TOTALIZATION OF VOLUME MEASUREMENTS IN DRINKING WATER SUPPLY NETWORKS

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Overview

- Motivation
- Measurement role in water utilities
- Measurement process
- Two operationnal systems studied
  - Variable flow (constant time interval)
  - Constant flow (variable time interval)
- Net balance of water utilities
- Next steps – creating impact

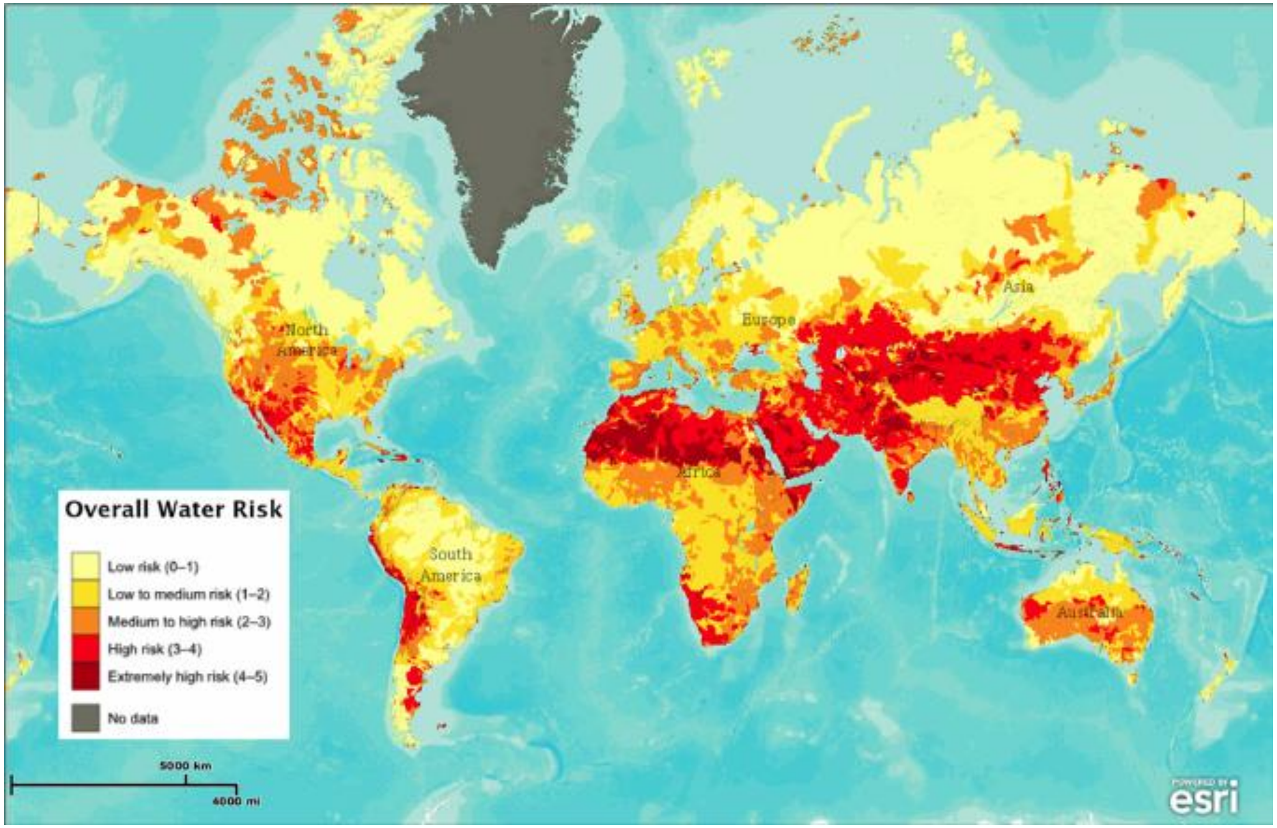
Motivation

United Nations SDG

TRANSFORMING OUR WORLD: THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT sustainabledevelopment.un.org A/RES/70/1

Motivation

The International map for scarcity of water



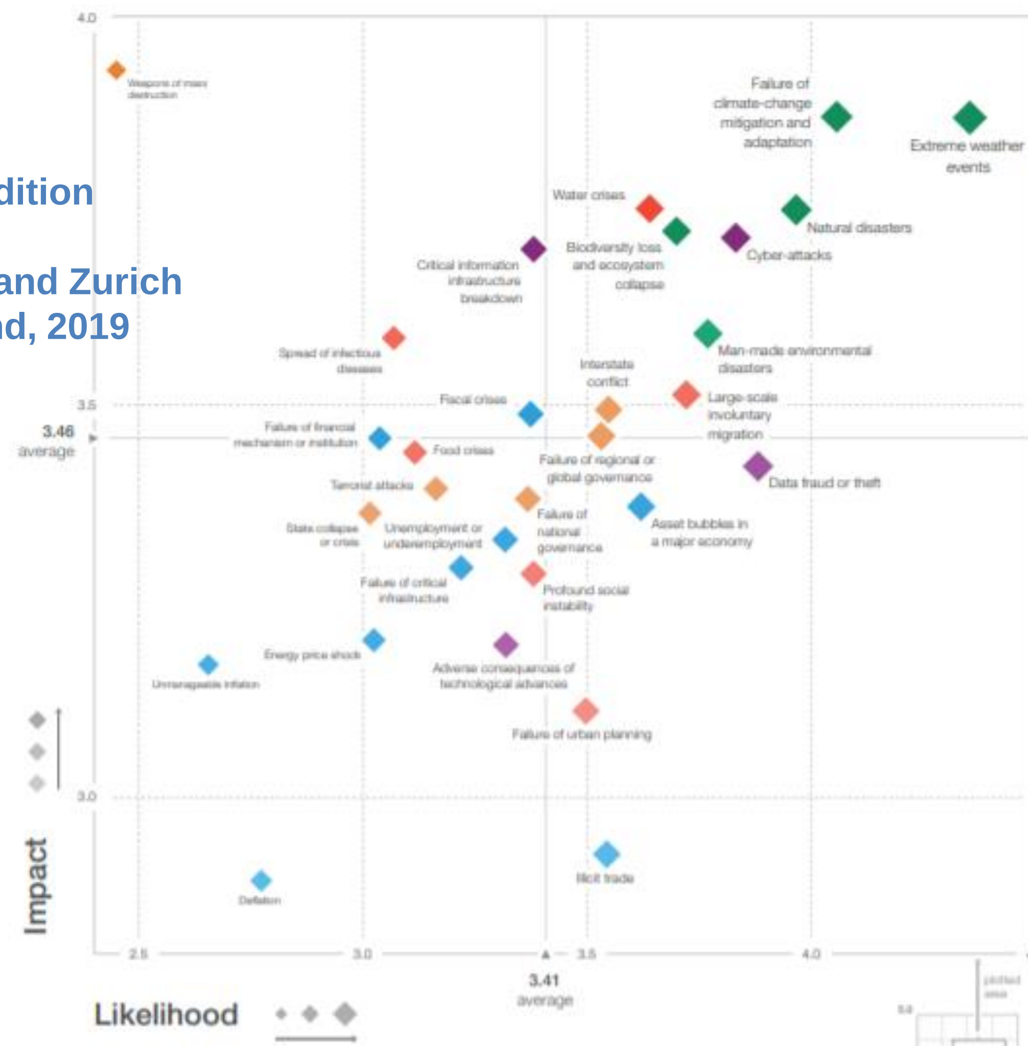
Data from World Resources Institute; Mapping: Gassert et al. (2013).

Motivation

Global risk

The Global Risks Report 2019 14th Edition
World Economic Forum.
with Marsh & McLennan Companies and Zurich Insurance Group, Geneva, Switzerland, 2019

Figure I: The Global Risks Landscape 2019



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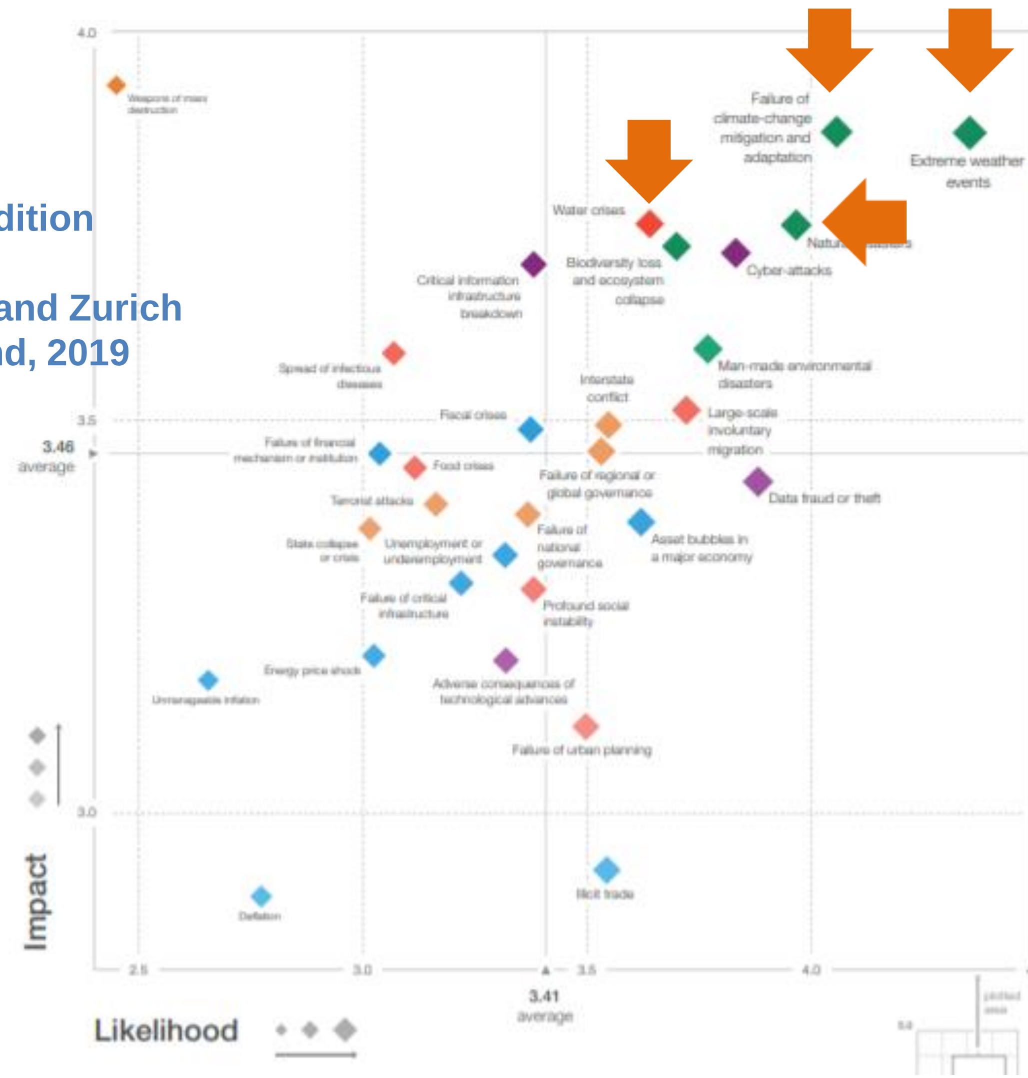
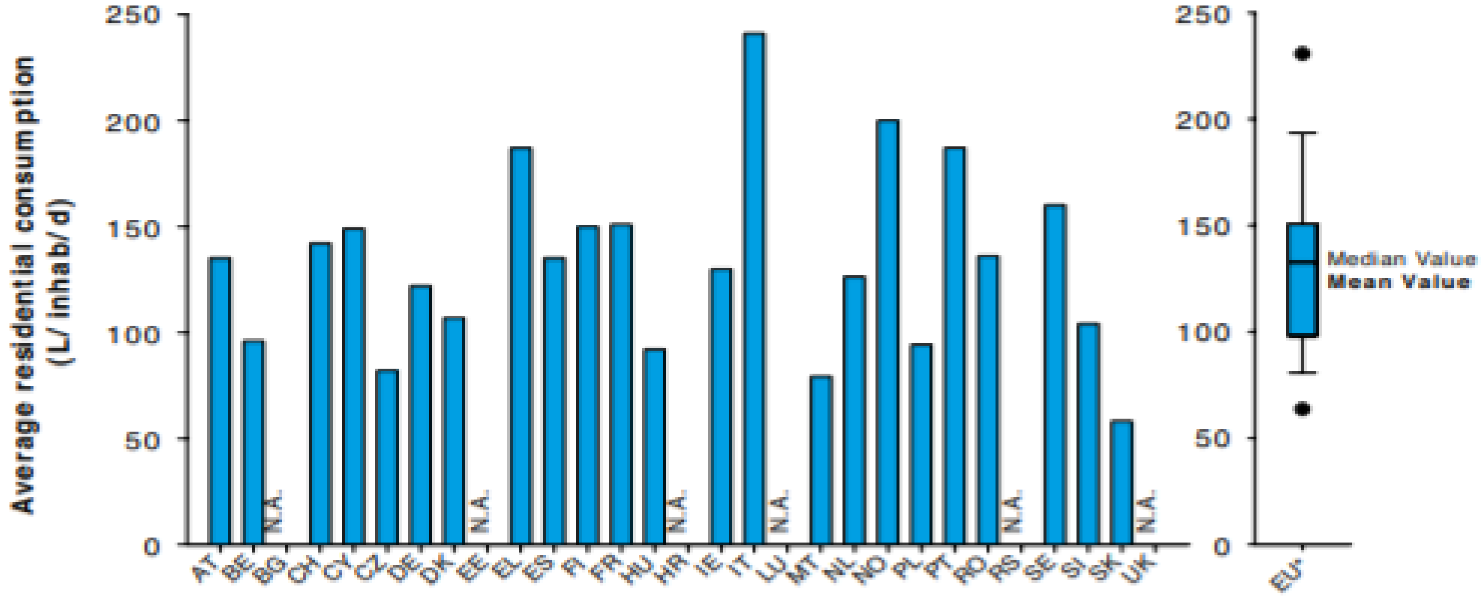


Motivation

Economic costs and management

Average daily water consumption per capita (Portugal) – 180 l (France: 150 l, UK: NA)



Europe's water in figures, 2017
EurEau The European Federation of National Associations of Water Services

Motivation

Economic costs and management

Average daily water consumption per capita (Portugal) – 180 l (France: 150 l, UK: NA)

Average annual water consumption (PT)

11 000 000 x 180 l x 365 = **727 700 000 000 l**

Price of liter of water: 0,002 €/l (PT) [0,003 €/l (FR), 0,004 €/l (UK)]

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Price of liter of water: 0,002 €/l (PT) [0,003 €/l (FR), 0,004 €/l (UK)]

Average annual cost (consumer´s price): 1,4 b€ (1 445 400 000 €)

Direct cost of 1% error: 14 M€ (14 454 000 €)

Direct cost of 5% error: 72 M€ (72 270 000 €)

Measurement role in water utilities

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

Management decisions are increasingly supported by information provided by measurement. The lack of knowledge regarding measurement data reliability and associated uncertainty is a key issue for the management of water supply networks.

Measurement process

The measurement process includes three stages:

1. **Data acquisition** of measurements with a certain frequency, generating a time series;

2. **Data processing**, to obtain the totalized volume for the time interval considered;

3. **The combination of totalized volumes** for the several locations to evaluate the net balance (sums and differences) of the system.

Measurement process

Frequently, the goal of the process is to have a **net balance between water inflow and outflow** of a system or subsystem, in some cases subsequently used in trade relations.

These **totalized results of flow or volume** should be conveyed with their associated uncertainties (usually expressed as relative uncertainties), to promote informed **decision-making** as well as increasing the confidence between the involved agents.

Measurement process

The definition of volumetric flow rate, Q, is the volume of fluid that passes per unit time (sometimes referred as volume velocity using the symbol $\dot{V}$) and having as SI unit m^3/s.

$$Q = \boldsymbol{v} \cdot \boldsymbol{A}.$$

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Considering a closed conduit with circular geometry having an internal diameter, D, and a cross section orthogonal to the velocity vector ($\theta = 0°$), the previous Equation becomes

$$Q = vA\cos\theta = v\frac{\pi D^2}{4}$$

Measurement process

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$$V = \int_{\Delta t} Q \, \mathrm{d}t$$

Measurement process

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$$V = \int_{\Delta t} Q \, \mathrm{d}t$$

At the experimental level, flow rate measurement is usually obtained at constant time intervals, Δt, creating a discrete set of n values in a time series

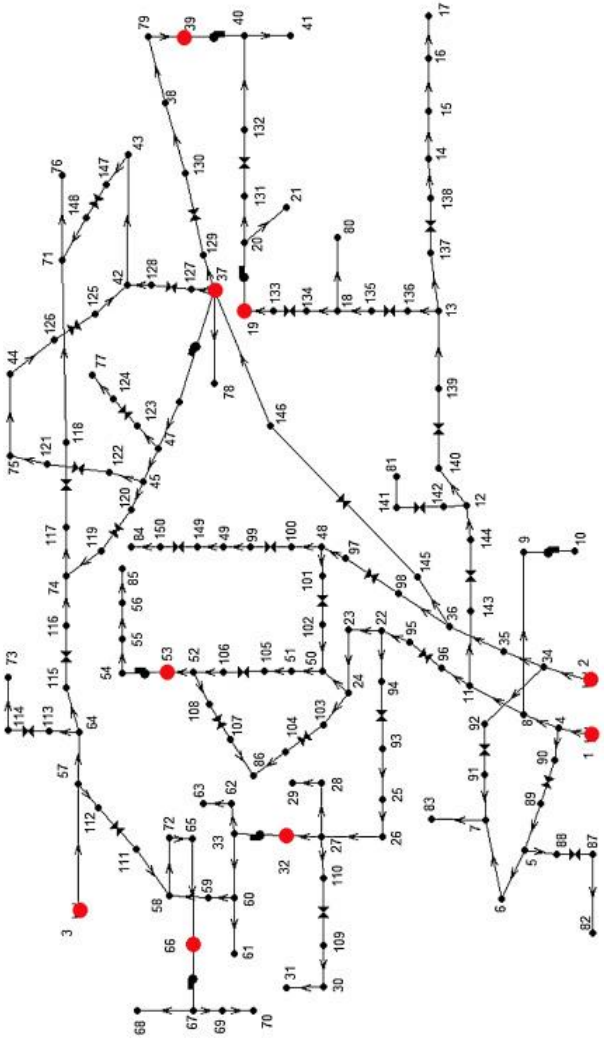
$$V = \sum_{i=1}^{n} (Q_i \Delta t)$$

Measurement process

If a direct approach is used, n values of volume of fluid, V_i, are obtained using sampling based on a constant time interval (Δt), the estimate of total volume being given by:

$$V = \sum_{i=1}^{n} V_i$$

Two operational systems studied



- flow with stochastic behaviour (users' demands).

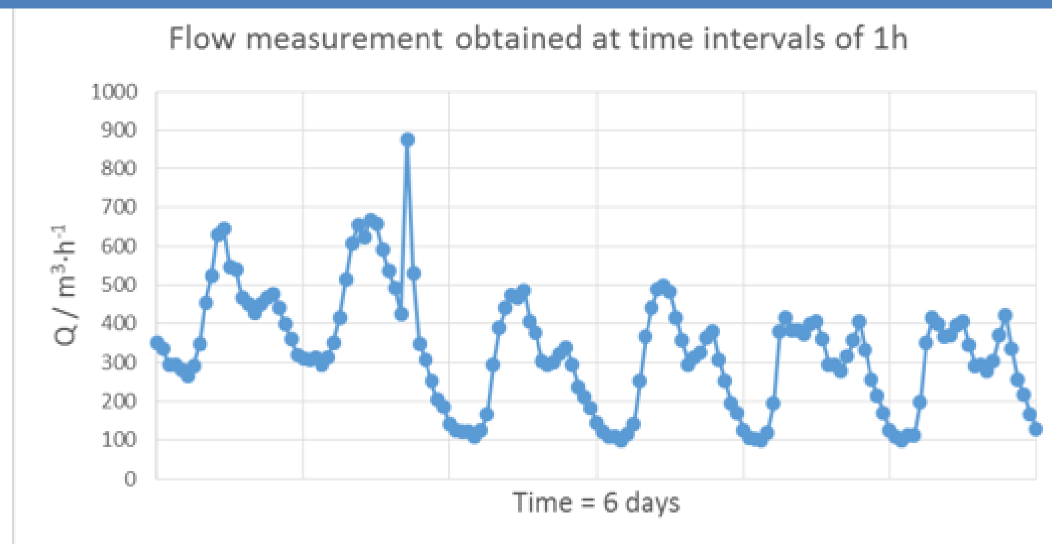
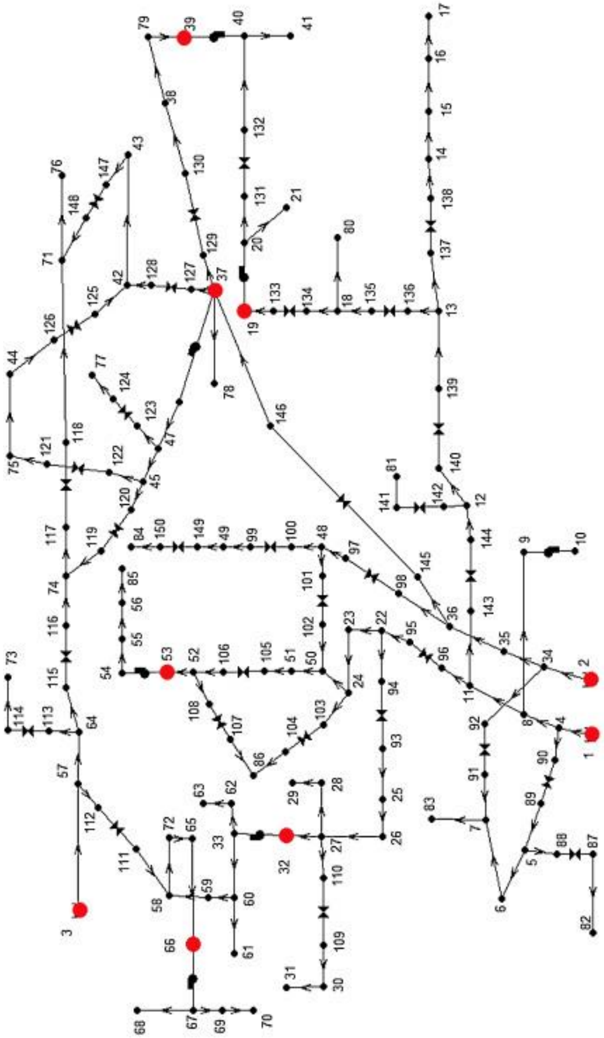


Figure 1: Input flow measurement experimental data obtained in a water distribution network with n users and water losses' during 6 days with time interval of sampling of 1 hour.

Two operational systems studied



- constant flow (controlled by the provider or by the user, e.g., filling of storage tank).

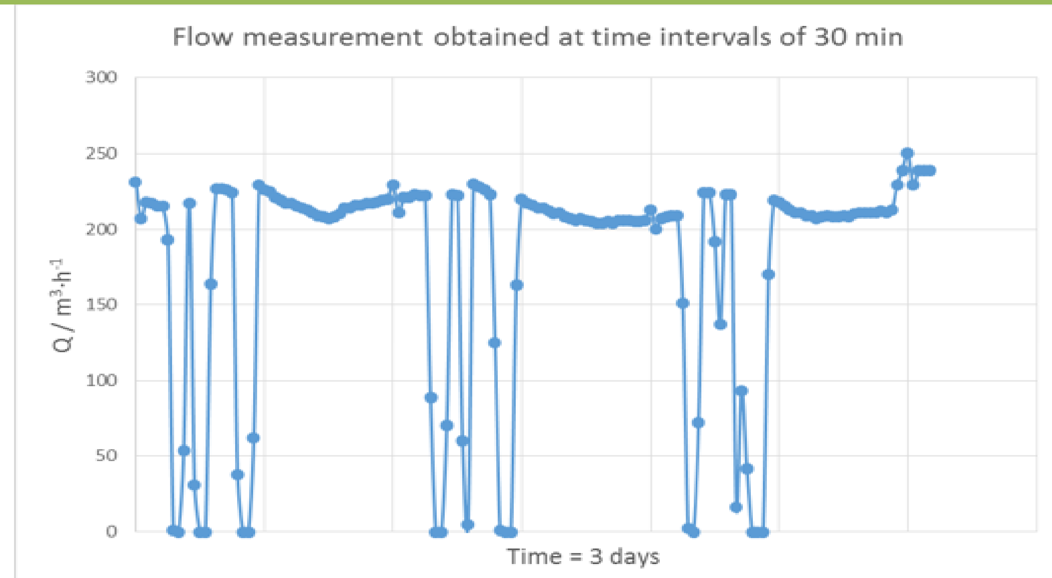


Figure 2: Flow measurement experimental data obtained at the entrance of a storage tank during 3 days with time interval of sampling of 30 minutes.

Variable flow

$$V = \sum_{i=1}^{n} V_i \quad \Rightarrow \quad u^2(V) = \left(\frac{\partial V}{\partial V_1}\right)^2 \cdot u^2(V_1) + \left(\frac{\partial V}{\partial V_2}\right)^2 \cdot u^2(V_2) + \cdots + \left(\frac{\partial V}{\partial V_n}\right)^2 \cdot u^2(V_n)$$

Variable flow

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

Variable flow

$$u^2(V) = u^2(V_1) + u^2(V_2) + \cdots + u^2(V_n) \quad \text{using} \quad w(V_i) = \frac{u(V_i)}{V_i}$$

Variable flow

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

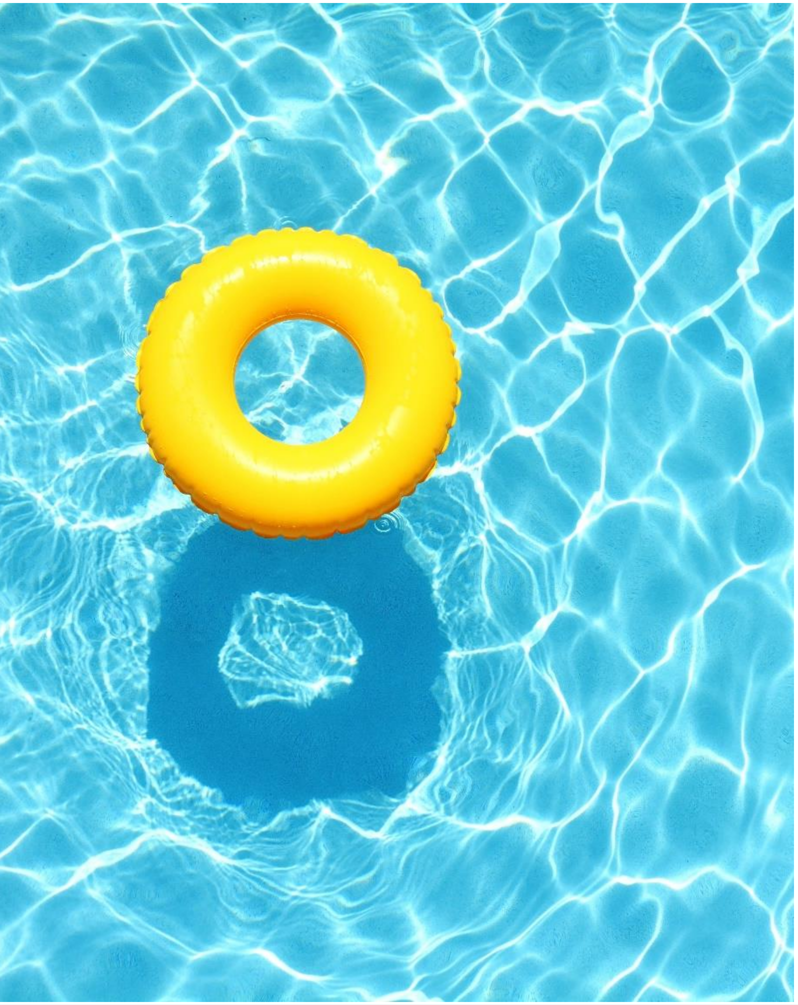
Variable flow

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

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

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

Variable flow – example of MU evaluation



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

Consider an example with 10 measurements of volume (experimental data given in Table 1), with relative uncertainty of 2,0 %.

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

V_1	58 m^3	V_6	61 m^3
V_2	63 m^3	V_7	52 m^3
V_3	62 m^3	V_8	57 m^3
V_4	57 m^3	V_9	69 m^3
V_5	79 m^3	V_{10}	76 m^3

With this information, using equations (11) and (12), the total volume standard uncertainty and relative uncertainty, respectively, would be evaluated for the total volume amount of 634 m^3.

$$u(V) = \sqrt{(0{,}02^2) \cdot (40\,878)}\ \mathrm{m}^3 \approx 4{,}0\ \mathrm{m}^3, \quad (13)$$

$$w(V) \approx 0{,}64\ \%. \quad (14)$$

Constant flow

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

Condition: $V_1 = V_2 = \cdots = V_n = V_i$

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

Constant flow

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

Condition: $V_1 = V_2 = \cdots = V_n = V_i$

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

$$u(V) = \sqrt{n} \cdot w(V_i) \cdot V_i$$

Constant flow

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

Condition: $V_1 = V_2 = \cdots = V_n = V_i$

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

$$u(V) = \sqrt{n} \cdot w(V_i) \cdot V_i$$

$$w(V) = \frac{\sqrt{n} \cdot w(V_i) \cdot V_i}{V}.$$

Constant flow

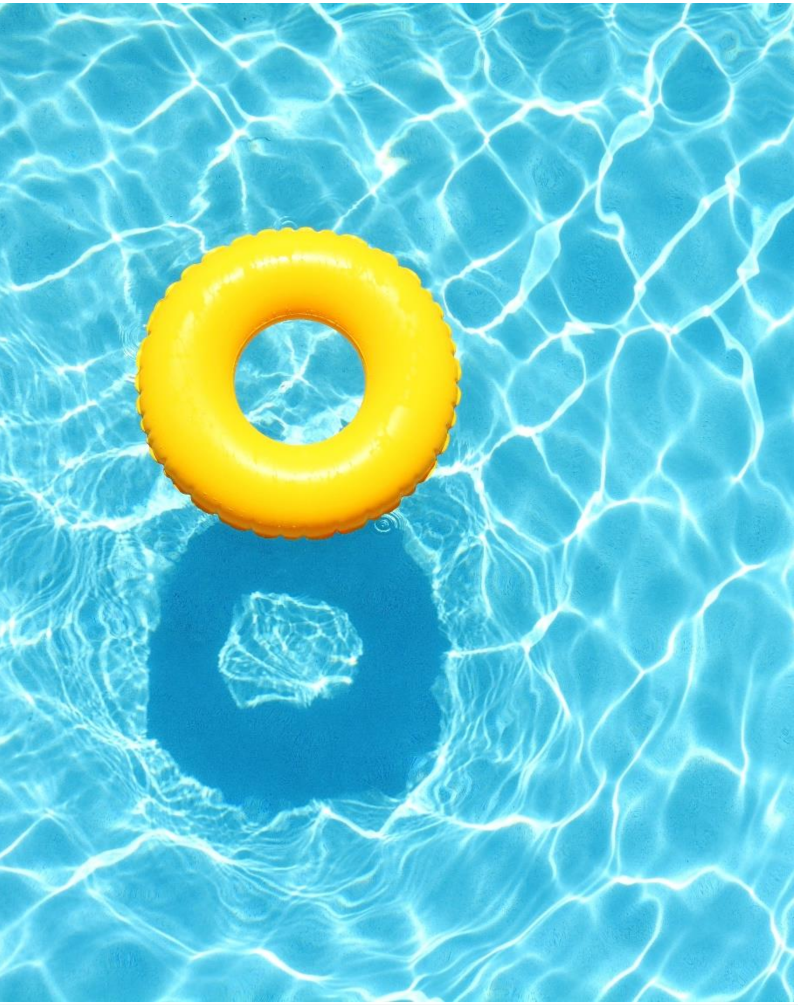
$$w(V) = \frac{\sqrt{n} \cdot w(V_i) \cdot V_i}{V}.$$

This Equation provides a relation between the relative standard uncertainty of the total volume and the number of samples, *n*:

$$w(V) = \frac{\sqrt{n} \cdot w(V_i) \cdot V_i}{V}.$$

If, $\widehat{V}_i = \frac{V}{n}$ $\Rightarrow$ $$w(V) = \frac{w(V_i)}{\sqrt{n}}.$$

Constant flow



$$w(V) = \frac{w(V_i)}{\sqrt{n}}.$$

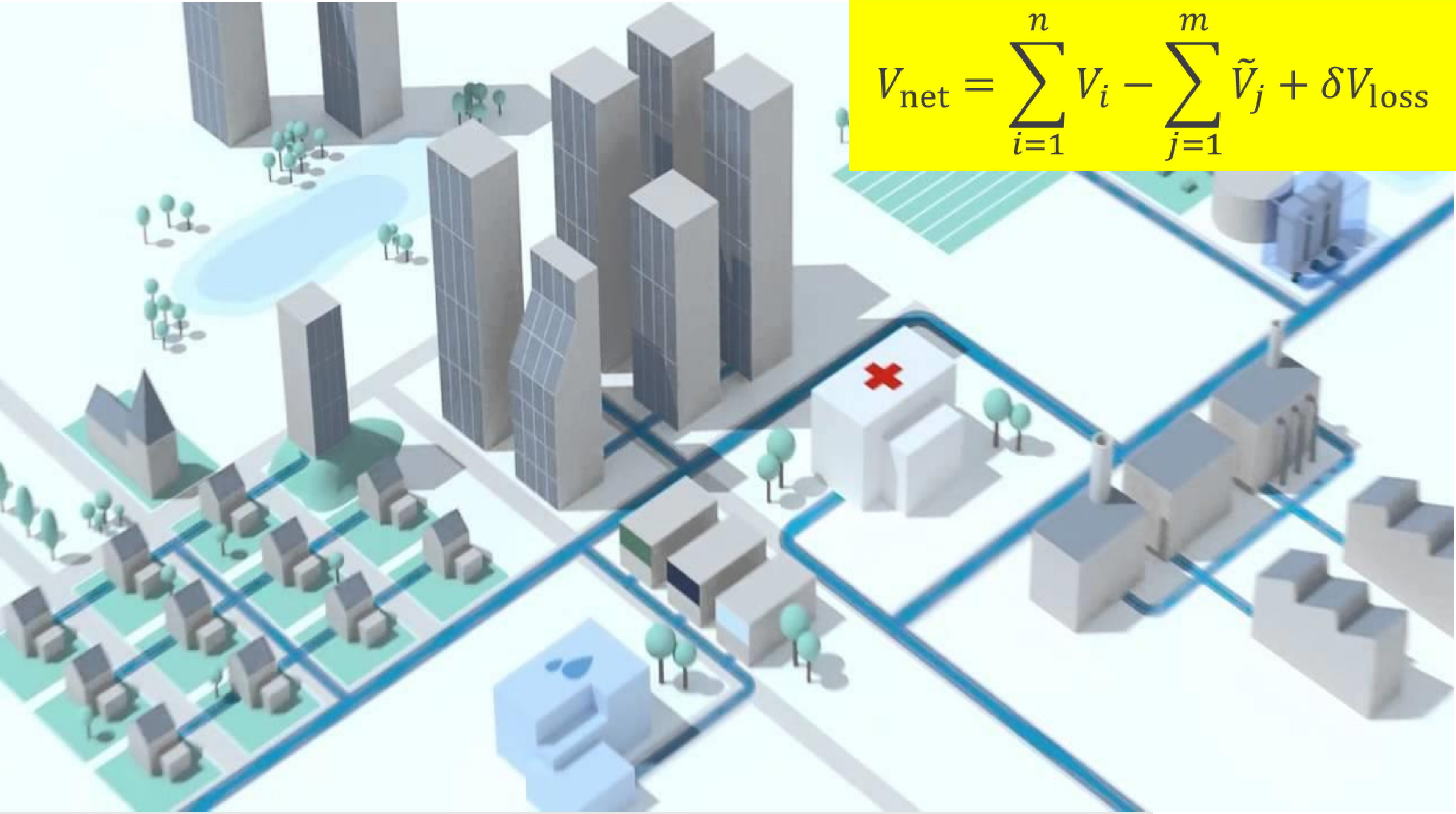
Consider a simple example, having a relative standard uncertainty of 2 %, and 10 observations each of 100 m^3, or 5 observations of 200 m^3, with total volume in both cases of 1 000 m^3. Applying Equation (20) the results are, for the data series of 10 values,

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

and, for the data series of 5 values,

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

Net balance of water utilities



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

Net balance of water utilities

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

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 of water in the system, and δV_{loss} the water losses during the transfer process.

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

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, a simplified equation is obtained:

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

Next steps – creating impact

EurEau is the European Federation of National Associations of Water Services, representing national drinking and waste water service providers from 29 countries, from both the private and the public sectors.

H2020 Centre of Excellence (DoE)

LIS-Water is an initiative of LNEC to create in Portugal an international CoE for frontier R&I on water services and related water resources with a high impact on public policies, management and regulation in Europe and worldwide.

European Federation of National Associations of Measurement, Testing and Analytical Laboratories

Other stakeholders being considered:

EMUE
Examples of Measurement Uncertainty Evaluation

Thank You for the kind attention!

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