Canal de Isabel II

BOOKLETS

Research + Development & Innovation

8

Accuracy in the measurement of individual water consumption in Madrid Region

Authors
Isabel Díaz Guzmán
Jaime Flores Cabeza

Project Direction
Francisco Cubillo

Acknowledgements
The work presented here would not have been possible without the specific contribution made by Francisco Arregui, from Universidad Politécnica de Valencia; Antonio Martín, from Monedero Instalaciones y Servicios; David Bollo, Asunción Hernández, Hugo Mañero and Ángel García de la Chica, from Canal de Isabel II; not to mention the expert technicians from the Dirección General de Industria, Energía y Minas and the Laboratorio de Metrología from Madrid Region, all of whom deserve a very special acknowledgment.

Juan Carlos Ibáñez Carranza, from the Deputy Direction of Research, Development and Innovation of Canal de Isabel II also deserves a special mention because of his collaboration in this study with the project for determining consumption histograms for domestic use, and Fernando Rodríguez Algaba from the said R+D+I Deputy Direction, for his collaboration in supervising field tests to establish the meter error curve.

ISSN: 2254-8955
ISBN: 978-84-936445-3-6
Legal Deposit: M-27910-2010

Accuracy in the measurement of individual water consumption in Madrid Region

Booklets
Research + Development & Innovation
Canal de Isabel II

8

Introduction

Canal de Isabel II's Research, Development & Innovation Booklets form part of the company's Knowledge Management Strategy and of the development involved in the Research, Development and Innovation Plan.

These Booklets represent an element for diffusion of projects and initiatives that are developed and sponsored by Canal de Isabel II for innovation in those areas related with water service in the urban environment.

A series of different problems that have been undertaken in each project are put forward in the Booklets, along with the results that have been obtained. The intention behind their diffusion by means of these publications is to share the experiences and knowledge that has been acquired with the entire water services sector, with the scientific community and with all those working on investigation and innovation tasks. What is aimed with the publication of these Booklets is to contribute to improvement and efficiency in water management and, consequently, in the quality of service that is provided to the citizens.

The R&D&I booklets published to date are as shown below by their titles in the following table.

Collection Number	Research, Development and Innovation Booklets published
1	Transferences of Water Rights between Urban and Agrarian Demands. The case of the Community of Madrid
2	Identification of Hydrometeorological Runs and Tendencies within the scope of the Canal de Isabel II system
3	Contribution of Canal de Isabel II to the International Demand Management Project (IDMF)
4	Micro-components and Explanatory Factors on Domestic Water Consumption in the Comunidad de Madrid
5	Virtual Water and Hydrological footprint in the Comunidad de Madrid
6	Study on the saving potential of water for residential uses in the Comunidad de Madrid
7	Potentials of efficiency in using dishwashers

Project Outline

Project title	**Accuracy in the measurement of individual water consumption in Madrid Region**
Research line	Management efficiency
Canal de Isabel II units involved	• R+D+I Deputy Direction • Commercial Management Direction • Water Quality Deputy Direction
External participation	• Dirección General de Industria, Energía y Minas in the Comunidad de Madrid • Universidad Politécnica de Valencia (UPV) • Monedero Instalaciones y Servicios S.A. • Wasser S.A.
Aim and justification of the project	Obtaining greater knowledge about the metrological state of the installed base of meters in Madrid Region, used by Canal de Isabel II to bill its customers for water consumption and to establish the volumetric error made on the basis of the different explanatory variables. To make a contribution to implementing efficient water meter management policies.
State of the art contribution	• Improving knowledge about the reliability of individual consumption measurement • Improving knowledge about how meter accuracy evolves and the factors that govern this • Improving the evaluation of apparent losses • New procedure for testing meters at the customers' facilities
Project development summary and milestones	• Selecting a representative sample of meters to be tested • Manufacturing the in situ measurement equipment and testing it in the laboratory • Conducting 2,000 in situ tests on meters • Analysing the information concerning the meter error curves • Plotting consumption flow histograms for a sample of 226 users • Establishing the weighted error in the base of meters and how it is evolving
Obtained results summary	• The weighted error in the base of domestic meters in Madrid Region accounts for **–14%** of the total measured. • The greatest contribution to the weighted error affecting the base of meters is due to the unregistered consumption in the range of low flow-rates, because in that range, the error made by the meter fitted is very high, and negative (under-registration). • The service life of the meters increases as their metrological quality increases, as is shown by the comparative study between Class B and Class C meters analysed (the latter having special construction characteristics). • The effects of a loss of accuracy as a result of the way meters are installed and of the consumption patterns on low flow-rates are greater than loss of registration due to deterioration in time, in many cases reaching half of the service life. • The criteria established by the legislation currently in force for designing service connections and meters given over to domestic use, are suitably adapted to domestic consumption. • There is a correlation between under-registration -in the low flow range- and the age, diameter and consumption. • The fact that there was very little over-registration found in the sample analyzed is worthy of note. • The starting flow rate also increases with the age, diameter, consumption and greater exposure to environmental conditions. • The project shows that there is a potential for regularly taking measurements of the accuracy of the meters installed, using portable field verification equipment and following standard procedures. • The designed portable testing equipment is currently in the process of being patented by Canal de Isabel II.
Research lines open for continuing the work	• Establishing a regulatory framework that governs the procedures for checking water meters in use. • Improving the way the factors that influence a meter's loss of accuracy are measured, when such factors are a consequence of the installation conditions. • Updating the methods used for the maintenance and inspection of meter installation conditions. • Effects on measurement accuracy of the water user consumption patterns. • Assessment of accuracy in non-domestic uses.

Executive Summary

It is in the interests of Canal de Isabel II to ensure that the volumes consumed by its customers coincide with the volumes billed to them, as part of the Company's commitment to providing the citizens of Madrid Region with a high quality of service.

The company is responsible for supplying water and sanitation to more than 6 million people who live in Madrid Region.

Canal de Isabel II has more than 1 million customers, all of whom are provided with a meter to measure their consumption. At present, every customer's consumption is generally measured on a 2-monthly basis. Before 2005, consumption was recorded on a quarterly basis. Since 1994, and in compliance with the regional regulations, every new property has its own individual contract and is equipped with its own meter. Before that date each building had one meter at least. Innovative measurement technologies have gradually been introduced. As a result of this, the installed base of meters in Madrid Region is composed of a wide range of models and categories, whose ages differ greatly.

Some of the main aims of the Company are to establish effective and efficient meter maintenance, renewal and replacement policies, guidelines for designing and improving knowledge about accuracy in the measurement of individual consumptions and uses.

In spite of its importance, evaluating the accuracy with which meters measure throughout their useful service life and under their actual location conditions is a question that water supply companies have not approached in an in-depth and scientific way. There is a lack of regulations concerning the inspection and assessment of meters throughout their service life. Furthermore, the companies in the sector do not rely on standard criteria for their renewal or replacement.

Current Spanish metrological control regulations are aimed exclusively at guaranteeing accuracy in giving approval to models and in checking meters when they are new.

Implementing renewal regulations and policies for meters that have already been installed would provide a valuable efficiency framework, which would be of benefit not only to Canal de Isabel II but also to customers, thereby guaranteeing equity of service to citizens.

In recent years, Canal de Isabel II has launched several campaigns to evaluate the accuracy of domestic meters; this work has been done both under laboratory conditions and at the users' installations. The conclusions reached from those tests make it advisable to carry out a more detailed programme, which will include all the new test procedures that are able to analyse factors that it had not been possible to envisage before.

Along these lines, Canal de Isabel II has jointly embarked upon a research project with the Dirección General de Industria, Energía y Minas of the Comunidad de Madrid. The project involves evaluating the measurement accuracy of the water meters fitted in the region, as well as identifying and quantifying the parameters that affect such accuracy.

Apart from a detailed analysis of the user consumption patterns, obtained throughout ongoing monitoring, the aim of the above-mentioned project is to contribute to obtaining greater knowledge about the actual controlled water consumption in the region, and to review the meter design and replacement policies.

The project has implemented a new policy for testing meters at the consumer' facilities, using innovative portable items of equipment for testing the meters to obtain in situ verification; this portable equipment has been designed and manufactured specifically for that purpose.

Finally, it is aim of the project to improve the assessment of apparent water losses as a result of individual meters under-registration.

Methodological approach

A meter's measurement error is the difference between the volume counted by the meter and what has really been consumed.
As a meter's measurement error varies on the basis of the flow that circulates through it, the difference between the volume counted and what is actually consumed has to be calculated by weighting the error that is made for each consumption discharge value with the percentage of volume that the customer uses in that same value.

Therefore, a meter's weighted error depends not only on its error curve but also on the way in which consumers use the water; the consumption histogram. It is also known as combined error.

A meter's error curve shows a meter's measurement error as a percentage, and it does so for each value of flow that circulates through it. The measurement error is established by conducting a test that compares the volume measured by the meter with the volume registered by a control device (master meter, calibrated tank, etc.).

If the volume that has been built up by the meter is less than the volume actually consumed, the error value is negative, which means under-registration. When the volume registered by the meter is greater than what has really been consumed, the error value is positive, in which case it is referred to as over-registration.

A meter's starting flow-rate can be understood as meaning either the discharge value for which the meter starts to register the flow of water, or the minimum flow-rate that keeps the meter registering. It lies at the far left of the meter's error curve.

Meters generally show greater discrepancies in consumption measurement when the flow-rates are low, than when they are average and high.

Establishing the error curve

The project for establishing the error curve by means of field tests consisted of the following stages, in chronological order:

- Characterizing the meters installed in Madrid Region
- Establishing a representative sample of 2,000 meters
- Designing and manufacturing a series of specific items of equipment referred to as "Portable field verification equipment"
- Developing the software to be installed in the equipment
- Validating the equipment in the laboratory: initial verifications
- Preliminary inspections of the installations
- Field tests and validations
- Data analysis

The project began in May 2006, and the stage involving data collection through field tests ended on 26th March 2008.

Characterizing the base of meters

The meters that are normally used to register domestic consumption have nominal diameters DN13 and DN15.

The majority of the meters in Madrid Region are the ones given over to registering domestic consumption (including meters with a nominal diameter greater than DN40). In 2006, they accounted for 84% of the total number and registered 68% of the consumption.

Of all the installed meters that register domestic-type consumptions, the study sample, comprising meters ranging from 13 to 40 mm, amounted to 99% of the total number of meters and accounted for 87% of the consumption in that sample.

The meter sample

The study covered more than 1 million meters. As it was unfeasible from technical and economic perspectives to analyze all the meters, a decision was taken to take a cross-section sample of 2,000 meters (approximately 0.2% of the total), which would enable those involved to extrapolate and reach conclusions about the metrological characteristics for the entire population of Madrid Region.

The representative sample selection process was laborious, in view of the great variety of brands and models installed in a water supply and management company as complex as Canal de Isabel II.

The threefold aim of using this sample was to obtain an overview that would enable those concerned to find out the following: the measurement errors for as many customers as possible, the metrology of the different meter types and the measurement errors in the volume of water supplied.

The sample was defined into categories, using the following criteria:

- Nominal diameter: ranging from DN13 to DN40
- Brand / technology: 9 different brands
- Age: 4 age-groups were established
- Consumption registered: every group, as defined by the above variables, was subdivided into consumption ranges, 50% of which fell into the "high consumption" meters, the remaining 50% falling into the "low consumption" group (on the basis of a consumption threshold established for each diameter)
- Installation site: 50% indoors; 50% outdoors
- Geographical location: 50% in the City of Madrid and 50% in the other boroughs of the region

Taking into account the fact that, to the greatest extent, the oldest meters are the ones that reveal wear and tear due to age and other factors, it was considered interesting to find out how they performed in greater detailed. Therefore, when it came to obtaining the sample, a weighting coefficient was applied that enabled those involved to increase the proportion of the oldest meters in the sample and reduce the proportion of the newest meters (where no major metrological discrepancies had been observed).

Portable field verification equipment

A series of items of portable field verification equipment were designed and manufactured for conducting the tests at the customers' facilities; these were used as the reference devices with which to compare the measurements registered by the users' meters.

The main equipment requirements were:

- High-precision master meter
- Reliable data-recording system
- Easy-to-handle cut-off and regulating valves
- Small and lightweight
- Suitable range, robustness and portability for field tests

A total of 8 items of portable field verification equipment were manufactured, using two different layouts and sizes, depending on the nominal diameters of the customers' meters to be tested.

In their capacity as master meters, the equipment were provided with one or two metrology Class C rotary piston volumetric meters, with pulse emitter.

The equipment was also provided with:

- Control valves for adjustment during the field tests and accurately establishing the starting flow-rate
- Pressure and temperature gauges
- Rechargeable batteries for providing the equipment with the required self-reliance
- Data recording and storage system
- Laptop computer, containing the database or sample of the meters to be tested in buildings, equipped with the software for collecting, evaluating and processing the data from each test.

Verifying the portable equipment in the laboratory

Once the final design was validated, the manufactured equipment was subjected to repeated cycle verifications at the Canal de Isabel II meter's laboratory; this was done before the field tests commenced. Twenty verification cycles were conducted, on two different test benches, in order to obtain the initial error values for the equipment, as well as the associated measurement uncertainties.

Regular monthly checks continued being carried out on the equipment at the Canal de Isabel II meter's laboratory during the course of the project in order to ensure their acute measurements The acceptance criteria for the equipment rely upon that the laboratory test results for any flow did not diverge by more than 2% from the error values obtained at the initial check, or in the successive check immediately before.

In the successive checks, apart from verifying the state of the meter, the air tightness of the cut-off valves and connections that were subsequently to be used in the field tests was also checked.

A total of 90 successive checks were made throughout the project.

Field tests on the portable equipment

A perfectly defined and structured procedure has to be established for the field tests if they are to be conducted correctly, and this has to be carried out by qualified workers who have attended training courses to that effect.

A field test consists of a series of steps whose order has to be rigorously followed. They include checking for pockets of trapped air or water leaks, the exact adjustment of the test flow-rates, to verify the stable stream flow and the pressure value. The final step involves establishing the meter's starting flow-rate, which is understood as the minimum flow-rate that keeps the meter registering the flow of water, for the purpose of which the stream flow has to be gradually reduced.

The equipment software evaluates the validity of the test so that it can be repeated if necessary.

The measurement error value, for each flow-rate, for the customer's meter in the building, must be corrected with the error value inherent to the verification equipment, at that same flow, established in the Laboratory.

Descriptive analysis of the data obtained in the project for establishing the error curve

Virtually all the categories defined were represented in the final sample, which consisted of 1,936 valid tests.

With respect to the metrological characteristics of the meters in the final sample tested, it must be pointed out that they were all of the velocity type, the highest percentage being of the single jet type, 64%; followed by multiple jet meters which accounted for 30%; finally, came the axial turbine meters, with 7%.

As far as the metrological class was concerned, 7% of the meters in the sample tested fall into metrology class C-H / C-V (Class C, both in horizontal position and in vertical position), required by the standard in force at the time when the sample was selected (Directive 75/33/EEC). The rest of the meters, 93%, are categorised into metrological class B-H / A-V (Class B, in horizontal position and Class A, in vertical position). It must not be forgotten that this classification is consistent with the metrological characteristics of the meters when they leave the manufacturing plant.

All the Class C meters in this sample have the axial turbine layout.

The test results were subjected to a process of outlier detection and removal. The term "outlier" is to be understood as meaning any atypical and/or erroneous observation, whose behaviour or performance is very different from the rest of the data.

Although the number of outliers detected and removed was high, only 1,252 meters being left after the data had been purified, it was possible to tackle a general study for the error curve, which led to the following conclusions:

- The general trend for the meters that are included in the sample is towards a clear under-registration in the range of low flow-rates, there being a correlation with the age, diameter and consumption.
- Under-registration increases in the range of low flow-rates with built-up volume and, so, with the use of the meters.
- The fact that there was very little over-registration found in the sample analyzed is noteworthy.
- No correlations have been detected between the error curve for the meters and such variables as pressure, the water temperature and the normal air temperature near of the meter.
- The meters' starting flow-rates also increases with their age, diameter, the consumption level and greater exposure to meteorological conditions.
- The starting flow-rate of meters in the metrological Class C is lower than the starting flow-rate of the meters in metrological Class B, for the same diameter, so it is considered that the former are generally more suitable for measuring low flow-rates.
- The results obtained can be used to estimate how the starting flow-rate will evolve with age, for each meter size.
- The data obtained will also enable the user to estimate the starting flow-rate from the errors at low flow-rates.

Establishing consumption patterns

The researchers were able to establish the domestic costumers' consumption patterns in the specific area of the research project that involved ongoing monitoring demand. This was achieved over a 6-month period, using high-precision equipment for the ongoing monitoring of a representative sample taken from Madrid Region comprising 226 customers that can register very low flow-rates, from 1 l/h.

The consumption patterns were obtained for users of meters whose nominal diameters range from DN13 to DN40.

Calculating the weighting metering error

As has already been pointed out, the weighting metering error is calculated by combining the consumption patterns at different flow-rates, with the error curve of the meters at those same flow-rates. This weighting can then be used to calculate the total amount of water that goes unregistered because of a measurement error affecting the meters.

The results yielded by the project to find the error curve through conducting field tests, together with the domestic user consumption patterns that were found, were then used to establish the weighted error for the segment of the base of meters managed by the company, made up of meters whose nominal diameters are DN13, DN15, DN20, DN25, DN30 and DN40, used to register domestic-type consumption, which jointly account for 83% of the total number of meters when they are by diameters; and 59% of the total volume billed by the Company (data for 2006).

The following considerations were taken into account when calculating the weighted error:

- The error curves begin with the starting flow-rate, to which a measurement error of -70% has been allocated.
- A linear function has been considered between known errors.
- The consumption is evenly shared out for each flow interval.
- The entire volume consumed, below the starting flow-rate, is not registered (the error for flow-rates lower than the starting flow-rate is -100%).
- The volume consumed in each interval of the consumption pattern is registered with its average discharge error, as obtained from the reconstruction of the error curve.

It was observed in all cases that, owing to the weighted metering error being negative, the volume registered by the meters with these diameters is less than the volume actually consumed.

The greatest error percentage is due to consumption in the low flow-rates range, below the starting flow-rate of the meters, which is an area where the meters are unable to register the volume circulating (under-registration). However, the range lying close to the nominal flow, concentrates most of the consumption, but as the meters are more accurate when measuring these flow-rates, the weighted error is practically insignificant.

When the actual volume circulating through the group of meters given over to registering domestic consumption whose diameters range from 13 to 40 mm is analyzed it can be obtained the volume that is not registered, or under-registered by this segment of meters, this value being **-14.32%.**

When generalizing the evaluation of the unregistered consumption for the total volume consumed and measured by customers of Canal de Isabel II, what is obtained is the value for the unregistered or under-registered volume for the entire base of meters.

The weighted error affecting the base of meters, which expresses the evaluation of the unregistered consumption for the total volume consumed and measured by the customers of Canal de Isabel II in 2006, was estimated of **-10.90%.**

This general weighted metering error value, referring to the total volume of water coming from reservoirs in 2006, came to **-8.42%.**

Considerations concerning meter design

If the meter is oversized, which means that it fails to operate or does so inefficiently at excessively low flow-rates, there will be under-registration errors, and thus economic losses for the company that manages the water supply. If the selected diameter is less than the suitable diameter (undersized meter), the meter will operate at flow-rates that are too high for their capacity, so its error curve will deteriorate prematurely, giving rise to major measurement errors in the service connection not long after it has been fitted, leading to a series of drawbacks and the extra cost involved in replacement.

Canal de Isabel II uses a table in its meter design procedure, which specifies the calibre of the meter to be fitted on the basis of the total design flow-rates to circulate. Although this table is correct from the perspective of selecting the right meter to ensure that it is not oversized, it does not guarantee that all the consumptions are totally counted for each service connection or zone.

The projects developed by Canal de Isabel II for monitoring meter consumption patterns have revealed that there is a proportion of the consumption that takes place at very low flow-rates, which either cannot be registered by the meter, or can be registered but only as a minimum fraction, because within this range of flow-rates the meter error is very high and negative (under-registration).

However, these same consumption patterns show that the highest percentage of consumption is concentrated within the nominal discharge range of the meter that is installed (where the meter error is also at its lowest), from which it can be deduced that the peak flow estimated when selecting the calibre has a value that lies close to the meter's nominal discharge, that selection being correct.

Meter replacement criteria

An analysis of the frequency with which installed meters should be replaced by new ones will depend, amongst other factors, on their cost, the tariff structure, the consumption and the effects of decay on the accuracy of the consumption measurement.

The service life of a meter is to be understood as meaning the life that generates the highest profit, i.e. the highest value of the current net value of the meter replacement chain.

This is calculated on the basis of the decay of the weighted metering error in time.

The following conclusions have been reached:

- The service life of meters increases as their metrological quality improves, this being shown by the comparative study between the Class B and Class C meters analyzed.
- The Class C meters analyzed are of the axial turbine type, so there is no reason why the conclusions obtained should be applied to meters with other construction characteristics.
- Unless signs of deterioration affecting the reading or operating failures affect them earlier, Class B meters ought to be replaced after 12 years up to DN30, and the DN40 meters should be replaced after 7 year. However, Class C meters have a much longer service life. The service life of a battery could be a much more important factor than accuracy loss, in cases where the meters are equipped with this element.
- The effects of a loss of accuracy, as a result of the installation conditions and the consumption patterns for small flow-rates circulation, is greater than the registration losses due to deterioration in time often reaching more than half a meter's service life.
- The difference in cost between Class B and Class C meters is not justified by the improvement in the initial accuracy. However, electronic components, the possibility of remote reading and other features that the Class B meters analyzed do not have, are included in the difference in cost.
- These replacement frequency calculations must be backed up by suitable supervision of the base of meters, so that it is possible to detect as soon as possible, any irregular behaviour or stoppage affecting the meters.
- All the conclusions that are listed here, apart from giving an indication of the characteristics of the installed base of meters in Madrid Region, are also a consequence of the distribution system operating regimes and, above all, a reflection of the very good water quality characteristics in Madrid Region.

http://www.canalgestion.es/galeria_ficheros/compromiso-social/publicaciones/Cuaderno8_I+D+i.pdf

www.cyii.es

Canal de Isabel II

Santa Engracia, 125

28003 Madrid (Spain)