Can Smart Meters increase billed consumption: Lessons from meter audits and replacements in South Africa

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Abstract

Water metering is an important component in revenue collection and reducing the non-revenue water component in the standard IWA water balance. Municipalities throughout South Africa are faced with a degree of billing or meter management crises with aged or faulty water meters and inaccurately populated billing databases. The challenges are exacerbated by a lack of data integrity in the collection of meter readings and meter details into the billing related databases (Mazibuko, 2013; Crous et al., 2016). Suppliers have started to promote smart metering solutions to address the meter challenges (Maize 2017).

This technology-driven approach is made possible through access to and availability of the internet of things (IoT) as well as the constant need for accurate meter readings and metering data. Smart metering plays an integral part of the smart city concept. Smart cities are broadly defined, pertaining mostly to the application of Information and Communication Technology (ICT) in the urban management space (Lee & Lee 2014). In South Africa, the predominant smart meter is either the prepaid water meter (used for domestic customers) and Automatic Meter Reading (AMR – used for commercial or industrial customers).

The paper synthesises the experience of the authors in recent projects across South Africa, in metropolitan, local and district municipalities. The authors will extract challenges and success factors in the installation and replacement of water meters. The findings relate not only to the physical meter selected, but also on the capacity of the municipality to manage the infrastructure required for the implementation of smart meters.

1. Introduction

Background

Water meters have been used across the world, and particularly in South Africa, for many decades. In South Africa, the water meter has subsequently become an important means of revenue generation for Water Service Authorities (WSAs), which typically refer to local government. The water tariffs in South Africa are typically composed of a fixed-tariff, related to a water connection fee, and a variable tariff, related to the water consumed by the consumer over the billing period. The variable tariff is typically a stepped tariff, or block tariff, which increases as the consumption increases. This block tariff aimed to encourage water conservation and demand management on the customers' property.

The consumption from water meters are used in the development of the water balance (Alegre et al., 2016). The relevant components in the water balance related to metering includes the billed metered, billed unmetered (estimated readings), and unbilled metered and unmetered (government customers or indigent households). These components are monitored in Non-Revenue Water (NRW) reduction programmes as a means of identifying

programmes to increase the billed consumption, which directly reduces the NRW volumes.

The water balance is used in South Africa by the National Treasury to benchmark WSAs, using the indicator “distribution losses,” which is the difference between the Water Purchases and Water Sales divided by the Water Purchases. Water Purchases refers to the sum of all water purchased from Water Boards and water purified directly by the WSA. Water Sales refers to the sum of all water invoiced on the billing system to customers through water meter readings, whether actual or estimate values. The South African norm for water distribution losses is considered between 15 – 30% (National Treasury, 2014), however, this is considered unattainable for most Water Service Authorities within South Africa. The apparent losses have been recorded as high as 40% of all NRW (Crous et al. 2017). Considering the challenge of high distribution losses (or NRW), many WSAs have implemented revenue enhancement strategies which focus on increasing the number and accuracy of customers billed, and increasing initiates to reduce the debt from customer non-payment. Sustained revenue enhancement initiatives require sustained initiatives throughout the customer water meter management lifecycle, as shown in Figure 1-1.

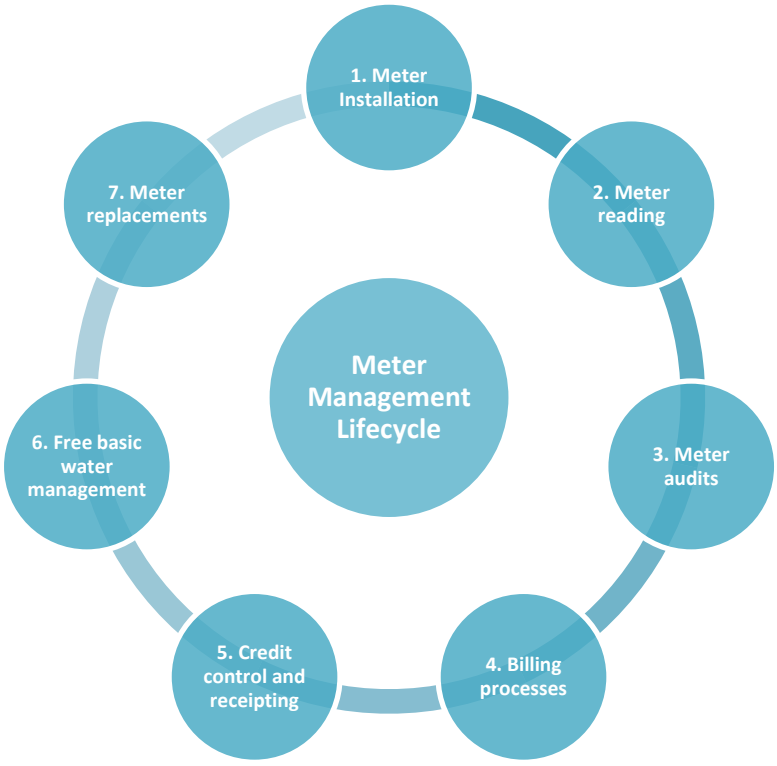

Figure 1-1: Meter Management Lifecycle

Revenue enhancement initiatives increase revenue through enhanced accountability of water from consumers and the reduction of NRW arising from unmetered or faulty connections, inaccurate or inaccessible water meters.

Water Metering Solutions

The main water metering technologies available include:

- Conventional metering;
- Smart metering, including prepaid meters (Token-based or STS-based) and Automatic Meter Reading (AMR) meters.

Conventional water meters are common throughout South Africa. Conventional water meters form the basis of all other water meter technologies, whether prepaid, AMR, or a combination of these. Water meters are typically defined by the mechanism used to

measure the flow of water passing through the meter. The most common type of customer water meter is the mechanical meter, but also include ultrasonic, electromagnetic, or insertion type meters.

The prepaid metering system is supplied as a single unit, consisting of a meter, an automatic valve to open and close the water supply, an electronic water management device which is used to dispense a volume of water for the proportionate monetary credit, and an electronic communication device which the customer interfaces with that indicates the level of credit (or water) available and allows for the customer to "upload" credit to the meter. Customers pay upfront for their water service charges in prepaid metering systems, based on the approved tariff rates. The technology is robust, having an extensive history within South Africa, with pilots dating back to 1992 (Marah et al., 2004). There are two main types of prepaid systems, which include the:

- token-based prepaid system, which are used for domestic customer meter applications; and
- Standard Transaction System (STS)-based prepaid system, which are used for domestic and bulk customer meter applications.

Automatic Meter Reading (AMR) systems consist of domestic or bulk meters (with communication ports or pulse outputs) which are connected to an external electronic communication device that records the meter readings (totalizer) and send the meter readings via an AMR network, whether a radio-, GSM-, or short-range network at the required frequency per minute, hour, day, or month, depending on the requirements of the municipality. AMR systems can be retrofit to existing meters, or are integrated into the meter itself. The introduction of the AMR system into the conventional domestic meter has made the use of electromagnetic metering a practical option in domestic metering applications.

AMR solutions can also make use of drive-by radio based data collectors and collect the meter readings from all meters, and transfer the data to the meter management system. The typical installation of an AMR communications network (Figure 1-3) includes the following components:

- Repeaters – used to transmit the meter readings from the meters to the collectors;
- Regional Collectors – used to send the meter reading information via GSM networks and transfers the data onto the database in the meter management system; and
- Meter Management System – used by the WSA to manage the information transmitted from the customer meters and input into relevant systems (such as the billing system).

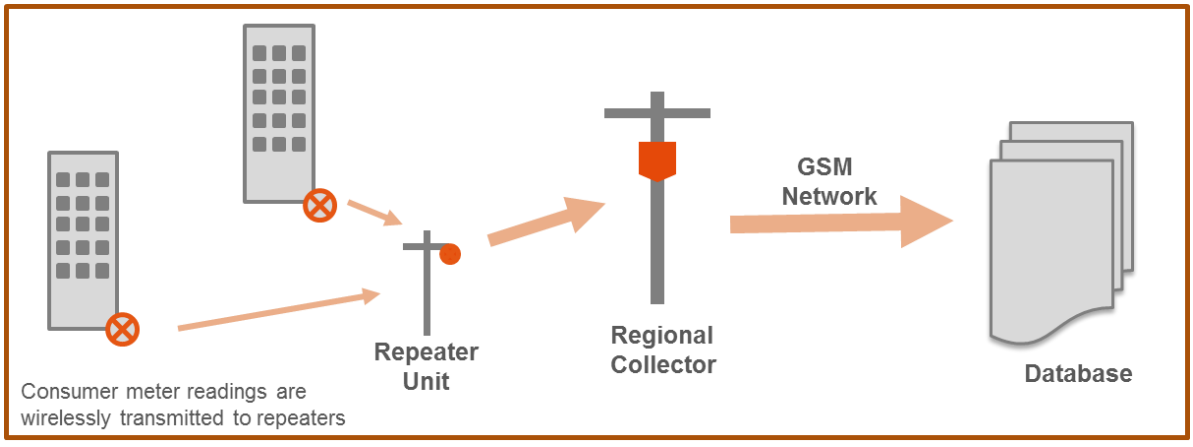

Figure 1-2: Typical AMR system overview

Both AMR and prepaid metering systems typically use third-party vendors providing solutions which capture the relevant information and present it to the municipality.

Water Meter Management

The roles and responsibilities for water meter management are distributed between the finance, customer, and technical (engineering) departments within a municipality or Water Service Authority, as indicated in Table 1-1.

Table 1-1: Typical roles for meter management

Metering Process	Requests Services	Implements Services	Approves Services	Uploads onto Billing System
1. Meter Installation	Finance Dept. (new connection)	Technical Dept.	Technical Dept.	Finance Dept.
2. Meter Reading	Finance Dept.	Service Provider (to Finance Dept.)	Finance Dept.	Finance Dept.
3. Meter Audits	Finance Dept. (Meter Readings) Customer Dept. (Call Centre)	Technical Dept. Service Provider (to Finance Dept.)	Finance Dept.	Finance Dept.
4. Billing Processes	Finance Dept.	Finance Dept.	Finance Dept.	Finance Dept.
5. Credit Control	Finance Dept.	Debt Collectors	Finance Dept.	Finance Dept.
6. Free Basic Water Management	Finance Dept.	Technical Dept.	Finance Dept.	Finance Dept.
7. Meter Replacement	Finance Dept. (Meter Readings) Customer Dept. (Call Centre)	Technical Dept.	Technical Dept.	Finance Dept.

Meter reading is typically conducted monthly in South Africa on the regular basis defined within the water bylaws of the WSA. The meter readings are typically considered a financial task as the information is used solely for billing purposes. The method for meter reading varies between WSAs, using either paper-based or electronic data capturing methods. Meter audits are performed reactively or proactively to ensure the billing system has the correct meter and customer information, and to ensure that the meter readings are correct. Billing processes are conducted by the finance department using a centralised municipal billing system which calculated the total service charges, rates and taxes for each customer. Credit control processes include debt collection from non-paying customers. Due to water being a basic human right in South Africa, it is not always possible to disconnect water services and WSAs often restrict the flow to the customers. South Africa has a Free Basic Water policy whereby all indigent customers within South Africa are legally provided with a basic water allowance of 25 litre/capita/day for a family of eight (DWAF, 2002). The policy requires that free basic water volumes are metered by the WSA. This has prompted several municipalities to consider prepaid water meters for indigent customers to curb excessive water usage from indigent customers,

with indigent customers paying for additional water volumes. However, such charges are often written off as bad debt.

Meter reading enables feedback on the operations of the meter and these monthly reports are also used to generate works orders for meter replacement, which is performed by the technical departments. Mechanical water meters specifically experience degradation over time (Stoker et al., 2012), which result from mechanical wear, poor water quality, abnormal water velocities, and incorrect meter sizing or installation. Thus, aging makes water meters can be attributed to revenue losses (Shields et al., 2012).

2. Methodology

Project Based Experience

The data presented are based on the assessment of seven WSAs within South Africa. The projects were based at three Metropolitan Municipalities (M), two Local Municipalities (L), and two District Municipalities (D). The overview of the WSAs' characteristics, based on their annual financial statements for 2015/16 are presented in Table 2-1. The total revenue for all WSAs, except for D-1 and D-2, include (1) property rates, (2) electricity service charges, (3) water service charges, (4) sanitation service charges, (5) refuse removal service charges, and (6) other revenue sources.

Table 2-1: Water Service Authority characteristics (National Treasury, 2018)

Category	M-1	M-2	M-3	L-1	L-2	D-1	D-2
Water Revenue (% Total Revenue)	16.3%	13.7%	18.7%	22.3%	14.4%	79.7%	62%
Sanitation Revenue (% Total Revenue)	9.19%	4.6%	6.6%	10.6%	4.2%	20.3%	38%
Water & Sanitation Revenue (% Bulk Purchases)	52.1%	88.9%	49.8%	70.5%	53.8%	164.7%	231%
Indigent Households (%) – *Census 2011*	35%	39%	40%	35%	50%	57%	52%

3. Findings

WSA M1 – Meter Replacements

The works at WSA M1 included performing the meter management functions and managing the contractors appointed to perform the meter installations or replacements. The relevant tasks performed included:

- Managing the relocation of water meters from inside the customer property onto the servitude to allow for accurate meter reading
- Ensuring that the new meter details are formatted correctly for uploading onto the billing system

The replacements included not only the relocation of meters onto the servitude, but also installing the meters in above ground boxes ensuring that the meters do not become buried or 'misplaced' in the future and making the meters identifiable by the meter readers and operation and maintenance teams. During 2013 to 2017, 50 000 meters were replaced. The benefits associated with the large-scale program was that the meter became visible and accessible by the meter readers, and reduced time required on site for the maintenance, which resulted in reduced unbilled metered consumption from unlocated, estimated meters. The estimated return on investment was calculated at two

years for domestic meters. Indirect benefits were that customers became conscious of their water usage and on-property leaks.

WSA M2 – Meter Installations and Replacements

The works at WSA M2 included performing meter management functions and managing the contractors appointed by the municipality to perform the meter installations or replacements. The WSA required all customer meters be replaced within 48 hours where there were significant leaks at the meter or no water available on the property. All new meter connections and aged meter replacements needed replacement within a 5-day period.

In a sample period, 17 000 meters earmarked for replacement, of which 35% were estimated for less than one year and 96% were estimated for less than five years. The replacements were predominantly related to meter inaccessibility (65%) and faulty meter (20%) on average.

The findings from site indicated that there were several properties which extended their boundaries over the municipal servitude, and the meter was not accessible, or where the meter was unlocatable due to road surfaces paved over the meters. This required municipal departments, such as the building inspectors, roads departments, or other capital project departments, to understand the importance of metering as a source of revenue and respond accordingly where the meter operations were affected. The municipality had a general resistance to battery operated meters, as batteries were found to frequently fail within the first five years.

WSA M3 – Meter Replacement and Audits

The works at WSA M3 included providing strategic support to the municipality's Non-Revenue Water and Water Demand Management initiatives. The relevant tasks performed included:

- Customer water meter audits approximately 15 638 properties
- A review of the billing system processes (Figure 1-1), as the municipality identified that it took approximately 12 -24 months to upload new water meter information onto the billing system.

The municipality was faced with a challenge in meters not being read by the external service provider appointed to read the meters monthly. A meter audit was performed on approximately 8% of the municipal customers. The two main categories of remedial actions were identified as billing remedial actions (Table 3-1) and refurbishment actions (Table 3-2). Table 3-1 indicated a significant number (34%) of customers on the billing system had incorrect data recorded, and 26% of customers were not recorded on the billing system.

Table 3-1: Billing remedial actions required from meter audit at M3

Meter Billing System Action	Total Audited
Add Customer to Billing System	4 037
Update Meter Serial on Billing System	5 200
Update Property Location on Billing System	200
No Action	6 201
Total Meters Audited	15 638

The refurbishment actions included installing a new meter at customer properties where no meter was installed (3%), and replacing meters found to be faulty, damaged or

leaking (7%). The impact of construction works burying meters are noted in requiring contractors to locate the meter (6%).

Table 3-2: Refurbishment actions required from meter audit at M3

Physical Meter Action	Total Audited
New meter to be installed	428
Replace Meter Installation	1 036
Replace Meter Fittings (valves or pipework)	87
Contractor to Expose Located Meter	230
Contractor to Locate and Expose Meter	779
No Action	13 078
Total Meters Audited	15 638

The shortcomings of the municipal meter management processes meant that the municipality had less meters added onto the billing system as the replaced meters were not being updated onto the billing system. The main finding was the base data on the billing system was not correct. This was due to the methods used to capture the details from site, and lack of quality control measures.

WSA L1 – Meter Readings

The works at WSA L1 included the development and implementation of a Water Conservation and Demand Management Strategy. The relevant tasks performed included:

- Review of billing system and development of annual water balances

The municipality performed the meter reading services using internal staff, using paper-based methods which took time and had limited quality control resulting in increased customer complaints, and reduced customer satisfaction. The municipality consistently read approximately 19% of the meters within the municipal area (Figure 3-1). A significant reason was a dispute between the Water Service Provider and the WSA, as to who was responsible for billing customers in a town having 42% of the customers, and the WSA not billing them.

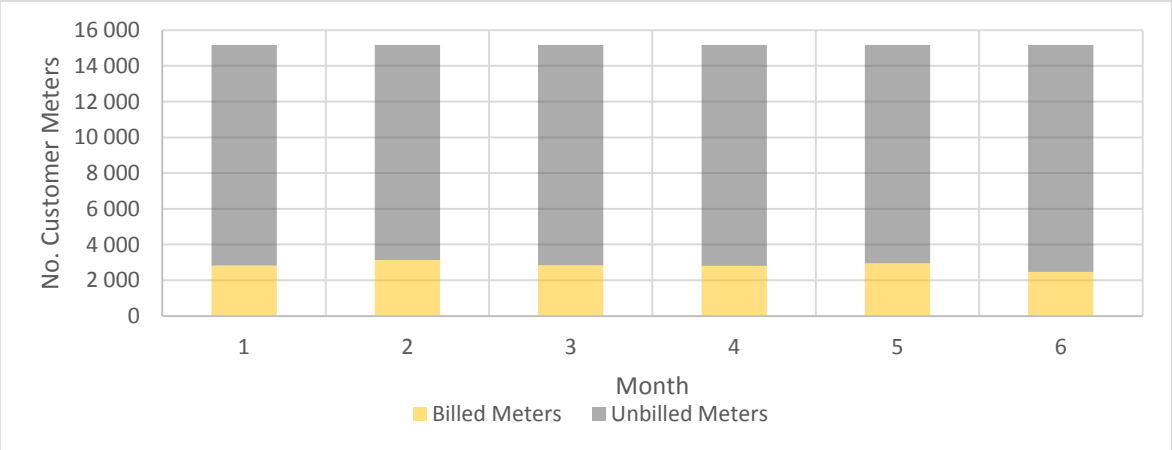

Figure 3-1: Number of Meters Read over Assessment Period at L1

The main recommendations were to audit meters not on the billing system, and implement electronic reading processes to upload readings directly into the billing system.

WSA L2 – Meter Installation, Reading, Replacement and Audits

The works included the development of a Water Conservation and Water Demand Management Strategy for the WSA and to implement the identified initiatives. The relevant tasks performed included:

- Review of billing system and development of monthly water balances
- Installation of AMR system for industrial and commercial consumers

The water meters at the municipality were read monthly, with a service provider appointed to by the finance department to perform the meter reading services. The meter reading reports were used by the technical department to prioritise meter replacements. There was a bottleneck in the issuing of works orders by the Finance Department and updating the information onto the billing system, which resulted in the meter not being replaced within the next three billing cycles and the replaced meter not being uploaded onto the billing system, creating multiple works orders generated and estimated readings. The project found that monthly meters read decreased (Figure 3-2), with 26% of the customer meters not read. There was a high percentage (18%) of customers estimated. The major challenge for meter estimates was due to were inaccessibility (61%), with secondary challenges due to billing database inaccuracies (27%) and physical meter faults (12%). Accessibility was due to the water meter being located within the customer property which is gated. It was recommended that an organic replacement of existing meters to the outside of the property gate together with strategic replacement and relocation of meters.

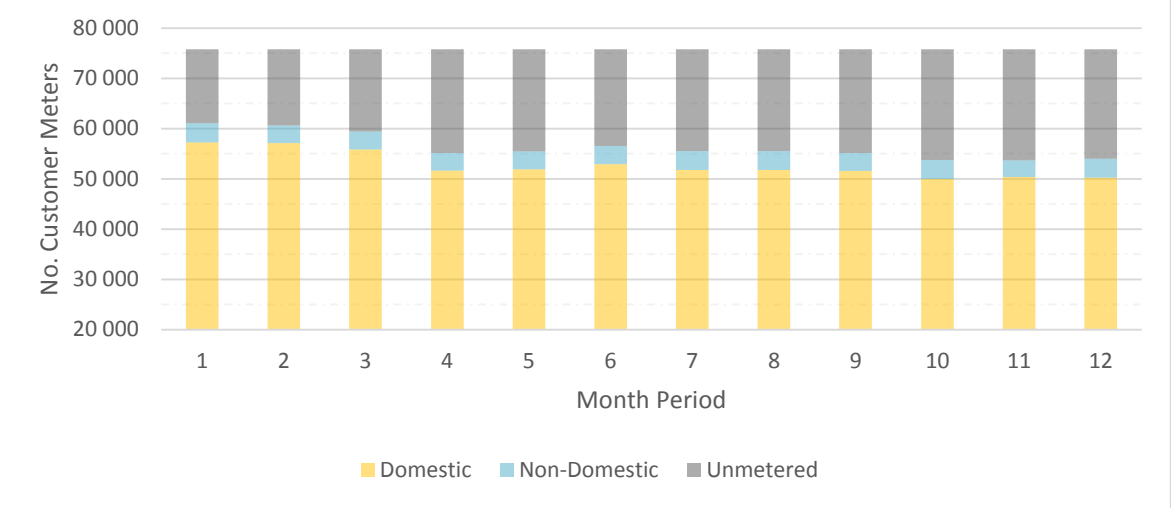

Figure 3-2: Number of Meters Read over Assessment Period at L2

The review of the billing system identified that the ~2 000 prepaid meters installed 10 years prior by the WSA were not generating revenue for over a year due to the meter battery failing and the WSA not having the required operations contract with the service provider in place to ensure the sustained use of the system. There was another low-income area where the WSA was installing ~3 500 prepaid water meters to to reduce the demand to the customers and increase the revenue collection. However, findings indicated high levels of NRW, with customers bypassing their meters and were using hydrants to obtain potable water. The vendor system did not integrate with the billing system, and the water balance required obtaining multiple billing datasets to report effectively on operational aspects.

The technical department installed an AMR system to service ~170 large customers within an industrial area to increase revenue collection and reduce data handling errors. The main benefits of the project were that customer complaints could rapidly be assessed by reviewing the AMR system and identify illegal connections. However, a significant challenge was in the updating of new meters onto the billing system due to poor data on the billing system. The AMR system was also not used for billing purposes and the meter were read manually. The O&M teams also replaced meters without notifying the AMR service providers, which required meters to be audited regularly.

WSA D1 – Customer Affordability

The WSA D1 aimed to implement an appropriate metering solution that would increase revenue collection and monitoring water services. The relevant tasks performed included:

- Reviewing the ability of the customers to pay for services
- Reviewing the revenue collection and debt collection

A key element of the project was assessing the customers' ability to pay the designated water tariffs. Non-payment are typically related to (1) administrative reasons – i.e. incorrect billing, poor meter management, lack of institutional capacity; and (2) socio-economic reasons – i.e. the inability of customers to pay for services due to their economic status. It was found that 57% of the population within the WSA was classified as indigent, with an annual income less than $ 2 352 (StatsSA, 2012). The indigent register had significantly less than the number of indigent households within the WSA, which meant customers could not pay accounts. Indigent customers were found to also have average water consumption higher than the free basic water allowance of 6 kL/household/month. This was exacerbated by the community's resistance to pay due to unreliable services, resulting in a vicious cycle.

The provision for bad debts as a percentage of revenue from water services grew from 66% in 2013 to 123% in 2016, indicating the municipality had growing expectations for non-payment and customers had a deteriorating ability to meet their payment obligations. Most of the debt (77%) was due to domestic customers.

WSA D2 – Meter Installation and Billing Processes

The WSA D2 had approximately 60 000 customer meters operational, with over 20 000 prepaid (smart) meters. The relevant tasks performed included:

- A review of the prepaid metering system to assess value for money and to identify any bottlenecks in the adoption of the prepaid metering system within the municipality.

One of the challenges the WSA faced was lack of project management and quality control measures from procurement to management, resulting in information lost between stakeholders. Meters were often procured but installed after the warrantee expired. The WSA's drought conditions resulted in intermittent supply, which damaged the prepaid automatic valve's ability to operate causing malfunction. An audit of over 7 000 meters indicated that approximately 4% of the installed prepaid meters were leaking and needed repairs within one year of installation.

Despite the third-party prepaid vendor system working effectively, it was found that approximately 55% of all prepaid meters were not linked to the billing system. This had nominal to no material impact on the revenue collected through the third-party system, it was expected to have an impact on the revenue collection from fixed tariffs for water connections and sewerage and treatment, as these were not included in the prepaid tariffs and the WSA had to generate separate invoices for the fixed tariffs. This also resulted in the WSA not being able to audit meter readings or the efficacy of the prepaid metering system. The investigation found that there were high levels of non-payment from the prepaid meters due to a combination of meter, system, and customer related issues. Meters were found to not always restrict water for non-payment due to automatic valve failures. The location of vendors selling water credits must be implemented following guidelines or bylaws for customer accessibility.

4. Discussions

The project experience covered all aspects of the meter management lifecycle (Figure 1-1). The results indicated that meter management is a complex system made up of various stakeholders which require integrated systems and processes to ensure that the meters generate revenue based on the actual consumption of the customers. The

predominant metering solution used in South Africa is the conventional water meters (Lillian, 2017), due to the economic efficiency of conventional meters (Mwangi, 2017).

The experience indicates that the meter, independent of technology, requires sustained operations by various stakeholders to ensure that the meter operations are sustained. The meter management lifecycle also requires an integrated design philosophy to provide directive approach for the systems and technologies used for metering and monitoring and evaluation. Quality control was an important aspect in the management of the meters from installation to accurate billing system data, and correct sizing of the meters (Brinkley n.d.). The WSA must model the correct tariff structure for prepaid metering to include the fixed and variable tariffs appropriately into the prepaid metering tariff. The billing crises faced within South African municipalities was highlighted by Mazibuko (2013) and the effect of such negatively impacted the sustained ability of the municipality to located and read the customer meters (Crous et al., 2016). The results indicated that the sustained use of meters requires basic management principles including standard guidelines, bylaws, and monitoring at each stage within the meter management lifecycle. The metering technology should be based on the problem that needs to be solved specifically within the WSA. Lillian (2017) stated that most WSAs made use of smart meters for debt management and cost recovery. Prepaid meters can reduce the customer debt; however, the WSA must monitor the services continuously to ensure that the customers are paying and are not bypassing the meters and the metering system is operational. The prepaid meter battery lifespan must be considered as it is reduced with excessive opening and closing of the automatic valve, and communications to and from the meter. It is essential that prepaid meter rollouts are prioritised not only to areas where payment is not received for services, but also consider affordability and capacity of the areas to maintain the prepaid metering system, which includes the type of service providers and vendors used, and the location to the customers.

AMR meter systems which collect the readings must be integrated into the billing system to ensure that the readings are used and that the WSA has sufficient staff for monitoring. Despite the accuracy benefits of the AMR meters, it is important to note that the customer is typically responsible for on-property leak repairs. Therefore, the AMR system may add more value to the customer, with the WSA encouraging the customers to monitor their consumption through stepped (block) tariffs, or other mechanisms. AMR systems are considered more valuable to the WSA in the monitoring of their water supply zones (DMAs). The challenges related to smart meters have been noted to be due to high capital cost of the meters, high failure rate of the electronic devices, communication challenges or interruptions, and social acceptance of the systems (Lillian, 2017).

5. Concluding Remarks

Smart meters such as Automatic Meter Reading or Prepaid metering technologies can be enablers for enhanced revenue collection where there is an enabling institutional environment. The complex processes related to the management of the meters requires WSAs to consider all aspects of the institutional environment prior to the adoption of smart metering technologies and systems for the perceived benefits to be realised. This requires stakeholders buy-in, specifically the operation and maintenance staff within the technical department, finance department, and new capital projects where water reticulation and meters are rolled out to customers, as well as the customers and relevant service providers supporting the WSA. The metering technologies themselves solve specific metering challenges, such as debt collection and water restrictions for non-payment, using prepaid meters, and reduced metering inaccuracies for AMR meters.

Smart metering technologies are not a replacement for the management processes, such as quality control measures and monitoring that all metered consumption is accounted for in the billing processes is maintained. The WSA should also adopt guidelines for meter installations and replacements, and manage turnaround times within

the processes using key performance indicators to ensure value for money is achieved. A key enabler for reducing unread meters was replacing below ground water meters with above ground water meters and relocating customer meters from inside the customer property onto the municipal servitude. Where more than one metering system is implemented, it is recommended that a meter management system be implemented to integrate the various systems to provide centralised, spatial and historic consumption trends of customers. Spatial mapping of meters is essential for both meter reading and for monitoring and evaluation purposes.

Finally, the use of smart meters requires extensive capital to rollout within the entire supply area, through retrofitting or replacing the existing meters and therefore the rollout of smart meters is not considered to be implemented overnight but will require systematic installations where required. Smart meters also have increased operation and maintenance costs and require appropriate skills to ensure the systems are sustained. The National Treasury's Municipal Public-Private Partnerships Guideline (National Treasury, 2008) can be used to as a framework to determine value for money and how to implement smart metering systems. Other arrangements, such as performance-based contracts or funding from internal revenue or national grants can also be considered for funding such projects.

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