Assessment of apparent losses in urban water systems

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Abstract

Apparent losses relate to water that is consumed but not paid for. Most research carried out in the last decade particularly in the United Kingdom focused mainly on leakage. Until now, there are no set procedures and guidelines for assessment of apparent losses. Much work remains to bring it to par with the available tools and methodologies for leakage management. In the absence of adequate data and proper methodology, most developed countries use default values, which tend to be lowest values for well-managed water systems, for computation of apparent losses. These may not be appropriate for developing countries. This paper presents a methodology for the assessment of different components of apparent losses based on field audit and operational data for Kampala city's water distribution system in Uganda. Metering inaccuracies and illegal use have been found to be significant components of apparent losses. Appropriate intervention strategies have been developed based on the assessment.

Introduction

One of the major challenges facing water utilities especially in sub-Saharan Africa is the high level of water losses. Nonrevenue water (NRW) is the difference between system input volume and billed authorized consumption according to the International Water Association (IWA) standard water balance and terminology, and consists of water losses (apparent losses and real losses) and unbilled authorized consumption (Lambert & Hirner 2000). Real losses consist of physical losses (leakage) and overflows from reservoirs. Apparent (commercial) losses are the nonphysical losses in that no water is physically lost via these losses from the water supply system. They relate to water that is being consumed but not being paid for. Apparent losses consist of four primary components: customer meter inaccuracy, meter reading error, unauthorized consumption (theft, meter bypass, illegal connections, misuse of fire hydrants, etc.), data handling and billing errors (Rizzo et al. 2004; AWWA 2006; Fanner et al. 2007b). Apparent losses result in appreciable revenue loss for water utilities and distort the integrity of consumption data required for various management decisions and engineering studies. This problem is more pronounced in the water utilities of the developing countries.

According to Kingdom et al. (2006), about 30 000 ML/day of water is delivered to customers in the developing countries, but is not paid for because of water theft, employee's corruption and poor metering practices. They estimate that about US$3 billion/year of revenue is lost in the developing countries due to commercial losses. They go on to conclude that the financial viability of utilities in developing countries is constrained as a result and this hampers necessary service expansions especially for the poor.

Most research that has been performed in the last decade in the developed continents of Europe, Australia and North America focused mainly on the real loss (leakage) component of water losses (Lambert et al. 1999; McKenzie & Seago 2005; Fanner et al. 2007a). In England and Wales, for instance, residential customer metering is still low and was estimated to be 25% by the end of the year 2006 (Thornton et al. 2008) and this probably explains why research has focused less on apparent water loss components. There is no reason for stealing water if billing is based on flat rate charges assigned by property rates. Actually, the UK water industry has not yet embraced the IWA standard water balance methodology and metering inaccuracies are accounted for as part of billed metered authorized consumption thus underdeclaring NRW levels.

Apparent loss control in water supply systems is in its infancy, and much work remains to be carried out to bring it to par with available real loss interventions (AWWA 2003). Until now, there are no set procedures and guidelines for assessment and control of apparent losses in the water distribution systems. Considerable efforts are being made by the IWA water loss task force (WLTF) to assess components of apparent losses and some initial results have been presented by Thornton & Rizzo (2002). Rizzo *et al.* (2007) proposed an apparent water loss audit based on a pilot zone or a district meter area (DMA) approach. They propose to first remove all leakages in the DMA or calculate the leakage component using the minimum night flow of the zone. They also propose that the first component of apparent loss to be analysed is water theft and the other two components are analysed later using automated meter reading (AMR). This approach is unrealistic, costly and is very difficult to apply in water distribution systems of developing countries with an intermittent water supply and rampant water theft.

In the absence of adequate data and a proper methodology, most developed countries use default values or rules of thumb (e.g. unauthorized consumption is computed as 0.5% of the total system input and domestic meter under-registration as 2% of metered consumption), which tend to be the lowest values for well-managed water systems, for component computation of apparent losses (Seago & Mckenzie 2007). In the BENCHLEAK model for calculating components of NRW, a lump sum default value of 20% of total water losses is used to compute the apparent losses component (McKenzie *et al.* 2002). For convenience, AWWA (2006) recommends the use of 0.25% of water supplied to compute unauthorized consumption. These default values may not be appropriate for developing countries with problematic and poorly managed water systems. Tabesh *et al.* (2009), in their study of evaluating water losses in one of the Iranian towns, attempted to assess apparent losses but did not clearly clarify how to verify meter-reading errors. They compare meter readings and consumptions, which is erroneous as you cannot compare apples with mangoes. They also introduce new errors of operational and management nature that they do not clearly define and compute. These operational errors and management errors are likely to cause confusion as they are different from those defined by IWA and accepted internationally.

This paper presents a methodology for assessment of apparent losses based on field audit and operational data for Kampala city's water distribution system in Uganda, East Africa. A framework for computation of apparent losses and its components in utilities of developing countries with similar utility profiles and context information is proposed. In so doing, the paper makes a contribution to the international efforts being made to assess and benchmark components of apparent losses. Metering inaccuracy and illegal use has been found to be higher than expected; meter-reading errors, data handling errors and billing estimates are so far lower than expected. Apparent loss reduction strategies have been developed based on the findings and cost–benefit analyses.

Utility profile and context information for Kampala City

Kampala city is one of the 22 large urban centres under the jurisdiction of National Water and Sewerage Corporation (NWSC-Uganda), a public utility established in 1972 to provide water and sewerage services to all large urban centres in the country. Kampala water supply service area encompasses an area of about $300 \, km^2$. Population estimates indicate that about 1.5 million inhabitants live within the service area, with 1.21 million in Kampala District (UBOS 2002). The annual growth rate since 1991 census is 3.8%, making Kampala one of the fastest-growing cities in the world. Water supply has not kept pace with the population growth and has resulted in water shortages and low pressures in most parts of distribution system. The current piped water service coverage is estimated at 71%.

The city of Kampala has one of the oldest water distribution systems in Uganda. About 50% of its water pipelines were installed before independence in 1962 and comprise of steel and cast iron pipe materials. The city's approximate water supply system of 2300 km of pipelines distributes about $135\,000 \, m^3$ of water per day to approximately 130 000 customer accounts. An average of 1000 new customer connections is added to the water network every month.

About 80% of the customers are of domestic use category and 17% are commercial. From the customer billing database, approximately 16% of the total customer accounts are inactive due to disconnections for nonpayment. The total unpaid customer debt (arrears) was USh25 billion (or about €8.2 million) as of the end of the year 2008. All customer accounts are metered and 94% of meters are of size 15 mm, followed by 20 mm meters at 5%. Because of an intermittent water supply, almost all customers have elevated storage tanks to mitigate against water supply interruptions. The average age of meters is 8 years, with a low meter replacement frequency of 0.3%/year. About 76% of meters are of the volumetric (positive displacement) technology type and 24% are of the multi-jet velocity type. The customer meter failure rate is high and an average of 7832 customer accounts were billed monthly based on estimates or 6% of the total water sales between November 2008 and April 2009 mainly due to

defective (stuck) meters and inaccessible customer meters. Average monthly water sales for 4 months (January–April 2009) were 2445 million litres and 50% are domestic sales, followed by commercial and industrial sales at 28%, then government institutions 17%, then public stand pipes (PSPs) and yard taps serving the urban poor at 5%. In Uganda's capital city of Kampala, NRW is estimated to be 18 000 ML/year or 40% of the system input volume. It is estimated that 52% of NRW is due to apparent losses.

The Kampala situation is similar to other cities in developing countries. It is estimated that in Asian cities, 50–65% of NRW is due to apparent losses (Mclntosh 2003). In a study carried out in Ghana's Accra Tema metropolitan area (ATMA), it was estimated that 55% of NRW was due to commercial losses (Lievers & Barendregt 2009). In the same study, it is reported that out of 17 231 disconnected customers investigated in ATMA, 18% of the customers were found on supply in 2008. Similar investigations carried out in Kampala on 2747 disconnected customer properties between March 2008 and May 2009 found 16% of the supposed disconnected customer accounts to be actually consuming water (or illegal reconnections). The Kampala illegal use database established in 2003 indicated that by April 2008, a total of 3659 illegal use cases had been confirmed. This translates into an average of 732 illegal cases per year, which is significant. The majority of illegal water use cases come in the form of illegal reconnections (40%), followed by meter by-pass (35%), then illegal connections (16%), meter reversals and tampering (9%). Surprisingly, this practice, perceived to be a developing country problem, has also been reported in water utilities of the developed countries. Annual investigations carried out in the USA's city of Philadelphia on customer accounts that registered multiple billing cycles of zero consumption were actually found to be consuming water and 45% of the zero consumption cases were confirmed to be due to meter tampering by customers (Kunkel 2008). In the Brazil's city of Sao Paulo under Sao Paulo Water and Sanitation Company (SABESP), out of 63 508 water fraud inspections carried out in the Central Business Unit, 7% fraud cases were confirmed and about 33% of water losses are due to apparent losses (Batista & Mendonca 2009).

Research approach

A water balance was carried out for Kampala city's distribution system using the standard IWA methodology (Lambert & Hirner 2000; Thornton 2002). The only difference is that real losses were computed first based on operational data and well-established procedures based on the burst and background estimate (BABE) methodology and the fixed and variable area discharge (FAVAD) theory (Fanner *et al*. 2007a). Apparent losses were then computed as the difference between systems input volume and real losses. Different approaches were then used to assess the different components of apparent losses (metering inaccuracies, meter-reading errors, billing and data handling errors and unauthorized use of water). The different approaches used for estimating different components are outlined below.

Metering inaccuracies

Meters, like any other mechanical devices, are subject to wear and tear, and hence loss of accuracy with time. It was worthwhile to assess metering inaccuracies for Kampala city as all customer service connections are metered. In order to assess the accuracy of a meter at any one time, one requires to test the meter at different flow rates representing typical customer water use. The proportion of water used at various flows is then combined with the meter accuracy at each flow to determine the weighted meter accuracy. The weighted meter accuracy is the parameter used by engineers and decision makers to define meter performance when measuring the water consumption of users.

The weighted meter accuracy was determined following the methodology outlined by Male *et al*. (1985), Yee (1999) and Arregui *et al*. (2006a). Statistical sampling methods (stratified random and cluster sampling) were used to determine the accuracy of meters. Meters were grouped by age (1–2 years, 3–5 years, 6–8 years, 9–11 years, 12–14 years and > 15 years). Samples for domestic meters (size 15 and 20 mm) were taken from each of the three major manufacturers, constituting 95% of all meter makes in the network. The samples were picked from different parts of the network to create a homogeneous population. The more homogeneous or well mixed the entire sampling population is, the fewer the samples needed to obtain a good representation. The number of samples to be tested was thus minimized. Ideally, the more the number of samples, the more representative the results will be from the total population. A trade-off had to be made between the numbers of samples that would yield meaningful data versus the number that could be realistically tested within the available resource envelope. The total number of meters tested was 250 or about 40 meters per age group. The samples were randomly selected from the customer billing database and ensuring that all parts of the network or 10 operational branches were represented. Metrological meter tests were performed at 11 different flow rates to depict as much as possible the customer profiles instead of the standard ISO 4064 three rates (Q_{min}, Q_t and Q_{max}).

The customer water consumption profiles were measured using master meters of excellent metrology and data loggers that continuously record the readings from the meter. Additional accuracy of existing meters was also checked by comparing weekly readings with the master meter. Ninety customer data loggings and 250 meters tested on the meter workshop bench in a period of 4 months.

Finally, the weighted metering error was computed using the following formula (Yee 1999):

$$\text{Weighted average meter accuracy} = (\text{PTC}_L \times \text{GAA}_L) + (\text{PTC}_M \times \text{GAA}_M), + (\text{PTC}_H \times \text{GAA}_H) \tag{1}$$

where PTC_L is the percentage of total consumption at low flow; PTC_M is the percentage of total consumption at medium flow; PTC_H the percentage of total consumption at high flow; GAA_L is the group average test result accuracy at low flow; GAA_M is the group average test result accuracy at medium flow; GAA_H is the group average test result accuracy at high flow.

The quantitative check and analysis used statistical measures of confidence limits, mean standard deviations and variance based on flow rates. The limit differences for the sampled meter groups turned out to be small and in the range of 1–2%. This implied that meter accuracies from the sample were representative of their respective groups in totality.

Equipment used

During the study, the following equipment was used for measuring the water consumption patterns:
- Very accurate 'Volumetric positive displacement'-type master meters with a low start-up flow (Class D, $Q_n = 1.0$–$1.5 \, \text{m}^3/\text{h}$). These meters are equipped with pulse emitters with a minimum resolution of 0.1 L/pulse.
- Sensus cosmos data loggers (CDL-4U) with extended memory capacity and high-resolution sensors designed for water metering analysis. One-week data loggings were carried out via pulse count on a 10-s interval.
- The Sensus free software (CDL WIN 3.5) was used for data retrieval from data loggers to the computer for analysis.
- In order to closely estimate the start-up flow and to take care of induced low flows by ball valves of service tanks that are almost everywhere in Kampala city, meters were tested at 11 different flows (3.75, 7.5, 15, 22.5, 30, 120, 185, 375, 750, 1500 and 3000 L/h) using a modified meter test-bench.

The experimental set-up used is as indicated in Fig. 1.

Fig. 1. Data collection of customer water consumption demand patterns.

Meter-reading errors

Customer meter reading in Kampala water distribution system is carried out using the common traditional approach whereby meter readers visit individual meters to collect readings. This method of meter reading is susceptible to human errors.

Meter reading audits were carried out in a day during the months of November 2008 and March 2009 to verify the accuracy of meter readings submitted by meter readers for billing purposes. The readings of the auditors were then compared with the readings submitted by meter readers. The readings that showed unrealistic variances were regarded as erroneous readings. The consumption volume on erroneous meter readings was then summed up ($z \, \text{m}^3$) and expressed as a percentage of volume of water sold ($y \, \text{m}^3$) for the total audited accounts. The result is the meter reading error ($z/y \times 100$) and is expected to be representative of the entire system. The auditors were utility employees from all departments including the executive director, senior managers and lower cadre staff. The total numbers of meters audited were about 12 000.

Data handling and billing errors

These errors arise in the process of transmitting or capturing data from the meter reading sheets into the customer billing database. Gaining access to some customer meters located inside customer premises is difficult due to increasing number of working couples, leaving no one at home or at times leaving guard dogs. In addition, there is an increasing number of defective customer meters and a lag of new connections' update in GIS that complicates the tracing meters installed. For these reasons, manual meter reading success rates in Kampala city are on the decline. Customer water use is then estimated based on historic consumption trends. While this is a reasonable approach, multiple cycles of meter reading without an

actual reading greatly increase the prospect of inaccurate estimates (AWWA 2006; Thornton *et al*. 2008).

A data-capturing audit was carried out to compare the input data used for billing and the readings on the meter reading sheets submitted by meter readers. The readings that were wrongly captured in the billing database were established and their corresponding total volume was computed ($x\,\mathrm{m}^3$). If the water sales for the assessment period were $y\,\mathrm{m}^3$, the percentage data handling errors were computed as ($x/y \times 100$). A sample of 7438 customer accounts was analysed.

Billing errors from poorly estimated volumes that resulted in billing adjustments were generated from the customer billing database and their volume was summed up ($v\,\mathrm{m}^3$). If the water sales for the assessment period were $y\,\mathrm{m}^3$, the percentage data handling errors were computed as ($v/y \times 100$). Billing errors for the 3 months (October–December 2008) were used for computation of billing errors' component of apparent losses.

Billing errors arising from the billing software programming and algorithms were considered negligible and were not assessed.

Unauthorized use of water

Identifying unauthorized consumption in a water distribution system is a challenging task. A proactive approach through investigations of suspicious trends of billing data consumption (zero consumptions, negative consumptions, etc.) and employing illegal use informers was utilized. These individual site inspections fall under the category of bottom-up auditing of unauthorized consumption. Advertisements were placed in the local newspapers requesting anyone with information on illegal use of water to report to the utility and once confirmed, a cash reward in the range of USh50 000–200 000 (or US\$25–US\$100) was offered depending on the size of the illegal user discovered. In addition, historical records on illegal users and their consumption patterns (average monthly per capita consumption of different user groups obtained from customer billing database) were used to quantify the total volume of unauthorized use ($q\,\mathrm{m}^3$).

The different components of illegal use were broken down as follows:
- Domestic illegal use, q_d=number of properties $\times$ 20 m^3 per month
- Commercial illegal use, q_c=number of properties $\times$ 500 m^3 per month
- Government institutions, q_g=number of properties $\times$ 500 m^3 per month
- Public standpipes, q_p=number of properties $\times$ 50 m^3 per month
- Total volume of unauthorized use, $q=q_d+q_c+q_g+q_p$

The total volume is then expressed as the percentage of water sales $y\,\mathrm{m}^3$ during the assessment period. This was the proactive unauthorized use of water component, computed as ($q/y \times 100$). The difference between the apparent losses volume and the sum of the volumes of the above components is the unknown unauthorized use.

This methodology is represented in Fig. 2 and could be used at the utility, zonal or DMA level.

Results and discussion

In order to assess the apparent water loss components, metering accuracy, meter-reading errors, data handling and billing errors and illegal consumption were analysed. The results for each of these components of apparent loss are elaborated below.

Metering accuracy

The test results from 90 loggings (60 domestic, 25 commercial and five PSPs) and 250 test-bench results carried out on meter sizes ranging from DN 15 to 100 mm are presented. The overall weighted meter accuracy for domestic meters (0–15 years) was 78% or a weighted meter error of -22%. This means that meters are under-registering consumption by 22%, resulting in significant revenue loss to the utility. The weighted metering error for users with a roof tank was more significant and at 25% while that of users on a direct supply was 7%.

The metering efficiency ranged from 80 to 85% (meter age < 5 years) to 72% (meters > 12 years). Most domestic meters (> 5 years) were unable to register low flows (< 100 L/h). The proportion of water volume passing through the meters at small flow rates (< 100 L/h) is about 40% for residences with roof tanks (82% of all customers) . For customers on a direct supply like PSPs or yard taps (18% of all customers), the proportion volumes delivered at small flow rates (< 100 L/h) are much lower (< 3%). Some meter models observed in the meter workshop had a high number of failure rates, with less than a cumulative volume of 100 m^3 (2–3 weeks old).

The probable reason for the high metering errors in Kampala city is the presence of customers' service storage tanks. Because water supply is very unreliable, over 80% of customers have storage tanks. The use of such tanks has been found to cause metering errors due to low flows induced by the ball valves reducing the ability of the meters to accurately measure water consumption (Arregui *et al*. 2006b). In addition, because about 70% of the water meters in Kampala city are of the volumetric type, which are very sensitive to suspended particles, it probably explains the high failure rates of new meters. Because of poor repair practices, the presence of suspended

particles in water is common and often observed in the meter strainers during servicing in the meter workshop.

Meter-reading errors

Out of the 12 000 water meters audited to confirm the accuracy of meter readings, only 73 water meters were found to have been incorrectly read. The meter reading error computed as a result was 1.4% of the water sold.

Data handling and billing errors

A sample of 7438 consumer accounts was audited to confirm the accuracy of data input capture into the billing system. Only eight accounts were found with wrongly captured readings. The corresponding data-capturing error computed was 2.5% of the water sold.

The customer billing database was queried to assess the billing adjustment made arising out of wrong billing consumption estimates for 3 months (October–December

2008). Out of 22 855 accounts found to have been billed based on estimates, 643 accounts had billing adjustments made as a result of customer complaints raised for wrong billings. The corresponding billing error computed was 1% of the water sold.

Illegal use of water (unauthorized consumption)

From the illegal use records of the last 2 years (2007 and 2008), the average number of illegal users discovered annually was 939 cases. The increase from 732 illegal cases (2003–2008) to 939 cases (2007–2008) could be attributed to proactive illegal use investigations and cash incentives for illegal use informers introduced in 2008. Out of these cases, 83.3% were domestic users, 12.5% commercial users, 2.1% PSPs and 2.1% government institutions. Using the average monthly consumptions for each consumer category and the annual water sales, the illegal use component was computed as 4% of the water sales.
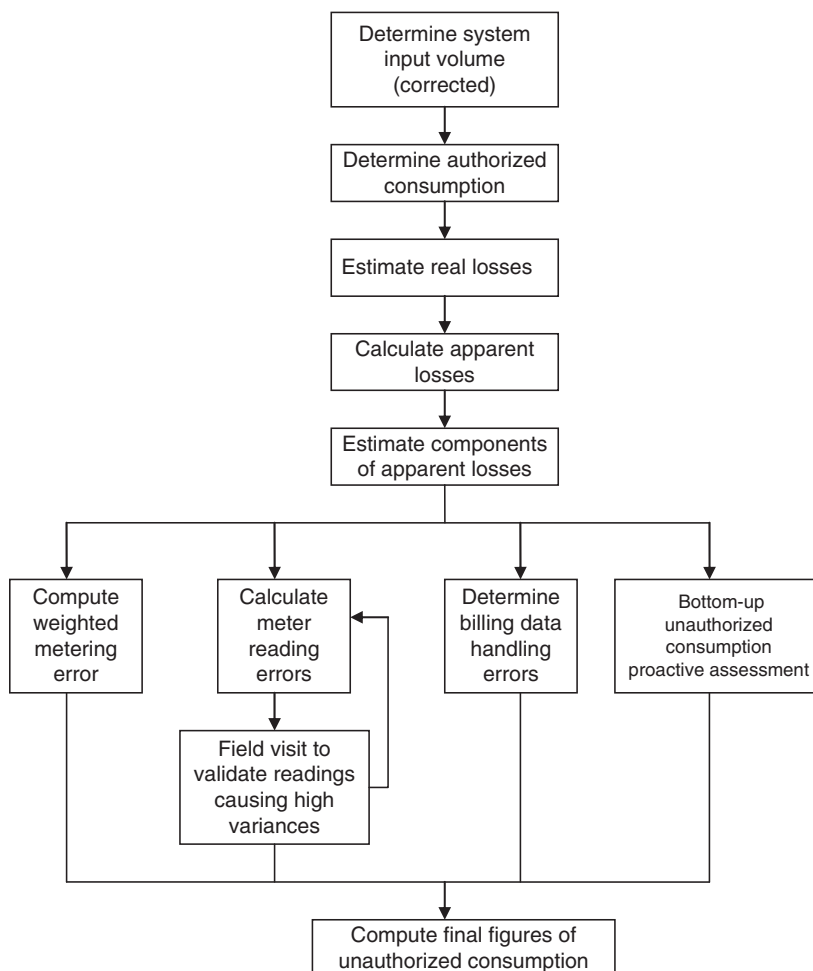

Fig. 2. Methodology for assessing apparent water loss components.

From the known figure of apparent losses computed from the water balance and the sum of all the above-computed components, the unknown unauthorized consumption was found to be 6% of the water sales.

Apparent loss component breakdown

The total apparent loss component for Kampala city's distribution network was found to be about 37% of the water sales or revenue water. The breakdown including uncertainties in data acquisition and processing is as follows:

- Metering inaccuracies – $22 \pm 2\%$ of water sales.
- Meter-reading errors – $1.4 \pm 1\%$ of water sales.
- Data handling and billing errors – $3.5 \pm 0.5\%$ of water sales.
- Unauthorized use of water – $10 \pm 2\%$ of water sales.

From the Kampala city's case study, reports from other NWSC-Uganda towns and the authors' experience in operations of water distribution networks in developing countries, the framework in Table 1 is proposed for estimating the apparent loss components for water utilities in the developing countries with similar context information and utility profile as Kampala city. Seago *et al*. (2004) proposed a similar framework for estimating apparent loss components for South African water utilities based on performance levels (very high, high, low, very low, poor, average, good) to describe data transfer errors and illegal use of water, water quality and meter age as the main factors influencing metering errors and percentage expressed as percentages of current annual real losses.

It is important to note that the figures for unauthorized use of water could be higher than indicated if no proactive mechanism is in place to investigate and invoke appropriate penalties for illegal use of water. Similarly, proper water meter management practices should be in place to minimize losses related to water meters.

Developed strategies for the reduction of apparent water loss

From the results of the assessed components of apparent losses, it is evident that metering inaccuracies and unauthorized use of water are significant components of apparent losses in Kampala. The following key reduction strategies have therefore been adopted for Kampala City to enhance water sales:

Metering technology: As a result of the high failure of piston-type meters due to suspended particles in the water, it was concluded that this type of metering technology was unsuitable for use in the Kampala water distribution network. New meter specifications (size 15 and 20 mm) of velocity-type meters have been prepared for domestic and small-scale commercial users. The meters include antifraud special designs against magnetic reversals and tampering.

Revenue protection unit (RPU): A new revenue protection unit has been established replacing the old illegal use unit. The RPU is well structured, with representatives from customer billing, technical, legal and commercial to aggressively carry out enforcement of the law to combat the rampant illegal use of water in the city. Special meter antifraud devices have been procured, among others, to minimize meter reversals and tampering.

Replacement of meters: All meters > 7 years are being replaced systematically with the new adopted metering technology and their performance will be tracked for the next 2 years to assess the impact on water sales.

New customer connections timely updates: Institutional arrangements with appropriate staffing levels and tools are being made to ensure efficient and effective updating of new customer connections to minimize meter reading

Table 1 Proposed default values for apparent losses for developing countries

Unauthorized use of water		Meter age and error			Meter reading, data handling and billing errors	
			With storage tanks	Direct supply		
City (> 100 000 service connections)	10%	Poor (> 10 years)	− 28%	− 10%	Poor[a]	10%
Municipality (50 000–100 000 service connections)	3%					
Medium towns (5000–50 000 service connections)	2%	Average (5–10 years)	− 20%	− 8%	Average[b]	6%
Small towns (<5000 service connections)	0.5%	Good (<5 years)	− 15	− 5	Good[c]	2%

[a]No management controls in place, employees are poorly remunerated and inefficient billing system.
[b]Management controls in place, fairly remunerated employees and good billing system.
[c]Well functioning utility with good customer billing system.
Percentage represents percentage of water sales or revenue water (m^3).

estimates. Previously, meter readers could not locate meters on new connections due to delays and errors in updating GIS Maps.

Further studies: AMR and unmeasured flow reducers (UFR) are being piloted to assess their cost-effectiveness with respect to increasing water sales. The optimal meter replacement schedule for Kampala is also being investigated and appropriate decision support tools will be developed. Current thinking is that meter replacement should not be based on age but cumulative volume that has passed through the meter. From these studies, policies on meter management will be developed based on the findings.

Conclusions

This paper outlines a methodology for the assessment of apparent water loss components in urban water distributions based on field audits and operational data for Kampala city in Uganda. The main conclusions drawn from this study are as follows:

(1) Assessing components of apparent water losses for water utilities can be a complex task particularly in developing countries, where they are more prevalent and reliable data are often not available.

(2) The study confirms that metering inaccuracies and illegal use of water are the major components of apparent losses in Kampala city's water distribution system. The results indicate that up to 37% of the water sales in Kampala is consumed but not paid for due to apparent losses.

(3) The domestic water use profile plays a crucial role in the determination of meter accuracy and, as a result, the amount of apparent water loss component attributed to meter inaccuracy.

(4) A framework within which assessment of components of water losses can be computed is presented based on the size of the utility, age of water meters and management audit procedures in place for data handling and billing.

(5) The proposed methodology is generic in nature and based on a practical logical sequence. Water utility managers will find it very helpful while carrying out annual water balances for their water supply systems.

(6) Each water utility should attempt to carry out its own apparent loss assessment and it is only by doing so that factors contributing to apparent losses will be identified, quantified and appropriate reduction strategies can be developed.

(7) Performance benchmarking demands uniform methodologies and precise definitions. Water utilities and regulatory institutions should promote the use of universally used water loss assessment methodologies.

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