Investigating the Impact of Utility Sub-metering on Revenue Water

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ABSTRACT
Due to rapid population growth and urbanization, there is a boom in the housing construction industry in most cities of the developing countries. As a result more and more multi-family apartments and commercial arcades have increased in the cities. Some property owners have requested water utilities to provide direct billing to the individual multi- family apartments and commercial arcades through sub-metering. Although sub-metering is widely used as a tool to promote water conservation, notably in the USA, its impact from the utility perspective of increasing revenue water is not very well understood particularly in poorly managed water distribution networks of the developing countries that supply water irregularly.

The aim of this paper is to analyze the water distribution system characteristics in order to understand the impact of sub-metering on revenue water. The study was carried out in Kampala city, Uganda. The results indicate a reduction in revenue water of about 14% due to sub-metering. This reduction in revenue water is not as a result of water conservation measures but due to metering errors. Following the findings of this study, we recommend guidelines of how to efficiently implement sub-metering to promote efficient use of water without necessarily reducing utility revenue water.

Keywords: Metering inaccuracies; Non-revenue water; Sub-metering; Water utilities

1.0 INTRODUCTION

One of the challenges facing water utilities in the developing countries is the high levels of non-revenue water (NRW) notably commercial (apparent) losses. Apparent losses refer to water that is used but not paid for due to theft and metering inaccuracies. According to Kingdom *et al*. (2006), more than 10 billion m^3 of treated water in developing countries is used but not paid for annually, costing water utilities about US$ 2.6 billion per year. Clearly it is unacceptable that water utilities which are starving for additional revenues to finance expansion of services and rehabilitate ageing infrastructure are the same utilities allowing water to be used free of charge.

The primary objective of water providers is to supply water of good quality at sufficient pressures and quantity to the users and in return receive payment for services rendered. The main link between customers and users is the water meter that measures actual volume of water used, as a basis for billing. However, when metering is inefficient, revenue water is lost and customer billing is inequitable. This problem is likely to be exacerbated by sub-metering of multi-family housing units and multifaceted commercial arcades.

The term "sub-metering" refers to any metering that occurs downstream a water utility's master meter to measure individual resident water usage in apartments, condominiums, mobile home parks, and small mixed commercial properties (AWWA, 2000).

In Kampala, the capital city of Uganda, there is a boom in the housing sector to meet the demand of increasing population and urban migration in search of jobs. As a result buildings of multi-family apartments and commercial complexes are on the increase. Traditionally, and in accordance with Cap.152 of the Water Act, (1995), the Water Utility is mandated to deal with landlords (property owners) for service provision of water and sewerage. The property owners are responsible for payment of water bills based on a single common master meter installed by the utility to measure water provided to the property (single or multi-family residences or commercial arcades). Landlords then recover water charges from tenants through monthly rent payments. The increasing costs of doing business as result of tariff and other increases have had a pronounced effect on property owners. As a result some property owners have requested the water utility to provide billing services directly to the tenants via sub-metering of individual service connections. This passes the burden of cost increases and revenue collection to the tenants and the utility. In the spirit of good customer care and the utility's slogan of "the customer is the reason we exist", the utility began to bill tenants directly without critically assessing the costs and benefits of sub-metering. In addition, Branch Managers regarded sub-metering as a means of achieving their monthly targets of new connections. It is now common to find a multi-family property that used to have one master meter, with over 20 sub-meters serving individual apartment units. The drop in water sales per connection from 362 m^3 (2003/04) to 217 m^3 (2008/09) partly explains the rapid growth in sub-metering in Kampala city.

Metering and customer billing is now widely acknowledged as a demand management tool. Water savings of 10 % to 30% have been reported as a result of sub-metering in the USA (AWWA, 2000). However, in urban water utilities of the developing countries with often poorly managed distribution networks supplying water irregularly, low network pressures and inefficient metering, the impact of sub-metering is not very well understood.

2.0 OBJECTIVES AND SCOPE OF THIS STUDY

One of the objectives of this study was to investigate the effect of sub-metering on revenue water from the utility perspective of increasing water sales. The investigations were technical and assessed the influence of distribution network characteristics on sub-metering. The scope of this study is defined as system characteristics (pressure, customer demand profiles and quality of meters) that influence metering errors after the master meter for sub-metered properties in the Kampala Water Distribution Network (KWDN).

3.0 METHODOLOGY

The following research approach was followed to accomplish the objectives set out for this study.

3.1 Quantifying Metering Errors due to Sub-metering

To assess the impact of meter separations on meter accuracy, new monitoring master meters were installed in series with property sub-meters for individual tenants as indicated in Figure 1; where M_T is the Master Meter and M_1, M_2, M_3 and M_n are the sub-meters for the individual property units from 1 to n. The total number of properties that were investigated was eight (seven multi-family properties and one commercial arcade) and spread out in different parts of the city for a fair representation of network characteristics so as to minimize on uncertainties. The weekly and monthly meter readings were taken for the master meter and the sub-meters for a period of 4 months. This was after thorough investigations to eliminate any leaks, illegal use and meter by-pass between the master meter and the sub-meters. The distance between the master meter and sub-meters was kept short and ranged from 1m to 8m to minimize risk of meter by-pass and leaks. The difference between the initial and final readings for each of the meters was obtained and taken as the volume through the meter.

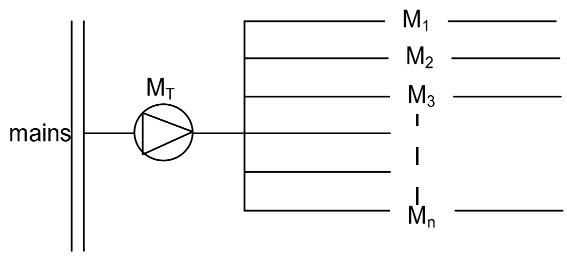

Figure 1: Meter separation arrangements

The sum of the sub-meter readings for each of the properties was obtained and compared to the master meter volume. The difference between the master meter volume and the sum of the sub-meter volumes was obtained for each of the properties. The total difference for all the properties was obtained and expressed as a percentage of the master meter total volume and this was taken as the metering error due to sub-metering.

3.2 Assessing Effect of Meter Quality on Global Metering Errors

Meter accuracy tests for all the meters (master meter and sub-meters) to determine the level of accuracy of the meters was carried out using the utility's meter test-benches. To minimise costs of testing and due to limited time of the study, the smallest property with six sub-meters was selected. The volumes that were registered by these meters were then corrected using the calculated individual meter errors in accordance with the water balance Equation 1. Thereafter all the existing meters were replaced by highly accurate master meters (Class D, Q_n = 1.0 to 1.5 m^3/h, size DN 15 mm) and the experiment was repeated to eliminate any influence of the meter age on the metering error. All master meters and sub-meters investigated in this study were typical small residential meters of sizes DN 15 and 20 mm and mainly of Class C and B of multi-jet and positive displacement (piston-type meters).

$$Q_{\text{master meter}} + Errors_{\text{master meter}} = \sum_{i=1}^{n} Q_{\text{consumer meter}} + \sum_{i=1}^{n} Errors_{\text{consumer meter}} \quad (1)$$

Where, $Q_{\text{master meter}}$ = Volume measured by the monitoring master meter, $Errors_{\text{master meter}}$ = Errors of the master meter, $Q_{\text{consumer meter}}$ = Volume measured by the separated meters, and $Errors_{\text{consumer meter}}$ = Errors of the sub-meters.

3.3 Assessing Effect of Users Demand Profiles on Metering Errors

Simultaneous customer demand profiling for the master meter and sub-meters was carried out at the same smallest multi-family apartment to investigate whether customer demand patterns had an influence on the metering error due to sub-metering. The details of the methodology and equipment used can be found in Mutikanga *et al.* (2010).

3.4 Assessing Effect of Pressure on Metering Errors

Pressure measurements were carried out at the properties (using Hydreka Vistaplus pressure data loggers type OCTC511LF/30) to investigate whether pressure differences also have an impact on the metering error due to sub-metering. To determine the effect of pressure on the metering error, the experiment to determine the metering error due to meter separations (using Class D meters) was repeated at the same small multi-family residential property under different network pressures in collaboration with the utility water supply department.

4.0 NUMERICAL RESULTS AND DISCUSSIONS

The summary of the results of metering error due to sub-metering and the different factors contributing to metering error in KWDN are presented.

4.1 Quantifying Metering Errors due to Sub-metering

The results of effect of meter separations for 5 apartment blocks, two housing estates and one commercial complex are presented in Table 1.

Table 1: Influence of Meter Separations

Number of sub-meters at Property	Monitoring Master Meter (m^3)	Sum of sub-meters(m^3)	Difference (m^3)	Metering Error (%)
6	152	133	19	12.5
9	676	714	-38	-5.6
32	1312	1138	174	13.3
12	898	625	273	30.4
8	203	213	-10	-4.9
18	504	485	19	3.8
34	1692	1363	329	19.4
18	5960	4276	1684	28.3
Mean				13.5
Standard Deviation				11.9
Standard Uncertainty				4.2

From Table 1, there was meter under-registration on all property sub-meters apart from two. Of the two exceptions, they had booster pumps before the separated meters and this is likely to have increased flow rates to within the higher ranges of meter performance. The metering errors (under-registration) due to sub-metering in Kampala city are estimated at 14±4% of revenue water through the master meters.

In Kampala service area, about 10% of total service connections (or 15,000 connections) bill directly by sub-metering. From Table 1, the average monthly consumption per property is 356 m^3. With the current average tariff (July-June 2010) of 1,800 per m^3 (or 0.82 US$ per m^3), the annual financial loss to the utility as a result of sub-metering is conservatively estimated at UShs 16 billion (US$ 7 million). This excludes the sewerage charge component for apartments with a sewerage connection, cost of new extra meters and metering installations, cost of meter reading and billing administrative costs.

4.2 Impact of Quality of Individual Water Meters on Global Metering Error

The experiment to determine the metering error due to sub-metering was carried out for one month period and the results are summarized in Table 2. The metering error due to sub-metering was 53% before correcting for individual meter errors. The meters were then tested and the individual weighted meter errors computed. The volumes that were registered by these meters were then corrected for the errors and the metering error due to sub-metering was recalculated taking into consideration the individual weighted meter errors. An error of 39% was obtained giving an improvement of 14% on the original error as indicated in Table 2. All the meters were then replaced by highly accurate Class D meters as a control and the experiment was repeated to determine whether the age and quality of the meters also had an impact on the metering error. An error of 20% was obtained implying a further 19% improvement in the error. This therefore implies that the error due to the metering error of the individual water meters was 33% (53% minus 20%) for these premises.

Table 2: Influence of the Quality of Meters and Meter Age

In-Service Meters (Average Pressure at MM = 0.5 bar, private tank elevations = 7 m)				Metering using Class D meters (Control)
	Consumption (m^3)	Weighted Meter Error (%)	Corrected consumption (m^3)	Consumption (m^3)
Master Meter (MM)	19.0	-4.0	19.76	8.3495
Sub meters				
1	0.3	-89.8	0.57	0.4499
2	0.6	-0.7	0.60	0.2132
3	2.0	-89.8	3.80	0.6864
4	4.9	-0.5	4.93	1.8009
5	0.7	-88.9	1.32	0.0006
6	0.5	-89.8	0.89	3.5122
Total	9.0		12.11	6.6632
Difference	10.0		7.65	1.686
Error	53%		39%	20%

These results should however, be interpreted with caution due to uncertainties in occupancy levels, thus likely variation in demand patterns while using in-service and Class D meters during the study period.

4.3 Impact of Pressures on Metering Errors

To determine the effect of pressure on the metering error, the experiment to determine the metering error due to meter separations (using highly accurate Class D meters) was repeated at the same multi-family residential property. The pressure tests revealed that the average water pressure at the property was only 0.5 bars, a value below the minimum pressure required of 10 m (1 bar) at property end point for all users (DWD, 2000). By closing off some supply areas of the water distribution network, pressure to the property was increased to an average of 2 bars. The results of this experiment revealed that the error dropped to -4% implying that the sub-meters were actually over registering by 4%. Increasing pressure increases flow rate through the meters in measuring ranges where they are more efficient.

In an experimental laboratory study carried out in Palermo, Italy to assess the impact of network pressures on water meter error curves concluded that there was no relevant impact of the system network pressures (between 0.5 and 2 atm) on metering error (Criminisi *et al.*, 2009). These differences in conclusions could be attributed to different conditions under which the studies were conducted e.g. elevations of private service tanks in the field.

Since this error value was below 5%, it was concluded that after taking care of both errors due to individual meters and errors caused by low flows due to low network pressures, the volume measured by the monitoring master meter was equal to the sum of the sub-meter volumes. The water balance proposed in Equation 1 actually balanced.

4.4 Influence of Customer Demand Profiles on Metering Errors

To assess the influence of users' profile on metering errors, an analysis of the demand profiles logged simultaneously at all the meters was carried out before the pressure was increased and the results of the percentage consumptions occurring below 15L/h (minimum flow for a 15 mm size, Class C meter, Q_n = 1.5 m^3/h) are presented in Table 3. The results show that an average of 26% of the total consumption occurs below Q_{min} and thus were not recorded by the meters. This affirms that the low pressures caused very low flow rates that could not be recorded by the meters thus contributing to the error due to sub-metering. It is important to note that the percentage of the consumption that was below Q_{min} (26%) is quite close to the metering error that was eliminated (20%) when the pressure in the system was increased.

Table 3: Percentage Consumptions below Q_{min}

Percentage Consumption below Q_{min} = 15 L/hr	
Meter	Percentage (%)
Master Meter	2.4%
Apartment 1	16.0%
Apartment 2	57.4%
Apartment 3	5.1%
Apartment 4	1.7%
Apartment 5	100.0%
Apartment 6	1.6%
Average	**26%**
Standard Deviation	**38%**
Standard Uncertainty	**14%**

It is likely that other factors such as the 'ball valve effect' of the private service tanks could have induced low flows through the meter thus contributing to metering errors (Rizzo and Cilia, 2005; Arregui *et al.*, 2006; Cobacho *et al.*, 2008; Criminisi *et al.*, 2009). The results also agree with recent findings in a study carried out by the Water Research Foundation in the USA on the inability of different quality of meters to measure ultralow flows, causing significant revenue losses to water utilities (Richards *et al.*, 2010).

5.0 CONCLUSIONS AND RECOMMENDATIONS

This paper presents findings from field measurements and observations including laboratory meter testing to assess the impact of sub-metering on revenue water. The influences of three variables on metering errors were examined (quality of meter, residual pressures and user's demand profiles). The results indicate that about 14% of revenue water through the master meter may go un-measured due to sub-metering. These meter errors are amplified by use of private storage elevated tanks to cope with intermittent water supply. The paper main findings are that metering errors due to sub-metering in Kampala city are caused by:

- The individual metering errors of the sub-meters: the quality and type of in-service meters are unable to measure accurately low flows that arise after the master meter
- The low flows induced by low residual network pressures and the ball valve effect of the private elevated storage tanks between the revenue sub-meters and user
- High percentage of water use at very low flows where sub-meters are least efficient

In light of the key findings of this study, the following recommendations and guidelines are proposed to address billing systems based on sub-metering:

i. Utilities must promote and support sub-metering as a policy in the context of promoting water conservation, efficient and equitable use of water.
ii. From the utility perspective of increasing revenue water and cost savings, billing of multi-family apartments and commercial complexes must be based on the master meter as is the practice in other cities such as Paris (Nguyen, 2010).
iii. The property owner or his agent should pass on the charges to the tenants based on actual consumption billing via the sub-meters and an agreed upon allocation formula.
iv. For condominium properties, formation of home owners associations (HOA) to mange

water billing payments (master meter) and allocations (sub-meters) is recommended.

v. Development of National guidelines and policies to regulate the rapidly growing business of sub-metering to protect all stakeholders.

vi. Use of Unmeasured Flow Reducers (UFRs) to enhance accuracy of sub-meters. UFRs have been reported to recover about 94% and 14% of water flows below start-up flow rate and at $_{Qmin}$ for domestic meters (1-7 years) of Class C turbine meters and $_{Qmin}$ of 25 l/h (Fantozzi, 2009).

vii. As a long-term goal, water utilities in developing countries should strive to provide 24 hour water supply of good quality and at sufficient pressures to minimize metering errors due to sub-metering.

viii. Further studies should be carried out on more sub-metered properties to minimize uncertainties due to a small sample space and have more confidence in the results.

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An Innovative Intervention by a Multiplicity of Surface and Underground Interlinked Dams/Weirs, Sand Storages, and Sub-Geological Engineering to Solve Karamoja's Perennial Water Stress

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ABSTRACT

If Karamoja has sufficient water to cause devastating floods that resulted in 50 fatalities and many more homeless in 2007 means that it has the potential to save its situation by turning the disaster around with application of interventions that target self-healing by innovative application of geological science and water engineering at surface and subsurface levels. Karamoja's problems of drought, despite the region being apparently highly "irrigated" with a vast network of (perennial?) rivers/streams, raises a question of what is really wrong? The fact is that most rivers and streams are simply seasonal and a sustainable solution to soil moisture management (retention and strategic utilisation) does not exist.

In this paper, it will be indicated that the water resources of the region are sufficient to sustain a normal non-drought prone lifestyle. The apparent problem is inherently indigenous and hence has more to do with the physical layout of the terrain criss-crossed by numerous stream-mini-valleys that provide quick drainage of any water that would come in contact withit. It is a situation of over drained landscape, which easily explains the devastating floods from rainfall that cannot be described as extreme.

With the intervention suggested, there will be no more devastating floods and instead the potential flood water will be slowed down till it infiltrates thus recharging the surface, underground, and sand storages. These will be a base for building up groundwater reserves that, by capillary action, will raise water even above the stream level thus proving needed soil moisture for normal growth of vegetation.

If these interventions proposed, underground dams, sand storages, and interlinked systems were adopted and executed, they would be engineered locally with minimal external consultation and from three years of the start of the project, visual manifestations of greenery will start occurring.

Keywords: groundwater engineering, floods intervention, subsurface dams, sand storages

1.0 INTRODUCTION

If Karamoja, a north-eastern region of Uganda, could have sufficient water to cause devastating floods that resulted in 50 fatalities and hundreds of homeless, in 2007, then it means that it has the potential to turn around its water stress situation by turning that potentiality into positive reality of applying interventions that target keeping the floods in/on the land to give it time to infiltrate/percolate thus recharging the soil moisture and subsurface storages.

The innovations would be based on geology of the area,engineering and scientific properties of soil, and applied through engineering and hydraulics of sub-surface media for water flow to impede the fast through-flow of gravity waterwhich currently makes it impossible for infiltration to take place. This needs to be planned and executedcorrectlybecause when done, the ease of regular rehabilitation would not be possible.With the known recharge rate at