National Physical Laboratory

Instituto Português da Qualidade

LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

# UNCERTAINTY EVALUATION OF TOTALIZATION OF FLOW AND VOLUME MEASUREMENTS IN DRINKING WATER SUPPLY NETWORKS

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18th International Flow Measurement Conference

Portugal | Lisbon | LNEC | 26-28 june 2019

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# Motivation

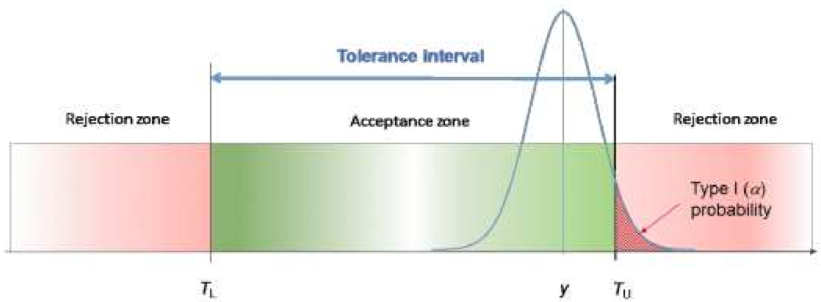
Clean water and sanitation are one of the 17 sustainable development goals (SDG) of the United Nations' 2030 agenda for action, being directly related to the objectives of economic growth, sustainable cities' communities, responsible consumption and production, and climate action.

# Motivation

ISO/IEC 17025: 2017 - General requirements for the competence of testing and calibration laboratories.

Scheme adopted for the accreditation of laboratories and mutual recognition at international level

New requirements, e.g., related with conformity assessment and the definition of decision rules, including uncertainty as a parameter of the criteria.



# Motivation

BIPM

**JCGM 100:2008**

GUM 1995 with minor corrections

**Evaluation of measurement data — Guide to the expression of uncertainty in measurement**

*Évaluation des données de mesure — Guide pour l'expression de l'incertitude de mesure*

First edition September 2008

© JCGM 2008

Development of GUM Uncertainty Framework by BIPM, JCGM Working Group 1

| | |
|---|---|
| *Evaluation of measurement data – An introduction to the "Guide to the expression of uncertainty in measurement" and related documents* | JCGM 104:2009 |
| *Evaluation of measurement data – Supplement 1 to the "Guide to the expression of uncertainty in measurement" – Propagation of distributions using a Monte Carlo method* | JCGM 101:2008 |
| *Evaluation of measurement data – Supplement 2 to the "Guide to the expression of uncertainty in measurement" – Extension to any number of output quantities* | JCGM 102:2011 |
| *Evaluation of measurement data – The role of measurement uncertainty in conformity assessment* | JCGM 106:2012 |
| *Evaluation of measurement data – Concepts and basic principles* | |

The following documents are at an early stage of preparation:

- *Evaluation of measurement data – Supplement 3 to the "Guide to the expression of uncertainty in measurement" – Modelling*
- *Evaluation of measurement data – Applications of the least-squares method*

EMUE Examples of Measurement Uncertainty Evaluation

EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

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# JRP-n02 EMUE - Examples of Measurement Uncertainty Evaluation

Advancing measurement uncertainty – comprehensive examples for key international standards

## Advancing the state-of-the-art

Transforming metrological knowledge quantifying correlation, assisting users in making the best choice of method, supporting the GUM "new perspective" actively pursue by the JCGM


**Impact**

Calibration, testing and comparison, and for conformity to regulation or specification

Enviroment, energy, quality of life, and industry and society

Wider appreciation of the application of uncertainty principles

NPL National Physical Laboratory · PTB · VSL · Rolls-Royce · nel technology for life · World Anti-Doping Agency · UKAS United Kingdom Accreditation Service · LGC · ACCREDIA L'Ente Italiano di Accreditamento · TÜV SÜD · BAM Bundesanstalt für Materialforschung und -prüfung · Institut za mjeriteljstvo Bosne i Hercegovine · INRiM Istituto Nazionale di Ricerca Metrologica · LNEC Laboratório Nacional de Engenharia Civil · Instituto Português da Qualidade · National Institute of Advanced Industrial Science and Technology AIST · economie · LNE Laboratoire National de Métrologie et d'Essais

# Water utilities & measurement

Water utilities make use of extensive infrastructures – water supply networks – engineering systems based on hydrological and hydraulic elements allowing the supply of water to households, industries, facilities and services.

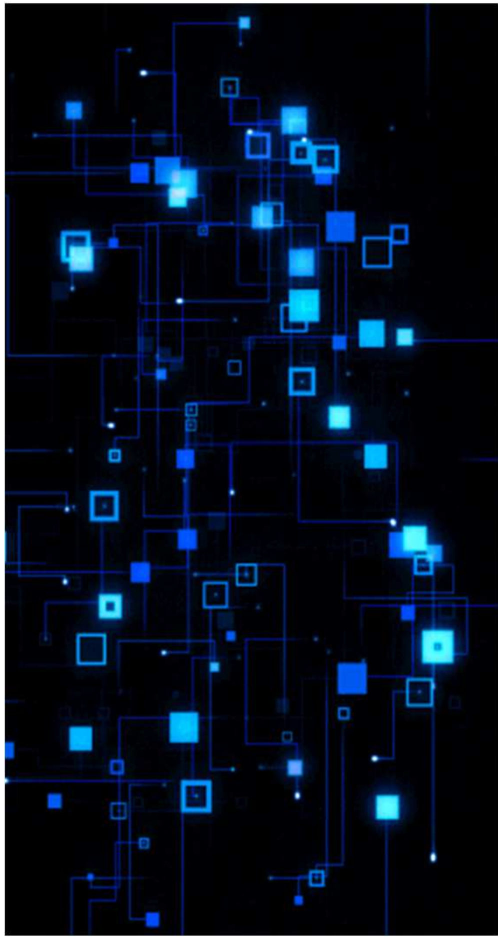
Management of these infrastructures depends on the use of equipment able to measure many quantities (flow, volume, level, velocity, pressure, temperature, water quality parameters, among others).

Measurements are also required to evaluate compliance with conditions established by regulations, technical specifications as well as management requirements of service and trade, becoming a relevant part of governance and of the global economy.

# Water utilities & measurement

The measurement process includes three stages:

- Data acquisition of measurements with a certain frequency, generating a time series;
- Data processing, to obtain the totalized volume for the time interval considered;
- The combination of totalized volumes for the several locations to evaluate the net balance (sums and differences)



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For many water utilities, the evaluation of uncertainty is considered important but still a difficult task, requiring support to apply the provisions of the guide to the expression of uncertainty in measurement (GUM).

Other situations adding complexity include missing data and dealing with large amounts of raw and processed data.

# Single point measurement of flow rate

The nature of the measuring approach is often related to the water supply process. For the purpose of this study, two types of systems were considered:

- flow with random behaviour (related to users' demands); Fig. 1 typifies the consumption of water measured during a time interval, sometimes allowing to model (predictive) the system demands; and

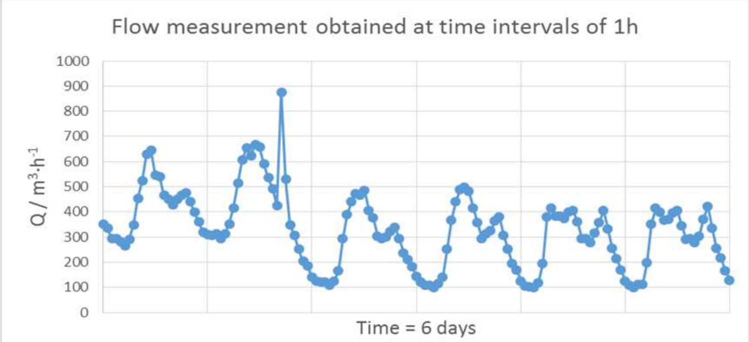


Figure 1: Input flow measurement experimental data obtained in a water distribution network with n users and water losses' during 6 days with time interval of sampling of 1 hour.

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- constant flow (controlled by the provider or by the user), as illustrated in Fig. 2, during a time interval (e.g. filling a storage tank).

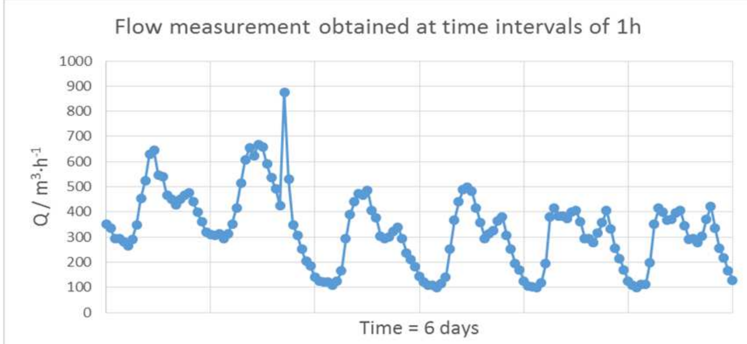


Figure 1: Input flow measurement experimental data obtained in a water distribution network with n users and water losses' during 6 days with time interval of sampling of 1 hour.

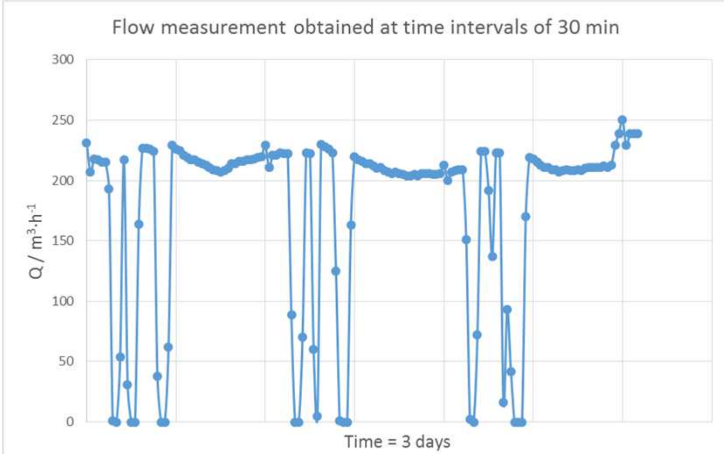


Figure 2: Flow measurement experimental data obtained at the entrance of a storage tank during 3 days with time interval of sampling of 30 minutes.

# Total volume uncertainty at a single measurement section of a network

To obtain the standard measurement uncertainty of the totalized volume, the law of propagation of uncertainty (LPU) of the GUM

$$u^2(V) = \left(\frac{\partial V}{\partial V_1}\right)^2 \cdot u^2(V_1) + \left(\frac{\partial V}{\partial V_2}\right)^2 \cdot u^2(V_2) + \cdots + \left(\frac{\partial V}{\partial V_n}\right)^2 \cdot u^2(V_n)$$

Considering that the partial derivatives of $V$ with respect to the $V_i$ are, in this case, all equal to unity,

$$u^2(V) = u^2(V_1) + u^2(V_2) + \cdots + u^2(V_n).$$

Flow measurement uncertainty is often known and expressed in relative form $w(V_i) = \frac{u(V_i)}{V_i}$.

$$u^2(V) = w^2(V_1) \cdot V_1^2 + w^2(V_2) \cdot V_2^2 + \cdots + w^2(V_n) \cdot V_n^2$$

# Total volume uncertainty at a single measurement section of a network

## *Case study of constant relative uncertainty*

Assume that the relative uncertainty is approximately constant for the measurement interval:

$$w(V_1) = w(V_2) = \cdots = w(V_n) = w(V_i),$$

applied in, $u^2(V) = w^2(V_1) \cdot V_1^2 + w^2(V_2) \cdot V_2^2 + \cdots + w^2(V_n) \cdot V_n^2$

gives $u^2(V) = w^2(V_i) \cdot [V_1^2 + V_2^2 + \cdots + V_n^2].$

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Table 1: Example of 10 measurements of volume obtained using a volumetric counter

| | | | |
|---|---|---|---|
| V1 | 58 m$^3$ | V6 | 61 m$^3$ |
| V2 | 63 m$^3$ | V7 | 52 m$^3$ |
| V3 | 62 m$^3$ | V8 | 57 m$^3$ |
| V4 | 57 m$^3$ | V9 | 69 m$^3$ |
| V5 | 79 m$^3$ | V10 | 76 m$^3$ |

total volume amount of 634 m$^3$

$$u(V) = \sqrt{(0{,}02^2) \cdot (40\,878)}\ \mathrm{m}^3 \approx 4{,}0\ \mathrm{m}^3$$

$$w(V) = \frac{u(V)}{V}. \qquad w(V) \approx 0{,}64\ \%.$$

# Total volume uncertainty at a single measurement section of a network

## *Case study of constant relative uncertainty and constant flow*

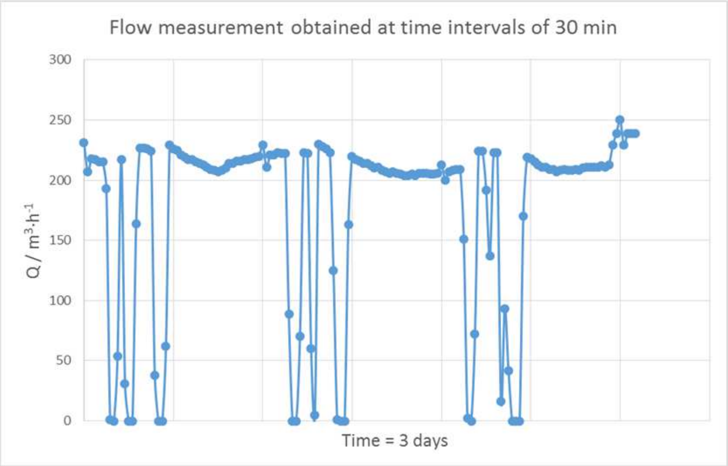
In this case, still considering that a constant relative uncertainty is also a condition of the system, we can assume that the relation between measurements obtained at the same interval of acquisition is

$$V_1 = V_2 = \cdots = V_n = V_i.$$

apllied to, $u^2(V) = w^2(V_i) \cdot [V_1^2 + V_2^2 + \cdots + V_n^2].$

gives, $u^2(V) = w^2(V_i) \cdot \left[n \cdot V_i^2\right]$

simplifying the calculus to $u(V) = \sqrt{n} \cdot w(V_i) \cdot V_i,$ and $w(V) = \dfrac{\sqrt{n} \cdot w(V_i) \cdot V_i}{V}.$



# Total volume uncertainty at a single measurement section of a network

## *Analysis of the effect of sampling in the constant flow case study*

Considering the previous example (constant flow case study), it becomes clear that results depend on the number of samples, $n$, and on the value obtained of each observation of the volume, $V_i$. For a certain total volume amount fixed, when $n$ grows, the single observation of volume decreases proportionally.

$$\widehat{V_i} = \frac{V}{n}$$

Thus, the equation $w(V) = \frac{\sqrt{n} \cdot w(V_i) \cdot V_i}{V}$. becomes $w(V) = \frac{w(V_i)}{\sqrt{n}}$.

Consider a simple example, having a relative standard uncertainty of 2 %, and 10 observations each of 100 m$^3$, or 5 observations of 200 m$^3$, with total volume in both cases of 1 000 m$^3$. Applying the previous Equation, the results are, for the data series of 10 values and of 5 values:

Set of 10 values:

$$w(V) = \frac{w(V_i)}{\sqrt{n}} = 0{,}63\ \%$$

Set of 5 values:

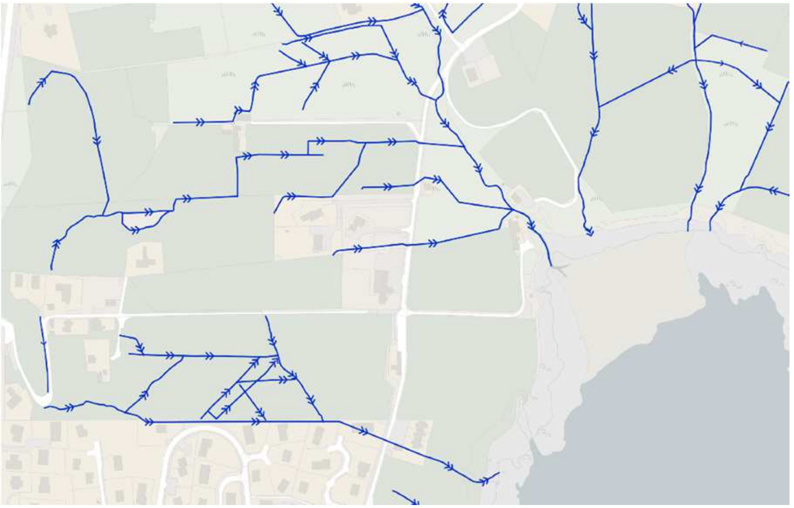
$$w(V) = \frac{w(V_i)}{\sqrt{n}} = 0{,}89\ \%.$$

# Total volume uncertainty related to net balance at a water supply system network

A functional relation to characterise the net balance is given by

$$V_{\mathrm{net}} = \sum_{i=1}^{n} V_i - \sum_{j=1}^{m} \tilde{V}_j + \delta V_{\mathrm{loss}}$$

where $V_i$ represents the $n$ measuring locations of inflow of water into the system, $\tilde{V}_j$ represents the $m$ measuring locations of water outflow in the system, and $\delta V_{\mathrm{loss}}$ the water losses during the process.



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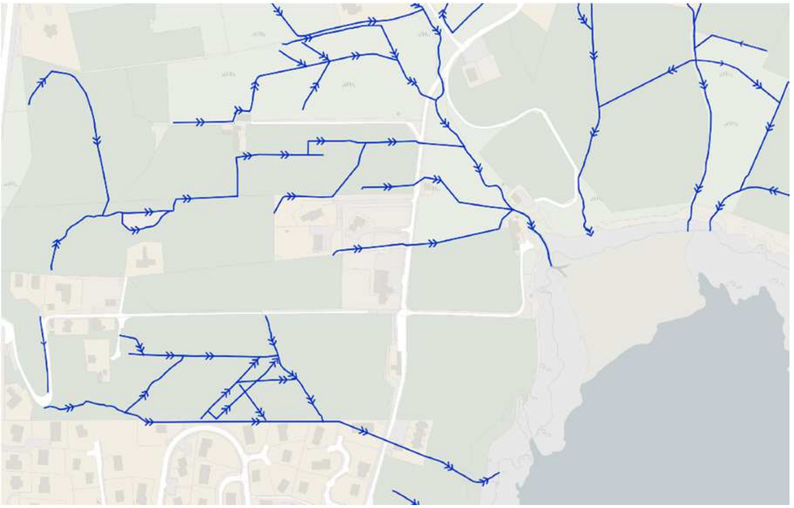
Applying the LPU

$$u^2(V_{\mathrm{net}}) = \sum_{i=1}^{n} u^2(V_i) + \sum_{j=1}^{m} u^2(\tilde{V}_j) + u^2(\delta V_{\mathrm{loss}}).$$

Considering the existence of a similar uncertainty magnitude, $u(V)$, for the inflow and outflow measurement locations, and neglecting the contribution related to the quantity lost,

$$u(V_{\mathrm{net}}) \approx \sqrt{(n+m)} \cdot u(V),$$



# Conclusions

Encouraging the sustainable management of water resources is a societal imperative considering the limited resources.

Adoption of the adequate strategies to increase robustness of the decision-making process supported by measurements requires measurements increasingly accurate and reliable, traceability and understanding the information given by uncertainty.

The focus of this paper is on the evaluation and use of uncertainty for two typical processes observed in water management: measurement of water consumption and filling of storage tanks. In both cases, simple equations were obtained in order to evaluate the output measurement uncertainty associated with totalized volume.

This paper also points out the relevance of an appropriate decision regarding the sampling time interval, an issue often disregarded in practice.

Finally, as expected, the number of locations used in the net balance has impact on the net measurement uncertainty, which can become relevant for large systems having multiple inflows and intermediate connections.

KEEP
CALM
AND
ACT LIKE A
METROLOGIST

# Thank you for your kind attention!

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