

Flow4Link - The flow in the hand

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Abstract

Due to greater awareness of the rationalization of water resources, Águas do Norte SA has a need to implement new methodologies to control water losses in order to improve the efficiency of their systems.

The Instrumentation&Automation team has developed some procedures, whose objective is to characterize the performance of the various flow meters, trying to reduce one of the components that define the apparent losses in water balance: measurement errors.

The present study has as scope the development of a work tool able to anticipate problems of measurement and equipment operation, in a park of flowmeters that totals about 950 flowmeters, some with about 20 years old and in different installation conditions than the initials. Safeguarding a minimum measurement chain uncertainties, several methods for information acquisition and identification of the flowmeters operating point and associated error were tested. For the calculation of the water balance, the improvement in the flow measurement will allow to quantify and possibly reduce a part of the apparent losses related to the measurement, which can be done in several ways: by replacing flowmeters with other more appropriate ones (reduction of diameter or measurement technology) or the change in operating way of some infrastructures.

The conclusions reached, highlighting the initial stage of the project, suggest that a part of the existing flow meters operate in operating ranges that are not the most adequate, taking into account the metrological characteristics of the meters, causing reading errors that contribute to the increase of apparent losses.

1. Introduction

Founded in 1999, the International Water Association (IWA) aims to monitor the phases of the urban water cycle, serving as a link between the various public and private entities operating in the water sector. Several scientific articles and "best practices" orientations for sustainable water management are published by International Water Association (IWA). In 2003, launched the publication of a series of articles on the results of experiments and guidelines aimed at combating the problem of water losses and, above all, reducing future water demand [1].

In 2018, in Águas do Norte SA, the losses reached an aggregate volume of 2,700,000 cubic meters of unbilled water, corresponding to 3.67% of the water value entered into the system.

To achieve these values, Águas do Norte SA has implemented several practices in the field, namely:

- Effective strategies to control and reduce water losses;
- Promotion of improvement of the quality of the cadastre;
- Definition of performance indicators of the supply systems;
- Replacement of sections of pipes with an abnormal history of breaks.

2. Definition and Quantification of Water Losses

The IWA, faced with the need to assess the volume of water losses and its components and thus allow an international comparison between the performance of different management entities, has developed a tool that has become the basis of all the analysis that is carried out around this theme - the water balance.

Added to the water balance concept is a set of definitions of the components related to water consumption and losses in the supply systems, which are articulated and outlined in Table 1.

Table 1: IWA Water Balance Table

System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
	Unbilled Authorized Consumption	Unbilled Metered Consumption	Non- Revenue Water	
		Unbilled Unmetered Consumption		
	Water Losses	Apparent Losses		Unauthorized Consumption
		Real Losses		Metering inaccuracies and Data Handling Errors
Leakage on Transmission and/or Distribution Mains				
Leakage and Overflows at Utility's Storage Tanks				
	Leakage on Service Connections up to Point of Customer Metering			

The meaning of each component of the water balance is as follows:

- System input volume - annual volume of water entering the supply system;
- Authorized consumption - annual volume of water measured or not measured but actually consumed by customers, by the supplier or by those who are implicitly or explicitly authorized to consume.
- Water losses - the difference between the volume of water introduced into the system and the authorized consumption, representing the total of actual and apparent losses;
- Unbilled water - is the difference between the volume of water introduced into the system and the authorized consumption that is actually billed.
- Apparent losses - corresponds to illicit consumption, theft or measurement failure.
- Real losses - annual volume that is lost through all types of leaks, ruptures, and extravasation of pipes, reservoirs and branches, up to the point of measurement of the customer.

The work reported here will focus on the component of "Metering inaccuracies and Data Handling Errors" in the water balance, with the attempt to define the error of measurement of a flow meter and, after this, obtaining the expanded error of a FLOMEKO 2019, Lisbon, Portugal

subsystem of water supply and, subsequently, the value of apparent losses.

3. Scope and phases of project implementation

Formed in 2017, the Instrumentation & Automation team has been working on the methodologies for the development of a tool, called "Flow4Link", which will allow the operation and maintenance technicians to obtain data on the efficiency of a subsystem of water supply in real time. However, the other aspect of the project is also the creation of functionalities that allow the online and predictive monitoring of the state of the measuring equipment of Águas do Norte SA.

Aims of the Flow4Link project:

- Collection of billing equipment;
- Obtaining the operating point of the flow meter;
- Calculation of global measurement error of a water supply subsystem;
- Instantaneous water balance;
- Operational management, configuration and remote diagnosis of instrumentation equipment;
- Proactive management of flowmeter problems;
- Reduction of costs in the travel of technical staff (municipal counts combined) and maintenance technicians.

To achieve these goals, there were defined the following phases for its implementation:

1. Installation of communications interface between flowmeters and Control Center;
2. Development of functionalities intended for telemetry and water balance, setting the current operating point and estimated error of each flow meter and calculation of the overall error per subsystem;
3. Development of functionalities intended for predictive maintenance and remote diagnostics of a flowmeter;
4. Link to the manufacturer's cloud for equipment park management, spares and documentation.

4. Implementation of the method of data communication

In order to obtain data from the meters, a register of the Águas do Norte SA flowmeter park was carried out. Some 950 flowmeters were identified and the ages can reach 20 years of operation.

Analyzing the characteristics of the various existing protocols and the limitations that each had, it was understood that the most comprehensive protocols available in most flowmeters regardless of age would be three:

- HART- Highway Addressable Remote Transducer;
- Profibus DP;
- Modbus RTU;

The more comprehensive and lower cost option fell on the HART protocol, as it would be the most functional and more information to obtain from the flow meter. In addition, it is the universal and widely expanded protocol able to reconcile communication between new and old flowmeters (Figure 1).

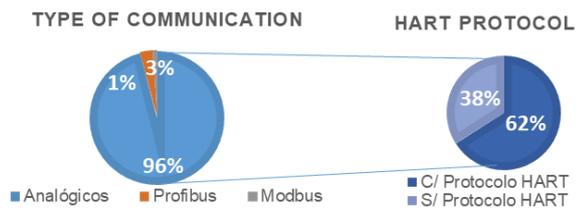


Figure 1: Communications protocols available in Águas do Norte flowmeters

Once the protocol to be used has been defined, several tests were carried out with flowmeters from different manufacturers for a common platform for the management of instrumentation equipment, using communication equipment between flowmeters and the Control Center, according to the Figure 2.

After this first phase, the exact digital data taken from the flowmeter will allow for greater accuracy in the information since this method does not add uncertainty or external disturbances in the transmission/measurement chain.

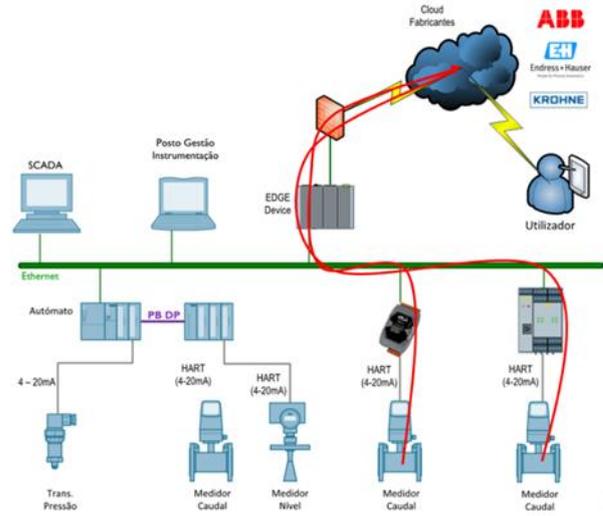


Figure 2: Diagram of data connection between flow and platform meters

To illustrate the advantage of data transmission in digital form, the example of Figure 3 illustrates a meter which is counting water volume and transmitting the information in two ways: electrical to the PLC and by digital communication.

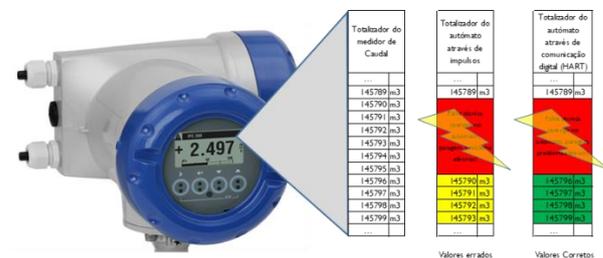


Figure 3: Example of data failure due to power failure

In a hypothetical power failure or failure of some electrical component, in the impulse data transmission chain, there was a failure of counting values in the supervision systems (SCADA). In turn, using a digital communication protocol, the count values will be the same as on the meter display.

This functionality will immediately allow some improvements in the efficiency of operations:

- Decreased travel of technicians to gauge monthly readings;
- Distance billing of a "click";
- Increased customer confidence.

5. Development of functionalities intended for telemetry and water balance

Establishing the communication of telemetry data between flowmeters and supervisory software, the

development of equipment productivity and analysis tools began.

5.1 Definition of the current operating point and estimated error of each flow meter

Considering as an example a flowmeter from a reservoir, instantaneous flow, and volume data were obtained over a period of 30 days, with minute-to-minute sampling, which resulted in about 43 000 flow measurements for the year in question. With this data, the statistical indicators presented in Table 2 were worked out.

Table 2: Statistical indicators of flow measurements (about 43000)

	Cavado.RME_FT001
Minimum flow (m3/h)	0,034
Mean flow (m3/h)	3,352
Maximum flow (m3/h)	28,306
Num. samples	42938
Calculation. Classes	16
Standard deviation (SD)	2,243
Increment	1,767
Mean + 2xSD	7,837
Corrected Average -2xSD	0,034
Mean - 2xDP	-1,134
Mode	0,955
Median	2,879

About the meter concerned, the calibration tests at the manufacturer indicated the deviations presented in Table 3 at the two reference flow points. Although not considered in the statistical treatment.

Table 3: Deviation values on the calibration test

Flow (m ³ /h)	Deviation
20,952	-0,09%
4,623	0,14%

Figure 4 shows the histogram of the sampling distribution of flow measurements. Around 80.61% of flow measurements are between 0 and 5 m3/h.

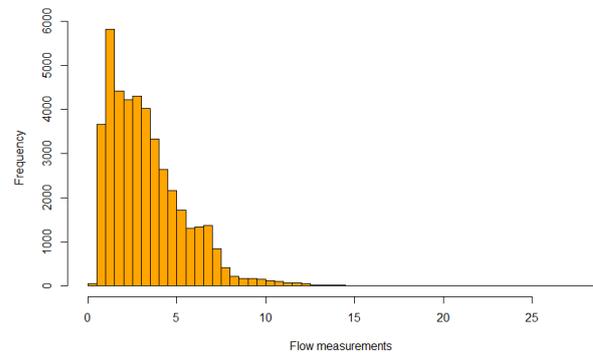


Figure 4: Histogram of flow measurements

Considering 20 000 random samples of size 50, by the central limit theorem, we can infer that 95% of sample means will lie within 2.735 m3/h to 3.967 m3/h and that the flow measurement means value converges to 3.352. The histogram of sample means is shown in Figure 5.

$$\mu = 3,352 \text{ m}^3/\text{h} \pm 0,615$$

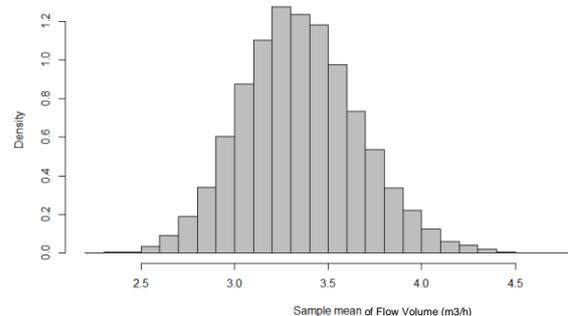


Figure 5: Histogram of sample means from 20 000 random samples of size 50

Taking into account the flow values for a given pipe diameter, it is possible to extract the flow velocity:

$$Q = 3600\pi \cdot v \left(\frac{d}{2}\right)^2$$

Where Q: flow (m³ / h)
v: flow velocity (m / s)
d: pipe diameter (mm)

In the practical case, corresponding to a flowmeter of diameter 90mm, used for billing, the values of minimum, average and maximum velocity of the flows observed are shown in Table 4.

Table 4: Calculated flow speed

Flowmeter Nominal Diameter = 90mm

Minimum Flow Speed (m/s)	0,002
Average Flow Speed (m/s)	0,146
Maximum Flow Speed (m/s)	0,342

For the calculation of the estimated maximum error, for the manufacturer's reference conditions, it is given by the following equation:

$$Er (\%) = \frac{1}{v * 1000} \times 100 + T_{Er}$$

Where Er: Maximum error (%),
V: flow velocity in (m / s)
Ter: Transmitter error (%)

One of the components of the error that is fixed is the transmitter, which many manufacturers commercialize with different precision, but in this example was considered of 0.2% taking into account the existing measurement.

In graphical terms, the error equation translates into the curve represented in Figure 6.

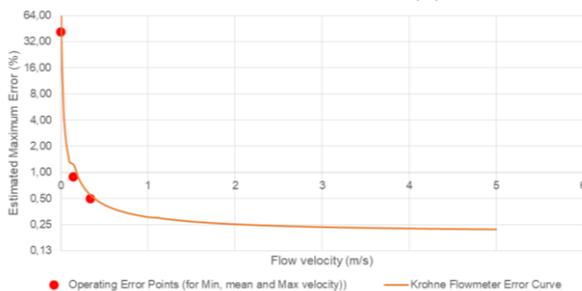


Figure 6: Operating Error Points for the Min, Mean and Max flow velocity

The maximum errors estimated for the above-mentioned flow values are presented in Table 5.

Table 5: Estimated errors for different flow speed

Flowmeter Nominal Diameter = 90mm	
Estimated Maximum Error (%)	±40,862
Estimated Average Error (%)	±0,883
Minimum Estimated Error (%)	±0,492

To calculate the expected maximum error of the flowmeter of this example, a resolution increase of the flow classes was made and the application of a weighted average. In this scenario, the result is:

Estimated maximum operating error (%)	±1,404
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It is important to state that although the error equations were defined for the manufacturer's reference conditions, other installation criteria were verified, such as upstream and downstream diameters, water conductivity, etc, to ensure minimum interference.

5.2 Measures to be implemented in cases of errors above 1%

With the goal of 1% tolerance error in the equipment, some of the measures to be implemented can be:

- Resizing the meter;
- Changing the mode of operation of infrastructure.

For the first case, considering that it is a billing meter, replacing and resizing the new equipment would improve accuracy. For example, for a diameter of 50mm, the estimated error values are given in Table 6.

Table 6: Estimated error for new flowmeter

Flowmeter Nominal Diameter = 50mm	
Estimated Maximum Error (%)	±20,772
Estimated Average Error (%)	±0,411
Minimum Estimated Error (%)	±0,290

In this case, the result for the example in question is about 50% below the previous value:

Estimated maximum operating error (%)	±0,571
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5.3 Calculation of the apparent losses of each subsystem

The second component to be developed in this project is the calculation of the global error resulting from the conjugation of several flow meters, in series or in parallel.

Normally, in the calculation of the water balance, in certain water subsystems, it happens that the sum of the partial volumes of the billing flowmeters does not coincide with the system input values, subtracting the actual losses.

After an analysis of a calibration data set of several flow gauges of the same diameter, it is possible to verify that, for smaller flow velocities, the reading

deviation tends to be positive and greater than in higher velocities, whose error tends to be lower and negative. An example is shown in Figure 7.

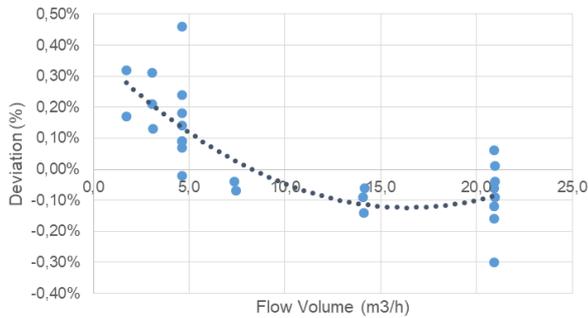


Figure 7: Deviation measurements for flowmeters with DN = 50mm

In this sense, due to the work developed, we can minimize the errors of the meter in lower flow operating regimes, avoiding the exposure to readings with greater measurement error. Considering the S. Jorge subsystem, which has a very extensive pipeline, it has a set of meters (Figure 8).

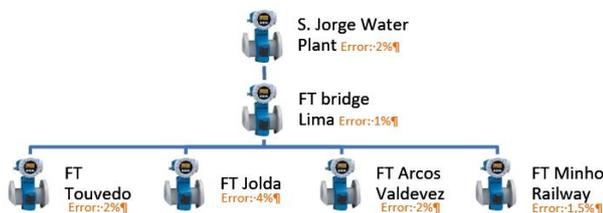


Figure 8: Illustration of a part of the flow measurement of the pipeline of the subsystem of S. Jorge - Minho

The work will go through the individual analysis of the behavior of each flowmeter, so as to ensure that all have an estimated error value less than or equal to 1%.

7. Development of functionalities intended for predictive maintenance and remote diagnostics of a flowmeter

Through the HART communication, it is possible to diagnose the state of the equipment and the reading of the variables of the same.

Up to now, functions have been developed to interconnect the PLC with the flowmeters so that the SCADA systems have the same field values and information on the state of the equipment.

In most meters it is possible to remove about 10 measurement variables using open software, like Pactware in Figure 9:

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- Flow Speed
- Volume Flow
- Conductivity
- Coil Temperature
- Counter 1
- Counter 2
- Counter 3
- Counter 4
- Diagnosis Value

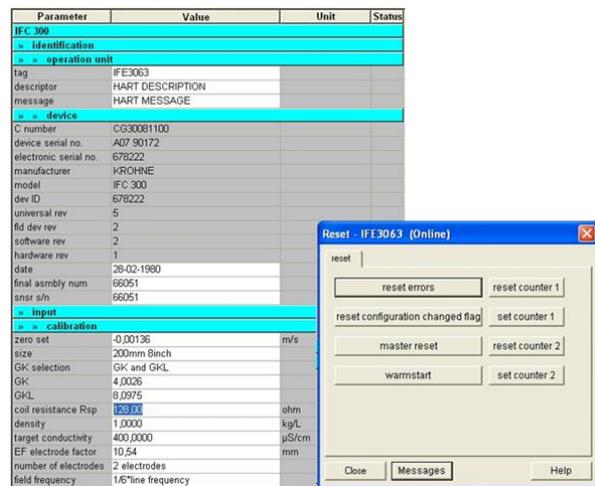


Figure 9: Example of meter configuration performed through HART protocol (Pactware)

7. Conclusion

The initial phase of the project has demonstrated practical and valuable results in obtaining data through digital communication, resulting in a very reliable level of data and the reduction of some of the tasks of field teams (e.g. monthly readings). Flowmeter status diagnostics, although using third-party tools, allow us to obtain important information that anticipates some actions on the ground, but to obtain them, manual verification routines are necessary.

The development of the functionalities related to the determination of the operating point of a flow meter allowed to identify some cases of meters that do not operate in the best operating zone and to estimate the average operating error, which in some specific situations results in an abnormal reading error for certain flow ranges. However, the statistical methods that support this component need to be further checked to see which are the most appropriate. Finally, the calculation of the global error of a water supply system has been more complex with the combination of the various uncertainties, lacking other tests to get a mathematical model.

References

- [1] Farley, Malcolm, and Stuart Trow. *Losses in water distribution networks*. IWA publishing, 2003.
- [2] Pedrosa, António Carvalho; Gama, Sílvio Marques, *Introdução computacional à probabilidade e estatística* (Porto, Porto Editora), 2004.
- [3] Henriques, José Duarte; Palma, João Carlos Pires; Ribeiro, Álvaro Silva; *Medição de caudal em sistemas de abastecimento de água e de saneamento de águas residuais urbanas* (Lisboa, Instituto Regulador de Águas e resíduos / Laboratório Nacional de Engenharia Civil), 2007
- [4] Sardinha, José; Serranito, Francisco; Donnelly, Andrew; Marmelo, Vera; Saraiva, Dias, Pedro; Guimarães, Nuno Ricardo; Morais, Daniel; Rocha, Vitor; *Active Water Loss Control* (Lisboa, EPAL Technical Editions), 2007.