Estimation of costs for monitoring urban water and wastewater networks

Marta Cabral, Dália Loureiro, Maria do Céu Almeida and Dídia Covas

ABSTRACT

In many water distribution systems, water losses are a major problem and an integrated management strategy is required for both the efficient use of water resources and the minimisation of non-revenue water. For foul sewer systems, the inflow of stormwater and infiltration of groundwater affects the management of both sewer systems and wastewater treatment plants. Monitoring of flows represents a critical task within approaches for control of either water losses in distribution systems and infiltration and rain-induced inflows in foul systems. Implementation of monitoring typically involves the following steps: (i) system information updating and digital mapping; (ii) system zoning; and (iii) system flow monitoring. Costs for monitoring are essential for utilities to estimate more accurately the costs of control of water losses, infiltration and inflow and to support more robust decision-making. Costs and infrastructure data were collected from 20 Portuguese water and wastewater utilities. Multiple linear regression analysis is used to obtain cost functions for meter chambers as a function of the volume and for purchase and installation of flow meters as a function of nominal diameter in water supply systems. For the steps of system information updating, digital mapping and system zoning single unit costs are estimated.

Key words | costs functions, flow monitoring, foul sewer systems, inflow and infiltration, water distribution systems, water losses

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INTRODUCTION

Globally, requirements for increasing the efficiency of urban water systems are more demanding, as are the challenges for water utilities managing these systems. Responsible use of water resources is imperative, avoiding wasting water and polluting good quality natural waters as a result of human activities. Water-stressed regions are even more in need of adequate systems to deal with water demands and scarce resources.

Monitoring of flows is essential to adequately manage urban water systems. Two examples of the application of monitoring are losses control in drinking water distribution networks and infiltration and inflows control in foul sewer systems.

For water supply services, flow monitoring is vital to ensure the financial return; in distribution systems, water losses are a major problem, requiring integrated and rational management that encompasses real and apparent losses and the water–energy nexus (Farley & Trow 2003; Loureiro *et al.* 2016). Non-revenue water (NRW) results from the difference between the volumes of system input and billed authorised consumption. NRW includes not only the real losses and apparent losses but also the unbilled authorised consumption (Lambert & Hirner 2000; Alegre *et al.* 2006). NRW is a measure of the operational efficiency of a water distribution system (Wallace 1987): high levels of NRW may indicate poor management (McIntosh 2003) as well as the poor physical condition of the infrastructure as a whole (Male *et al.* 1985). Leakage often leads to service interruption and represents a significant operational cost associated with

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water production (Cabrera *et al.* 2010; Mutikanga *et al.* 2013). Monitoring is essential for water losses control.

According to the Annual Report on Water and Waste Services in Portugal (ERSAR 2016), real losses represent 170 million m^3 per year, estimated as 12% of the water entering these systems. The report points to significant potential for improvement with the implementation of methodologies to reduce water losses in public urban water systems. In water supply systems, the performance associated with a real losses indicator is reasonable with a value equal to 6.3 m^3/(km.day) and, in distribution systems, with a value of 126 L/(service connection.day), both for the year of 2015.

For the wastewater systems, a common problem identified throughout the world is the undue inputs to these systems, which deteriorate their performance significantly. Despite the major purpose of separate foul sewer systems being to collect domestic, industrial and commercial sewage and to transport it to pumping systems or to wastewater treatment plants, often these systems receive excessive water from infiltration and rain-induced inflows, which frequently overload sewers, pumping stations and treatment plants (Kaczor 2011; Taheriyoun & Moradinejad 2015). The gradual reduction of infiltration and inflow is of the utmost importance to increase the economic, environmental and operational efficiency and effectiveness of the systems (Almeida & Cardoso 2010).

Infiltration consists mainly of groundwater flowing into the sewer system through joints, fissures and defective connections. Inflow consists mainly of rain-induced water entering the sewer systems through sewer manhole covers and incorrect house drains, among others (Almeida & Cardoso 2010; Ellis & Bertrand-Krajewski 2010).

Problems derived from excessive inflows and infiltration include: (i) reduction of the sewer system hydraulic capacity, eventually leading to overcharging, overflows and flooding; (ii) hydraulic surcharge, overflow and efficiency reduction of pumping installations and treatment facilities; (iii) increased pollution of receiving waters; and (iv) operational costs and structural deterioration (Machado *et al.* 2007).

Monitoring is also necessary to approach the control of infiltration and inflow in foul sewer systems, even if it is more demanding given the added difficulties of measuring free surface flows transporting relevant quantities of solids, both suspended and near the bottom (Machado *et al.* 2007). Typical accuracy ranges are significantly lower than with pressure flow measurements in water pipe systems.

Despite the differences in water and wastewater flow characteristics, the approaches and methods for the monitoring and control of water losses and of infiltration and inflow, in general, include the following steps (Mutikanga *et al.* 2013; Almeida *et al.* 2017):

(i) **system information updating and digital mapping**;
(ii) **system zoning**, including definition and setting of areas of analysis;
(iii) **monitoring**, through setting up flow measurement installations including, as applicable, construction of meter chambers and purchase, installation and maintenance of measurement equipment.

These steps are time- and resource-consuming, and information on associated costs is scarce. The **system information updating and digital mapping** is essential to utilities to support efficient asset management and part of the normal operational activities of the utilities. It consists of collecting detailed information about the different assets of the system including identification, type, location, dimensions, shape, material, depths, service connections, and other relevant information. This information may exist in different formats and media, including paper or digital support. Map updating usually requires surveys or field inspections (Alegre & Covas 2010; Almeida & Cardoso 2010).

System zoning requires the use of mapping information complete enough to have included the main components regarding the system's functioning. In methods for losses control in water distribution systems, zoning is typically associated with district metered areas (DMA) (Farley & Trow 2003). To implement DMA, as a delimited area of a distribution system, it is necessary to carry out physical actions (e.g., the closure of valves) to ensure the continuous metering of water volumes entering and exiting the area (Morrison 2004). Other benefits of zoning include an easing of the systems' operation, allowing a better understanding of water consumption, as well as a more accurate estimate of water losses and methods to be adopted for its control (Farley & Trow 2003). Each water distribution system might have a significant number of DMA. Recommended size for DMA is around 2,000 service connections or even lower (e.g., 300–600 service connections), although it should be adapted according to water demand characteristics and existing practices for real loss control (e.g., active leakage control) (Alegre *et al.* 2005).

In general, for sewer systems, the concept of zoning is inherent to system functioning and design since most networks are branched, and flows are free surface and by gravity. In a recent study, a newer integrated methodology to address undue inflows to urban water systems was proposed (Almeida *et al.* 2017), and zoning with associated metering is one of the primary methods to support a system's performance assessment and the establishment of intervention priorities. Herein the serviced areas to support this work are referred to as foul sewer serviced areas (FSA).

Monitoring, with the aims of controlling water losses and undue inflows, requires adequate levels of accuracy in measurements. Relevant factors include a selection of adequate measurement sites, proper selection of equipment for specific site conditions with appropriate metrological characteristics, equipment installation according to manufacturer indications, appropriate inspection and maintenance programmes. Continuous data acquisition systems, either permanently or in shorter-term measurement periods, allow for obtaining data to fully implement the approaches for control of losses and undue inflows. Proper monitoring enables reliable results to be obtained, as outcomes are based on better information, as well as a better return on the investment on monitoring systems. Additionally, these measurements are often valuable to other sectors of the water utility.

Implementation of the methodologies mentioned above involves defining the amount of work and programming the tasks of system information updating and digital mapping, system zoning and monitoring. Cost functions represent essential information for determining the costs of construction, operation, maintenance, and disposal of capital assets over their life cycle. Furthermore, the cost functions are of use to calculate the fair value and the current replacement cost for water supply and wastewater assets and for estimating the capital cost of future infrastructure (Alegre *et al.* 2012; NSW 2014).

The current paper aims to present a methodology to estimate costs for the steps involved in monitoring and control of water losses, infiltration and inflow. The proposed methodology is based on two existing methodologies for estimating construction cost assets of the urban water cycle (Marchionni *et al.* 2016; Cabral *et al.* 2017). These costs include the cost of update and digital mapping water and wastewater infrastructures, the cost of zoning (including the cost of definition and maintenance of areas of analysis) and the cost of flow monitoring (including the cost of construction of meter chambers and purchase and installation of flow meters). Costs can help utilities to improve cost estimates for different intervention options, thus improving their assessment and selection, and to develop sound plans for tactical and operational levels.

METHODOLOGY

The methodology presented herein to estimate costs for monitoring and control of water losses, infiltration and inflow follows those proposed by Marchionni *et al.* (2016) and Cabral *et al.* (2017).

The methodology includes the following five steps: (1) data collection, processing and analysis; (2) present cost value calculation; (3) infrastructure characterisation and identification of key parameters; (4) cost functions' and prediction bands' estimation; and (5) cost functions' testing.

In Step 1, *data collection, processing and analysis*, relevant infrastructure and equipment data are identified as key parameters of costs, namely, assets' physical characteristics (e.g., material and dimensions of the meter chambers, type and nominal diameter of the flow meters).

In Step 2, the *present cost value calculation* is carried out as costs collected in the database refer to different dates. The respective present values, *PC*, (for the year 2016) are calculated using Equation (1):

$$PC = IC\prod_{i=0}^{n}(1+t_i) = IC \times IF_{0-n} \qquad (1)$$

where *IC* is initial cost in the construction year; t_i is the inflation rate in the year $_i$; $_n$ is number of years between construction and the reference year (2016); IF_{0-n} is cumulated inflation factor. The present cost value is calculated based on the harmonised index of consumer prices, published by Banco de Portugal.

In Step 3, *infrastructure characterisation and identification of key parameters*, infrastructures are described, and their unit costs presented. Also, the main key parameters for the different infrastructures are identified (e.g., the nominal diameter of flow meters as explaining the variable for purchase and installation costs). Table 1 presents the infrastructure components involved in obtaining the cost of system information updating and digital mapping, the cost of the system's zoning and the cost of flow monitoring.

In Step 4, *cost functions' and prediction bands' estimation*, construction of cost functions is assumed linear, following a linear regression model, whose general form is in Equation (2):

$$Y = b_0 + b_1 X_1 \quad (2)$$

where Y is the dependent variable (the estimated cost);, X_1, is the independent variable; and b_0 and b_1 are the equation coefficients. Prediction bands' estimation (described by 25 and 75 percentiles) is useful to obtain estimated values, assuming that 50% of estimated data points are within the band defined as in Equation (3):

$$\hat{Y}(x_k) \pm t_{\left(1-\frac{\alpha}{2};\, n-2\right)} \hat{\sigma} \sqrt{1 + \frac{1}{n} + \frac{(x_k - \bar{x})^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2}} \quad (3)$$

where $\hat{Y}(x_k)$ is predicted value $\hat{Y}$ for a specific value of x, x_k, not included in the original set of observations; $t_{\left(1-\frac{\alpha}{2};\, n-2\right)} = \left(1 - \frac{\alpha}{2}\right)$ quantile of a t-distribution with (n – 2) degrees of freedom; $\hat{\sigma}$ is standard deviation of residuals; and $\bar{x}$ is sample mean.

In Step 5, *cost functions' testing*, model testing is an important step to assess the reliability of the models before they are used. Once parameter identification is carried out,

Table 1 | Analysed assets and cost key parameters

Cost	Infrastructure components	Key parameters	Units
Water supply and distribution systems			
Updating and digital mapping	Water network	Network pipe length	€/km
	Network valves, fittings and service connections	Number of units	€/unit
	Tanks and other infrastructures (e.g., pumping stations)	Covered/occupied area	€/m^2
Systems' zoning	Definition of DMA	Number of systems	€/system
	Characterisation of DMA	Network length	–
		Number of clients	–
		Number of service connections	–
	Maintenance of DMA	Number of systems	€/system.year
Monitoring	Construction of meter chambers	Type of meter chambers	€/unit
		Volume of meter chambers	
	Purchase and installation of flow meters	Type of flow meter	€/unit
		Nominal diameter of the flow meter	
Sewer systems			
Updating and digital mapping	Sewer network	Number of manholes	€/manhole
	Service connections	Number of units	€/unit
	Stormwater network	Number of manholes	€/manhole
System zoning	Definition of FSA	Number of systems	€/system
	Characterisation of FSA	Network pipe length	–
		FSA area	–
		Number of service connections	–
	Maintenance of FSA	Number of systems	€/system.year
Monitoring	Construction of manholes	Type of meter chambers	€/unit
		Volume of meter chambers	
	Purchase and installation of flow meters	Type of flow meter	€/unit
		Nominal diameter of the flow meter	

it is essential to confirm the goodness-of-fit of the model and the statistical significance of the model and the estimated parameters. Testing of assumptions for checking the goodness-of-fit includes: (i) linearity and additivity of the relationship between dependent and independent variables; (ii) statistical independence of the errors; (iii) homoscedasticity of the errors; and (iv) normality of the error distribution. The residuals analysis was carried out in Software R to identify and remove outliers through testing the assumptions defined previously. The data-considered outlier can be visualised through a box-and-whisker plot, in which the ends of the whiskers represent the minimum and maximum of all of the data, the bottom and the top of the box are the first and third quartiles, and the band inside the box is the second quartile (the median). Additionally, to confirm the goodness-of-fit of the model, the coefficient of determination, R^2, was calculated.

In this paper, this methodology is applied to estimate the costs in the different steps of monitoring and control of water losses and inflow and infiltration – mapping information, zoning and flow monitoring.

CASE STUDY

Data relative to the infrastructure and cost were collected through a set of Portuguese water utilities involved in the iPerdas project, which is a Portuguese initiative for the efficient management of water losses and energy efficiency (www.iperdas.org) and by other utilities. Data were provided by 20 utilities located in different Portuguese regions: four from the northern region, 13 from the central region and three from the southern region.

Percentages of systems with updated and digital mapping are given in Figure 1. Updated mapping corresponds to the ratio between the length of mapped mains with a capture tolerance compatible with a scale of 1:2,500 and the total mains length; while digital mapping corresponds to the ratio between the length of digitised mains with a capture tolerance compatible with a scale of 1:2,500 and the total mains length (Alegre *et al.* 2006). Only eight utilities provided information about updated and digital mapping. Updated mapping varies between 47% and 100%, and digital mapping varies between 0% and 100%. Most of the

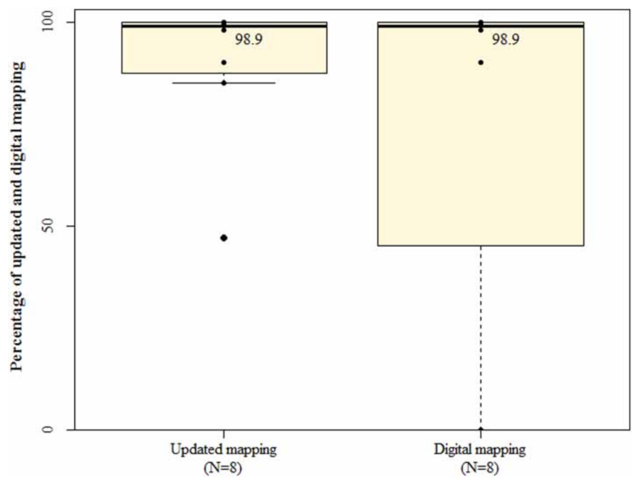

Figure 1 | Percentage of updated and digital mapping in water supply systems.

utilities have an updated mapping of their systems, the major challenge being the digital mapping, but for both indicators, the median value is 98.9%. There was a positive relationship between the updated and digital mapping, in which the utilities with the highest percentage of updated mapping also presented the highest percentage of digital mapping.

For water distribution service providers, network zoning data, including identification and characterisation of the DMA, were requested, including number of clients, number of service connections, network length, type of DMA (permanent or temporary) and type of area (rural, urban or semi-urban). Figure 2 presents the general characteristics of 181 analysed DMA: 94 from rural areas, 15 from semi-urban areas and 72 from urban areas. It was not possible to collect information on the number of clients for all DMA. As expected, the number of clients per DMA is higher in urban areas, followed by semi-urban and rural areas; urban DMA have the highest median value of 1,630 clients, with a maximum number of clients of 15,280. The number of service connections in DMA is quite variable, with semi-urban and urban areas having the highest number of service connections with median values of 533 and 480, respectively. The median DMA network length varies from 11 km in rural areas up to 13 km in semi-urban areas. All values above the maximum indicated in the box-and-whisker plots were considered outliers, using the statistical analysis tool in Software R.

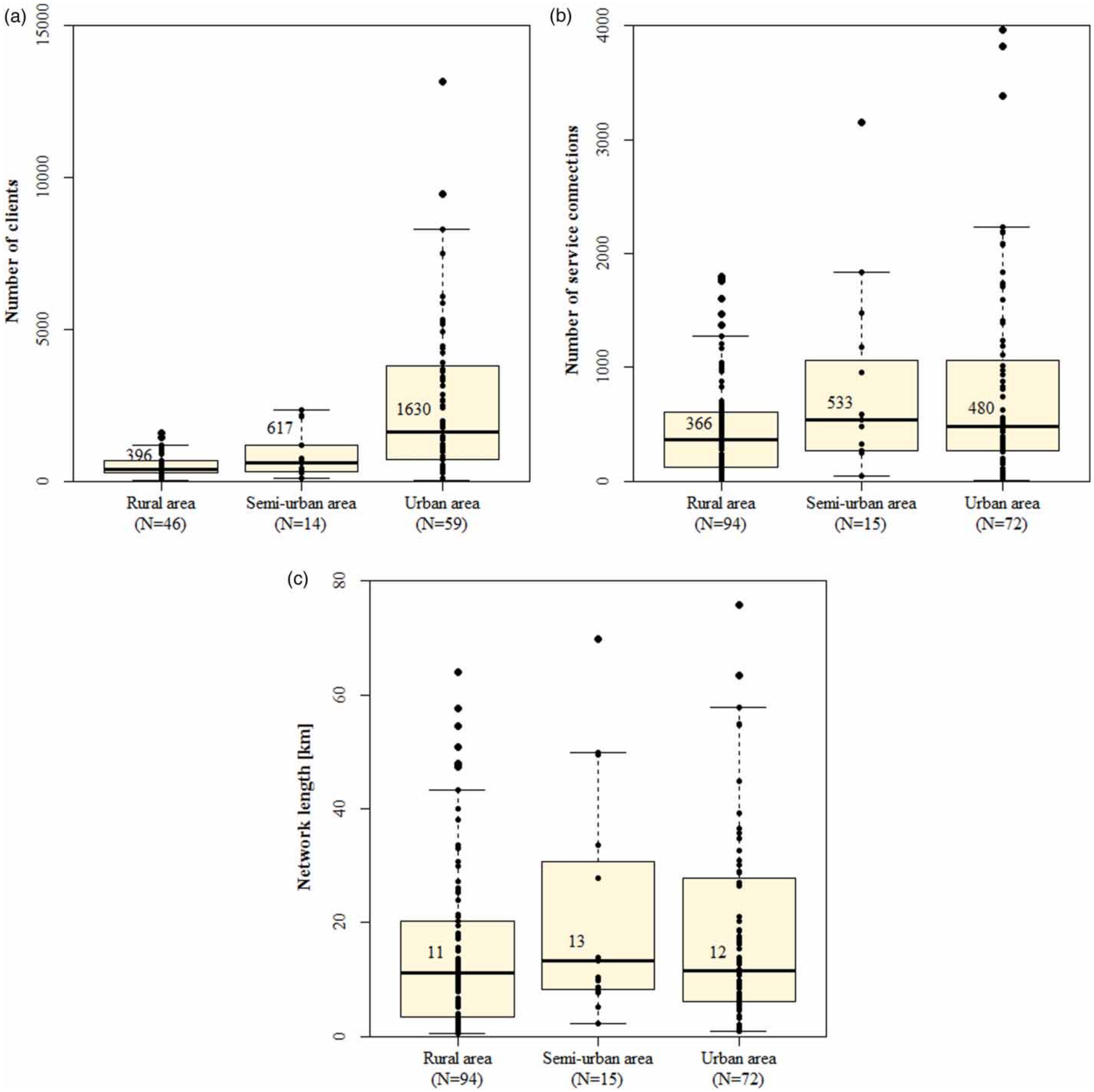

Figure 2 | General characteristics of analysed DMA: (a) number of clients; (b) number of service connections; and (c) network length.

Wastewater utilities provided information on identification and characterisation of existing FSA, including network extension, area and number of service connections (Figure 3). Utilities provided data for 240 FSA. The FSA network length ranges from 0.2 to 33.5 km, with a median value of 8 km; the FSA area varies between 0.1 and 21.2 km^2, with a median value of 4 km^2. An element from the sample associated with the network length was considered an outlier by the statistical analysis tool in Software R and removed from the sample. Regarding the number of service connections, these range from 15 to 123 service connections.

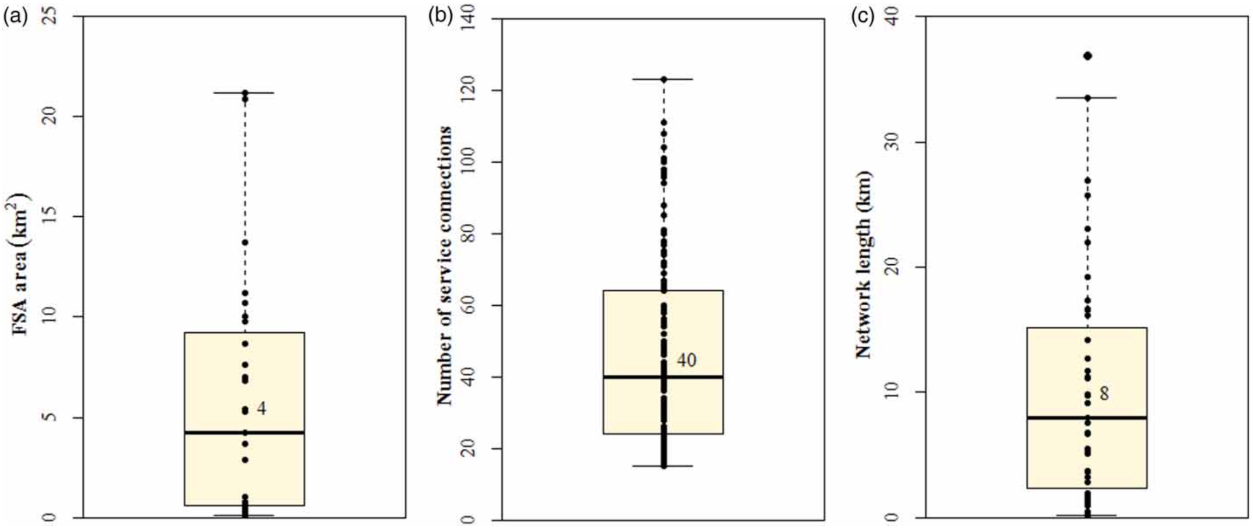

Figure 3 | General characteristics of analysed FSA: (a) FSA area; (b) number of service connections; and (c) network length.

Table 2 | Cost values (median and range) of system updating and digital water distribution system mapping

Components	**Updating cost**		**Digital mapping cost**	
Water network	222 €/km	340 €/km [230–450 €/km]	–	30 €/km [20–40 €/km]
Network valves, fittings and service connections	17 €/unit [2.91–31.25 €/unit]		10 €/unit [2.03–27.8 €/unit]	
Tanks and other infrastructures	0.65 €/m^2 [0.5–0.97 €/m^2]		0.85 €/m^2 [0.15–1.55 €/m^2]	

RESULTS

Costs associated with updating and digital mapping

Costs associated with the system information updating and digital mapping data are determined for several water distribution systems' components (i.e., pipe networks, storage tanks, pumping stations, fire hydrants, meters and valves, see Table 2), as well as for foul sewer systems' components (e.g., sewer network with and without service connections and storm water networks, see Table 3).

The cost of water distribution network updating is 222 €/km. If other components (such as fire hydrants, meters, valves and service connections) are included, the cost can vary between 230 and 450 €/km, with a median value of 340 €/km.

Usually, the cost of data collection for each component (including service connections and valves) results from the sum of the costs associated with geo-referencing (approximately 5 €/unit), collection of the equipment characteristics (approximately 5 €/unit) and remaining works (e.g., construction yard, prior recognition, reports, measurement records, inspection), which may be significant costs (with a median value of 7 €/unit). The median cost of update mapping of tanks and pumping stations is 0.65 €/m^2.

The costs of digital mapping data in a geographic information system (GIS) are strongly dependent on how the data are organised and presented. The cost of digital

Table 3 | Cost values (median and range) of system updating and digital sewer system mapping

Components	**Updating cost**	**Digital mapping cost**
Foul sewer network	21.49 €/manhole [10–30 €/manhole]	3.50 €/manhole
Service connections	2.70 €/service connection [0.57–5.20 €/service connection]	1 €/service connection
Stormwater network	17.21 €/manhole [8.66–22.40 €/manhole]	3.50 €/manhole

mapping of water distribution networks, including equipment and tanks, varies between 20 and 40 €/km, with a median value of 30 €/km. If only networking components are mapped, the cost is 10 €/unit, and if only tanks and pumping stations are mapped, the median cost is 0.85 €/m^2.

In foul sewer systems, the cost of system updating and digital mapping depends on the number of manholes and service connections (Table 3). Since it is also of interest to gather updated information about existing stormwater sewers, these costs are also presented. The updating and digital mapping of foul sewer networks and stormwater networks is carried out along the network, although its cost is defined per manhole. The cost of updating mapping of foul sewer networks and stormwater networks was calculated considering a mean distance between manholes of 36 m. The median cost of updating mapping for foul sewer networks is 21.49 €/manhole, and the cost of digital mapping is 3.50 €/manhole, including service connections. If only service connections are mapped, the median cost of update mapping is 1.10 €/service connection, and the cost of digital mapping is 1 €/service connection. In stormwater networks, the median cost of update mapping is 17.21 €/manhole, and the digital cost is 3.50 €/manhole.

A useful technique to inspect foul sewer systems is using CCTV (closed circuit television). The average reported cost for this type of inspection is 2.54 €/m or 122 €/manhole. Although this inspection is carried out along the network, its cost is defined per manhole.

Costs associated with systems zoning

Costs associated with monitoring and control of water losses and infiltration and inflow include definition, maintenance and implementation of zones, DMA (in distribution systems) or areas of analysis, such as FSA (in foul sewer systems). DMA definition usually consists of the following steps: setting DMA boundaries and dimensions, the preliminary location of flow meters, hydraulic simulation and consumer identification. DMA maintenance consists of the modification of the DMA limits, the introduction of new service connections or changes in the operational regime. The DMA definition cost obtained is 2,000 € for each DMA, and the annual cost of DMA maintenance is 1,000 € for each DMA.

For foul sewer systems, it was not possible to calculate the cost of defining areas of analysis, but the annual cost of maintaining these areas was between 500 and 1,000 € per each FSA. These activities are usually carried out by the utilities, thus it is more difficult to quantify the respective cost. In some utilities, the cost was calculated considering the number of people and the hours needed to carry out the work.

Cost functions associated with monitoring of water losses and inflow and infiltrations

Monitoring water losses in water distribution systems is associated with DMA implementation, and it includes the construction of chambers to install the meters and the purchase and installation of equipment, namely, pipes, valves and flow meters. Five different types of chambers were identified:

- Type A: in-site built chamber made of masonry and painted brick (typically rectangular);
- Type B: cylindrical chamber made of prefabricated concrete rings;
- Type C: chamber made of metal;
- Type D: prefabricated small size ($0.60 \times 0.40 \times 0.35$) chamber made of PVC;
- Type E: prefabricated reinforced concrete chamber.

The cost of construction of these chambers varies according to their volume. Collected data resulted in eight elements for Type A, two elements for Type B, four elements for Type C, one element for Type D and two elements for Type E. For Type A and Type C it was possible to derive the cost functions of construction of meter chambers according to their volume. The remaining typologies (B, D, E) were merged to obtain a single cost function, given their similar nature of prefabricated chambers and the insufficient number of elements per typology to obtain specific cost functions.

Figure 4 shows the unit costs of the construction of different types of chambers as a function of the chamber volume. The construction of masonry chambers (Type A) and metal sheet chambers (Type C) had the highest costs; reinforced concrete chambers (Type E), circular chambers with concrete rings (Type B) and PVC chambers (Type D) have much lower values. Prediction bands were not calculated due to the small sample size.

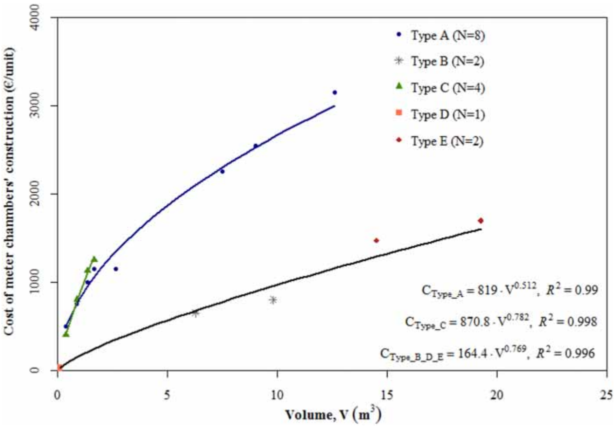

Figure 4 | Construction cost of meter chambers as a function of the volume in WSS.

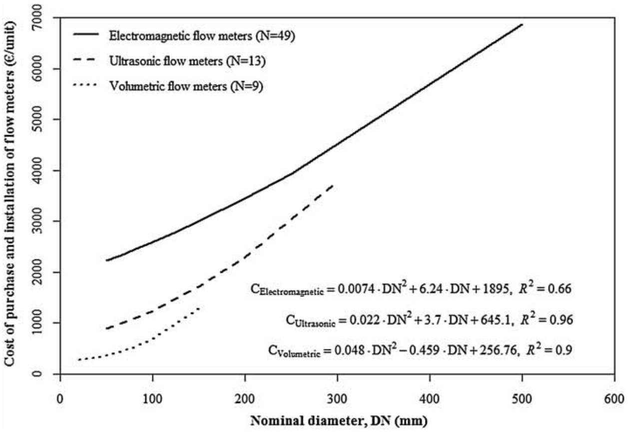

Figure 5 | Purchase and installation cost of flow meters as a function of nominal diameter in WSS.

The cost of purchasing and installing flow meters includes the cost of the following works:

- the equipment purchase (characterised by a nominal diameter and pressure class);
- the equipment assembly, including transmission pipes' adaptation, disassembly/assembly joints, transition joints and all accessories required for complete installation; dismantling and delivery of existing mechanical flow meter;
- the electric works, including protection circuit breaker, power and signal cables with programming and commissioning.

Different types of flow measurement technologies were identified: electromagnetic, ultrasonic and volumetric. Figure 5 depicts the unit cost of purchasing and installing flow meters as a function of nominal diameter. The electromagnetic flow meters have the highest costs, and the volumetric meters have the lowest costs. Prediction bands considering the percentiles of 25–75% were calculated for the three types of flow meters, including the range of parameters and *p*-values shown in Table 4. Low *p*-values confirm the significance of the derived models.

Monitoring inflows and infiltration in foul sewer systems is associated with areas of analysis implementation, such as FSA, and it includes the construction of meter chambers and the purchase and installation of equipment, namely, pipes, fittings, flow and level meters and rain gauges. The construction of meter chambers in drainage systems includes the following works: earthworks (excavation, removal, loading, transport and storage of leftover volumes), gravel and concrete works (gravel and simple concrete for regularisation and reinforced concrete in solid slabs and walls) and coatings (paint and surface waterproofing). Table 5 presents the construction cost of concrete meter chambers for different dimensions.

The equipment was divided into different categories: electromagnetic flow meter for gravity flow, electromagnetic flow meter for pressure flow, radar flow meter with level

Table 4 | Prediction bands' equations for purchase and installation costs of flow meters in WSS

Flow meters	Prediction bands (25–75%)	Range of parameters	*p*-value
Electromagnetic	$\widehat{C_{Elect}}(ND_k) = \pm 0.68 \cdot 521.48\sqrt{1.02 + \frac{(ND_k - 99.18)^2}{258567.3}}$	DN = [50; 500]	1.277×10^{-11}
Ultrasonic	$\widehat{C_{Ultr}}(ND_k) = \pm 0.70 \cdot 166.59\sqrt{1.08 + \frac{(ND_k - 121.15)^2}{58707.7}}$	DN = [50; 300]	5.807×10^{-8}
Volumetric	$\widehat{C_{Vol}}(ND_k) = \pm 0.72 \cdot 121.46\sqrt{1.11 + \frac{(ND_k - 68.33)^2}{12900}}$	DN D = [20; 150]	9.901×10^{-4}

Table 5 | Unit cost of construction of concrete meter chambers in FSA

Dimensions	Unit cost (€/concrete meter chamber)
1.5 × 1.5 × 2 ($N = 1$)	1,400.00
2.5 × 2 × 2.75 ($N = 1$)	4,078.55
Ring of 1.5 × (2 to 4 m) ($N = 1$)	1,700.00

Table 6 | Unit cost of purchase and installation of flow meters for different nominal diameters

Flow meters	Nominal diameter (mm)	Unit cost (€/unit)
Electromagnetic flow meter for gravity flow ($N = 5$)	<250 [250, 300]	11,493.31 12,366.92 [11,372.10–13,361.74]
Electromagnetic flow meter for pressure flow ($N = 4$)	200 350 600 1,000	10,029.14 11,176.21 44,142.60 46,896.63
Radar flow meter with level measurement ($N = 2$)	[250, 300] <250 [250, 400]	16,554.00 18,285.04
Doppler flow meter with level measurement (N = 1)	[350, 1,200]	14,756.00
Ultrasonic level meter (N = 1)	–	1,562.28

measurement, Doppler flow meter with level measurement and ultrasonic level meter. The unit cost of flow meters includes the cost of purchasing and assembling the equipment. Table 6 shows the unit costs of purchasing and installing flow meters for different nominal diameters.

CONCLUSIONS

The current paper aims to present costs for the steps involved in monitoring and control of water losses, infiltration and inflow based on an established methodology for estimating construction costs of urban water cycle assets. These costs include the cost of system information updating and digital mapping, of system zoning (including definition and maintenance of areas of analysis) and system flow monitoring (including the flow meter purchase and installation and the chamber construction).

The established methodology from previous works was used to estimate these costs using a five-step procedure: (1) data collection, processing and analysis; (2) present cost value calculation; (3) component characterisation and key parameters' identification; (4) cost functions' and prediction bands' estimation; and (5) cost function testing. Cost and infrastructure data provided by 20 utilities allowed application of the methodology and estimation of the cost.

A multiple linear regression analysis was used to derive cost functions for meter chambers' construction and purchase and installation of flow meters. Prediction bands (25–75%) were also calculated for different types of flow meters (electromagnetic, ultrasonic and volumetric). For the remaining components, unit costs were calculated and compared. These costs can help utilities to estimate the costs of different interventions correctly and to develop a more sustainable assessment of them, as well as improving the implementation of tactical and strategic plans in water utilities. For future work, the authors recommend estimating the costs of monitoring and controlling water losses, infiltrations and inflows associated with each water and sewer system of different sizes (per km of the network). This analysis allows us to verify if these estimated costs are financially attractive compared to the cost corresponding to water losses from the water distribution network or the increased cost of sewer management due to infiltration and inflows.

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