. Based on this, water meter types were selected for monitoring small flow rates in the project. In parallel, test infrastructure for leakage detection was set up. A dynamic profile for low flows was developed and implemented by project partners. Data sets containing defined leakage were obtained which were then used to derive requirements which need to be fulfilled by devices for leakage detection in households based on flow measurements.

A travelling standard was selected for a comparison of on-site test infrastructures for low flow rates at participating partner’s institutes. This travelling standard was recently used in bilateral inter-comparison test which yielded a very good general agreement between the measurement results obtained by the participants.

Based on a preparatory study and a review of existing algorithms used for leak detection in a network, a promising approach for a leakage detection algorithm was identified for use with household meter applications. An algorithm for leakage detection was developed. The approach is a mixture of the Minimum Night Flow and the Data Driven Demand Forecast. By using pattern recognition methods, the typical usage profile connected to the water meter is obtained. The algorithm was tested on simulated leakage data inserted into real consumption data. The test gave very satisfactory results: e.g. the total leakage volume was accurately recovered by the algorithm. The algorithm identified three types of anomalies: baseline, night time and daytime anomalies. The technical report on the algorithm is available here.

Furthermore, a hardware platform was developed for detecting small flow on domestic water meters using image-based correlation. With this, older analogue water meters can be upgraded to a meter with a digital output which then can be combined with a leakage detection algorithm. The hardware platform is generic and is ready for implementing leak detection algorithms.

Objective 3 was fully achieved. Requirements for a real-time monitoring of water consumption were derived. An intelligent algorithm for the detection of leakage at household level was developed and successfully tested. Furthermore, a feasibility study was carried out about domestic water meters suitable for the detection of small flow rates (i.e. below 3 L/h). To facilitate the uptake of the project outputs related to Objective 3 the associated deliverables were made available for downloading on the project's website.

To develop a virtual flow meter, to simulate effects of the operation conditions on the performance of water meters (Objective 4)

The main purpose of developing the virtual flow meter was to make measurement results obtained within the Metrowamet project related the effect of water quality on the performance of domestic water meters available to all interested parties via a user interface. The information is anonymised with regard to the water meter manufacturers with each given an arbitrarily assigned alias.

It was originally planned to describe changes in the measurement performance of the water meters depending on water quality empirically via formulas instead of providing the individual data sets. This proved to be not feasible because the changes in the measurement deviations turned out to be too heterogeneous. The concrete changes apparently depend at least on the combination of water meter type and manufacturer, maybe sometimes even on the meter batch. In consequence, misleading interpretations would be obtained if empirical descriptions were to be used. As a result, the interface was designed differently. Now the measurement deviations of the various water meters tested can be selected according to different parameters and plotted in a diagram.

The database and user interface were set up in such a way that they can be used and made available in the long term without a great deal of maintenance. The database will be supplemented with existing and future measurement data on water meters obtained outside the project. Database and user interface are currently undergoing IT security checks. The user interface will be made accessible via https://www.ptb.de/empir2018/metrowamet/information-communication/downloads/. For the time being performance data and their diagramming are provided via an excel-application available at the project website.

Objective 4 could not be realised in its entirety. It was originally intended to describe and predict changes in the measurement performance of the water meters (according to type, size, measuring range) depending on water quality empirically via formulas. This proved to be not feasible because the changes in the measurement deviations proved to be rather heterogeneous and strongly dependent on the individual manufacturers. For this reason, the individual anonymised data sets were made available on the project website

Impact

Eight presentations were given by the project partners at European and international conferences. As of the end of the project, the project's progress was presented at ten events organised by the project consortium. In November 2019, a one-day dissemination workshop was held at CETIAT. The focus was on dynamic measurements methods and consumption measurements in water metering. In June 2020, a first webinar covering Metrowamet results was held. A second webinar giving updates on project results took place in June 2021. In September 2021, an online dissemination workshop was organised at which all project outcomes were presented and discussed. Furthermore, an outlook was given on how to proceed with the project findings. The presentations of the dissemination workshop can be downloaded here. With more than sixty participants from all over the world, the webinars as well as the dissemination workshop were well attended. Representatives from water meter manufacturers, regulatory authorities participated as well as members of metrological institutes and representatives from relevant associations.

An end-user advisory board was set up, comprised of water meter manufacturers, water utilities and standardisation bodies. Further to this, AQUA, given their long-term and diverse experience, provided useful insights from a water meter manufacturer's perspective. WRC Ltd contributed the perspective of water utilities. In addition, articles on the Metrowamet project appeared in four newsletters related to water utilities in Germany and Denmark. One trade article was published on the WaterTech website which is targeted at professionals working with water and water circuits.

Impact on industrial and other user communities

As a result of the project, metrological infrastructure and protocols are available to assess domestic water meters under dynamics load changes in the future. The rigs developed in the project for meter tests under dynamic load changes were realised based on different principles, which facilitates uptake by stakeholders (e.g. manufacturers of water meters) and strengthens confidence in the novel test regime and associated measurement uncertainties.

International key players in the manufacturing of high-quality domestic water meters are located in Europe. The project outputs will thus strengthen the position of European manufacturers of domestic water meters as it will render the deployment of low-cost meters with low performance quality unattractive. By this, the outputs of the project will simultaneously support consumer protection. Water utilities will be supported to better demonstrate the quality of water meter performance in case of customer enquiries.

All aspects in the project related to measurements under dynamic load changes are of interest to the entire community active in liquid flow measurements as dynamic calibrations are moving more and more into focus. Moreover, due to forthcoming developments, the reaction of fast responding heat meters to real world-loads is under discussion. The outcomes of the Metrowamet project can be used to pave the way to solve these issues.

The project brings benefits to water utilities, by providing for the first time, a concise overview of potential deterioration of water meter performance due to operating conditions and a user interface to assess overall potential risks of legal non-compliance when participating in sampling procedures. The compilation of typical operating conditions in Europe and the provision of assorted test scenarios supports meter manufacturers and testing laboratories to set up dedicated performance tests of water meters in the future. This will be of further interest when meters based on novel technologies are put on the market, as they need to undergo a procedure of qualification and their measurement stability needs to be demonstrated beforehand. Thus, the outputs of the project will contribute to a shorter time window between meter development and market maturity.

Impact on the metrology and scientific communities

Based on the outputs of the project, NMIs (National Metrology Institutes) and DIs (Designated Institutes) will be able to establish new capabilities at their institutions for calibrations under dynamic flow conditions. A metrological framework is available now to address water meter performance under real-world operation conditions. The comprehensive insights gained in the project and the facilities available will enable the metrological community to better support their industrial stakeholders (i.e. manufacturers of water meters, water suppliers) in this regard.

Knowhow and capabilities established at NMI and DI level on device assessment for rapidly changing flows and small flows (lower than 3 L/h) will prove to be extremely useful for reliable flow measurements in other applications, such as nozzle-specific optimised fuel injections in engines or process control by monitoring the momentary flow e.g. in pharmaceutical and food industries.

The composition of usage and peak factors related to water consumption in households, including other outputs of the public supply networks and their potential developments with regards to climate and socio-economic changes are of major interest and thus, are the topic of various research projects. Any in-depth studies related to these factors or differentiated forecasts on future consumptions, including correlations with climate changes or socio-economic factors, rely amongst others on time-resolved water consumption data from households. The recommendations developed in this project for consumption monitoring and reliability assessment of water meters will support research in this regard.

Impact on relevant standards

Since actual water consumption profiles deviate strongly from the well-defined, constant and reproducible reference flows as prescribed in existing documents in legal metrology such as OIML R49 or ISO 4064, this might affect the cumulative uncertainty of water meters which is not seen in the standard continuous test regime. The research carried out in this project and the infrastructure and protocols established in this context will contribute towards solving this key issue. The project has already delivered input and will continue to do so to all relevant international and national bodies dealing with sampling of water meters as it will provide systematic insights on how real-world conditions may affect water meter performance, including associated measurement deviations, and the means to estimate their effects.

In particular, the project and its progress were presented at CEN/TC92/WG2 “Water meters - General Requirements”. Further reports were presented at meetings of working groups dedicated to water meters of national bodies and associations. The WELMEC WG13 “Water and heat meters” received updates about the project on a regular basis. Furthermore, ISO-TC 30 “Water meters” and OIML-TC 8 “Water meters” were provided with brief reports on the project linked to their meetings.

Longer-term economic, social and environmental impacts

Water is about to become the most valuable resource on Earth, taking in account that aquifers and river basins are depleted or polluted, and reservoir capacities prove insufficient in many regions. New technologies like smart meters as supported by this project are progressively playing a more important role within the water sector by helping to gather information from consumers, which is the first requirement for developing an efficient water management system. The progress made in the project regarding leakage detection and monitoring of small flow rates can be put to direct use in this context and will contribute to the European Commission’s s goal for rational and responsible use of Europe’s water resources. An approach which can contribute towards prolonging the lifetime of a water meter or provide incentives for conserving water as envisaged by this project, will help to ensure affordable access to this commodity in Europe. Since shorter verification periods for water meters can lead to immediate and high basic costs for consumers, an improved understanding of meter performance under real-world operation conditions will help water suppliers to get a better grasp of the metering quality and enable them to plan accordingly.

Used water meters are thrown away as it is not economically viable to have them maintained. However, if the operating period of a batch could be prolonged by improved knowledge on meter performance under real-world operation conditions as gained by this project, then fewer meters would have to be thrown away and a significant amount of material and energy resources could be saved.

Extensive installation networks, changes to materials used for buildings and installations as well as popular do-it-yourself (DIY) works in households have led to a significant rise in water pipe damages. Methods which enable the early detection of unusual water consumption will help insurance companies and individuals to save damage related costs. The outputs of the projects related to background leakage detection such as the leakage detection algorithm can contribute to mitigating these risks.

The European water sector is characterised by a complicated regulatory environment across various political hierarchy levels which results in fragmentation such as varying regulations and standards in different countries. This severely hampers overarching innovations in the water sector, hence a much-needed pan-European approach in this field was prepared in this project, with the intention to lessen barriers.

List of publications

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Pietrosanto, A., Carratù, M., Liguori, C., 2021. Sensitivity of water meters to small leakage. Measurement, vol. 168, https://doi.org/10.1016/j.measurement.2020.108479

Schumann, D., Kroner, C., Unsal, B., Haack, S., Kondrup, J., Christophersen, N., Benkova, M., Knotek, S., 2021. Measurements of water consumption for the development of a new test regime for domestic water meters. Flow Measurements and Instrumentation, vol. 19, June 2021. https://doi.org/10.1016/j.flowmeasinst.2021.101963

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:		01 June 2018, 40 months	
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Internal Funded Partners: 1 PTB, Germany 2 BEV-PTP, Austria 3 CMI, Czech Republic 4 DTI, Denmark 5 NEL, United Kingdom 6 RISE, Sweden 7 TUBITAK, Turkey 8 VTT, Finland	External Funded Partners: 9 DVGW, Germany 10 FORCE, Denmark 11 UNISA, Italy		Unfunded Partners: 12 CETIAT, France
RMG: -			