EXPERIENCES WITH ADVANCED WATER METERING IN SOUTH AFRICA

The State-of-the-Art in Advanced Metering Technology and Application

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

INTRODUCTION

Advanced water metering is part of a larger movement towards smart networks and intelligent infrastructure. In high-income countries, advanced metering technology is generally focused on the need to obtain meter readings without human intervention. However, in South Africa and other developing countries, advanced water metering (specifically in the form of prepaid meters or water management devices) is driven by the need to provide services to previously unserved communities and deal with the problems caused by rapid urbanisation.

For this study, conventional water metering was defined as systems using water meters that display their readings on the meter itself, and advanced water metering as systems that add additional components or functionality to the system.

Advanced metering has the potential to provide substantial benefits if appropriately applied. However, compared with conventional metering, these systems are expensive and complicated and often rely on technology that is still being developed. Advanced metering systems therefore carry a higher risk of failure, poor service delivery and financial losses, unless implemented with careful design and thorough planning.

The main aim of this study was to develop guidelines for successful implementation of advanced water metering technology in South Africa, based on case studies implemented in different parts of the country.

The case study evaluations considered four areas: technical, environmental, social and economic. The technical evaluation was based on the systems complying with relevant national metering standards and good metering practice, the environmental evaluations on battery disposal and water savings and the social evaluation on broad socio-economic indicators. It should be recognised that social issues are particularly complex and that no general evaluation framework can accurately predict whether an advanced metering system will be accepted by a particular community.

The economic evaluations were based on reduction of the current system cost and not absolute values. Economic performance indicators included the effective surplus (income minus expenses averaged over the meter service life) and capital repayment period.

CASE STUDIES

Five case studies were evaluated: a modelling study of prepaid meters in a typical low-income area, water management devices in Cape Town, in iLembe District Municipality in KwaZulu-Natal, in Olievenhoutbosch in Tshwane, and automatic meter reading in the Epping industrial area of Cape Town. Key lessons learned from the case studies are as follows:

- *Prepaid Metering in a Typical Low-Income Area*. Typical parameter values were selected for a low-income system with 1000 connections, and used to investigate the economic feasibility of a prepaid metering scheme. It was found for the typical case that prepaid meters were economically feasible with a capital repayment period of 32 months. However, conventional meters performed much better than advanced meters (capital repayment period of 4.4 months) even though a significantly lower payment rate was assumed. In addition, the financial risk associated with the prepaid meters was much higher than that of conventional meters. A sensitivity analysis showed that advanced water metering is especially unsuitable in communities with high existing payment rates, low water consumption (e.g. using the free basic water allowance only) and when advanced meters have high failure rates.

- *Water Management Devices in Cape Town.* The City of Cape Town has been using water management devices to assist low-income consumers to manage their consumption since 2006, and 160 000 devices have been installed. The water management devices have resulted in substantial savings in water consumption, but these meters were not found to be economically feasible. Thus the additional cost of implementing advanced metering may be considered as the price the City of Cape Town is willing to pay to reduce consumption levels.
- *Water Management Devices in iLembe Municipality*. Water management devices were installed to improve revenue collection and reduce debt, but none of the benefits anticipated were realised. In particular, the scheme was found not to be economically feasible. A considerable number of challenges in running the new advanced schemes were faced by the municipality, calling into question the durability of the different advanced metering products and their technology. These issues further emphasised the need for feasibility studies before advanced meters are installed.
- *Water Management Devices in Olievenhoutbosch.* Some benefits were obtained from the advanced meters, in large part due to the lower rates for users on the prepaid compared to conventional schemes. These rates endeared the prepaid scheme to the community. Proprietary vending issues were one of the distinct challenges in the scheme. The need to train sufficient skilled municipal personnel to handle any problems with the scheme was also a major factor. The water management devices were not found to be economically feasible. In addition, it was found that using conventional meters instead of advanced metering would have made the scheme economically feasible even at much lower payment rates.
- *Automatic Meter Reading in the Epping Industrial Area*. The focus of this pilot study was on industrial and not domestic consumption as in the other case studies. The major distinctions were that social feasibility didn't play a big role and individual consumption for this scheme was much higher. However, in spite of the increased consumption rates, the advanced meter reading system was found to be expensive and operational deficits were incurred. Thus, the pilot study was discontinued and the area was returned to conventional metering.

KEY FINDINGS

It was observed that the challenges in using advanced meters generally outweighed the benefits. Alternatives that could meet the primary objectives of these advanced meter installations should therefore be examined, with advanced metering viewed not as a goal, but as part of many alternative solutions to a particular problem. There may be cases where the additional cost of advanced metering is justified by benefits such as reduced consumption, but it is unlikely that advanced metering itself will be economically feasible.

Most case studies revealed that community involvement is critical in changing attitudes towards advanced meters and therefore extensive stakeholder engagement must be carried out before the roll out of any new scheme.

It was also realised that there are currently a number of policy issues that need to be clarified in order to better guide future advanced metering upgrades in South Africa. These include uniform communication and payment system standards that will protect municipalities from being tied in to one supplier and encourage competition, qualification standards for staff supporting advanced metering systems, legality of advanced meter records for billing purposes and labour reallocation.

Although the cost of advanced metering is high, its advantages in terms of leak detection and consumption monitoring make it an attractive option on bulk and zonal meters.

Since the technology of advanced meters is still developing, strict procurement specifications should be set in order for utilities to obtain more durable metering products with minimal failure rates. Finally, it is recommended that suppliers are bound by medium- and not short-term performance guarantees to ensure that municipalities don't carry the risk for inherently flawed products.

CONCLUSION AND WAY FORWARD

The entire project lifecycle should be considered when determining the feasibility of advanced metering, including product selection, project implementation and operation and maintenance. This will enable utilities to make more realistic projections of economic, environmental, social and technical benefits, if any, before the scheme is put into place.

Setting performance objectives is key to both selection of appropriate advanced meters to meet a utility's needs as well as determining their feasibility using the evaluation framework developed. Some objectives may affect each other; for example, environmental benefits such as consumption reduction may reduce economic viability. It may, therefore, not be possible to meet all objectives and that may be acceptable in cases where one objective is traded off against another.

It is critically important that proper engineering planning is conducted, using tools like the ones developed in this project, before an advanced metering project is specified. Just as important is continual monitoring of the system's performance and comparison of actual to projected performance. Suppliers should be required to carry the risk of their products malfunctioning on a medium-term (3 to 8 years) basis to ensure that this is not borne by the public.

The evaluation framework presented in this report offers guidelines that should be adapted to each situation by competent technical staff. Use of a sensitivity analysis once the evaluation model has been developed will improve the robustness of decisions made.

Taking into consideration the overall benefits gained compared to the challenges faced in most of the case studies above, it is critical that utilities approach advanced metering as part of many alternative solutions to a particular problem, not as a goal in itself.

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ABBREVIATIONS

AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
CDMA	Code-Division Multiple-Access
CoCT	City of Cape Town
CoT	City of Tshwane
DWD	Domestic Water Dispenser
FBW	Free Basic Water
GSM	Global System for Mobile communication
HAN	Home Area Network
LAN	Local Area Network
MIU	Meter Interface Unit
NIST	National Institute for Standards and Technology (United States)
NRW	Non-revenue Water
PLC	Power Line Communication
RF	Radio Frequency
SABS	South African Bureau of Standards
SEP	Smart Energy Profile
STS	Standard Transfer Specification
UIU	User Interface Unit
UMTS	Universal Mobile Telecommunications System (UMTS)
USC	Utility Systems
WAN	Wide Area Network
WBKMS	Web-based Knowledge Management System
WCDMA	Wideband Code-Division Multiple-Access
WMD	Water Management Device
WMN	Wireless Mesh Network
WRC	Water Research Commission

1. INTRODUCTION

1.1 Background

Advanced water metering is part of a larger movement towards smart networks and intelligent infrastructure. In some parts of the world, advanced metering technology is driven by the need to obtain meter readings without human intervention, whereas in South Africa and other developing countries, advanced water metering (in the form of prepaid meters or water management devices) is driven by the need to provide services to previously unserved communities and deal with the problems caused by rapid urbanisation.

Advanced metering has the potential to provide substantial benefits, if appropriately applied. However, compared with conventional metering, particularly in developing countries, these systems are considerably more expensive and complicated, and often rely on technology that is still being developed. Advanced metering systems therefore carry a higher risk of failure, poor service delivery and financial losses unless the system is implemented with careful design and thorough planning.

The main aim of this study was to develop guidelines for successful implementation of advanced metering technology in South Africa, based on case studies from different parts of the country. Case studies are reports on projects and schemes that have been previously implemented to solve a certain problem or improve on the current situation. They are, therefore, very useful tools for assessing the success or failure of a project or scheme.

This report is a product of a research study commissioned by the Water Research Commission and called "Experiences with Advanced Metering in South Africa".

1.2 Defining Advanced Metering

Water meters have been used in South Africa for several decades, with the development of advanced metering systems resulting in different terms being introduced into the market. These terms are often not clearly defined or consistently applied and thus it is necessary to clearly define the terms used in this report:

- ***Conventional water metering:*** the system uses water meters that display their readings on the meters themselves and have no additional functionality. Meter-reading data from conventional water meters is obtained by physically visiting each meter and taking a manual reading.
- ***Advanced water metering:*** the system uses water meters which have additional components and functionality over and above conventional water meters. Advanced water metering systems often require additional infrastructure, such as specialised communication systems or tokens to operate. Added components may allow the meter to perform functions such as processing and storing data, sending and receiving signals from a remote station and automatically shutting off the water supply using a valve.

It is also useful to distinguish between two types of advanced water meters based on whether they include an automatic valve or not.

- ***Water management devices*** are advanced meters with a valve that can be automatically activated by the meter to shut off or limit the water supply. These meters are essentially prepaid water meters and are the later generation of meters developed from prepaid meters.
- ***Smart water meters*** are advanced meters that cannot control the flow to the consumer, but include advanced technology to communicate the meter reading to the municipality and/or consumer.

1.3 Layout of This Document

A case study of a typical low-income area, and four field case studies, are used to analyse the current status of advanced metering projects in South Africa. The benefits, challenges and lessons learned from these case studies were used to formulate some of the guidelines for selecting and implementing advanced water metering projects, provided in Report 1.

The document is structured as follows:

- CHAPTER 2: A few notable international and local case studies in advanced water metering are summarised in this chapter.
- CHAPTER 3: A case study on prepaid metering in a typical low-income area is described here with a sensitivity analysis conducted to investigate the impact of different parameters on the feasibility of the system.
- CHAPTER 4: A case study on water management devices in Cape Town.
- CHAPTER 5: A case study on prepaid meters installed in the iLembe District Municipality of KwaZulu-Natal.
- CHAPTER 6: A case study on prepaid meters installed in the Olievenhoutbosch area of Tshwane.
- CHAPTER 7: A case study on automatic meter reading in the Epping industrial area of Cape Town.
- CHAPTER 8: An overview of the lessons learned from all the case studies.
- APPENDIX A: A guide to using the spreadsheet-based evaluation framework that is provided as a separate file. The different input fields of the evaluation framework are discussed and typical ranges for these parameters based on published literature, interviews with experts and case studies.
- APPENDIX B: The evaluation framework's application to the typical low-income area, and four field case studies, is presented, and the results of each application are discussed.

1.4 Additional Resources

This document aims to provide field experiences of advanced water metering schemes in South Africa, and can be used in conjunction with Report 1, titled *Guidelines for the Selection and Evaluation of Advanced Water Metering Systems*. However, several other sources are available that may be consulted for more information and guidance on advanced metering.

The additional sources most relevant to this study are three MSc dissertations from the University of Cape Town Department of Civil Engineering. The first two deal with advanced water metering in low- and high-income communities, and the third with South African case studies. These dissertations may be downloaded from the University of Cape Town website.

- Malunga, M. (2017). Advanced water metering and its application in low-income communities.
- Mburu, M. (2017). Advanced water metering and its application in high-income communities.
- Ngabirano, L. (2017). Advanced water metering case studies in South Africa.

The following relevant reports are available from the Water Research Commission:

- Van Zyl, J.E. (2011). Introduction to Integrated Water Meter Management.
- Van Zyl, J.E. (2014). Introduction to Operation and Maintenance of Water Distribution Systems.

The following report written for the World Bank Group provides an excellent overview of the application of prepaid water meters in Africa:

- Heymans, C., Eales, K. & Franceys, R. (2014). The Limits and Possibilities of Prepaid Water in Urban Africa: Lessons from the Field, Washington DC: World Bank Group.

2. NOTABLE PAST CASE STUDIES

A brief review of some international and South African experiences with advanced meters is provided in this section. The different areas' experiences with these meters show both the multitude of functions and improvements that can be achieved with advanced meters as well as the significant challenges they pose, particularly when implemented in low-income areas. Considerations prior to implementation should therefore be made on a case-by-case basis, as will be inferred from the different case studies below.

2.1 Operation Gcin' amanzi in Soweto

This case study summary is based on a report by Singh and Xaba (2006).

Rand Water Board supplies water primarily to Gauteng, and to the North West up to Rustenburg. In 2003, Johannesburg Water, one of its big clients, was delivering 1/3 of its purchased water to Soweto, a township in the south-west of Johannesburg, with a population of about 1.3 million people. Of this water, 70% was unbilled and, therefore, in an attempt to conserve water and reduce the volumes of non-revenue water (NRW) in Soweto, Operation Gcin'amanzi was started in July, 2003. A total of 170 000 properties were expected to benefit from this project which included installation of prepaid meters, and other interventions like plumbing fixture repairs on private properties, upgrading of individual connections and upgrading of network pipes in the area. The prepaid meters were programmed to dispense the 6 Kl per month free basic water (FBW) allocation and an additional amount of water depending on the consumer credits purchased.

This project was considered successful as it achieved an 83% reduction in bulk water, and generated about R13 million in revenue from the purchase of water above the FBW amount. Debt write-offs for prepaid meter recipients and other lessons in soliciting community buy-in, improving the technical standards of prepaid meter units purchased to minimise failure rates, and tariff application in the use of these meters were among lessons learned from this project. These lessons were used to ease the roll-out process of these prepaid meters in other parts of Gauteng and South Africa.

2.2 Klipheuwel Prepaid Metering

This case study summary is based on a report by Kumwenda (2006).

Klipheuwel is a low-income community situated north of Durbanville, in the Western Cape. A prepaid metering pilot project was launched here in 2001 by the City of Cape Town to deal with the city's problems of inefficient dispensation of FBW, poor payment levels for water services and rapidly increasing water demand and wastage. Of the 147 households found in the formal housing area of Klipheuwel, 138 were fitted with prepaid meters programmed to dispense 6 Kl of water per month, an additional 200 litre emergency reserve and, thereafter, an amount purchased by the consumer. This pilot, if successful, was to be a prelude to similar implementation in Bishop Lavis, Netreg and Richwood. Unfortunately, the City abandoned this project in 2005 and reverted back to the old conventional system. The technology was found to be largely accepted by the community for its ability to dispense the FBW allocation as well as enable them to manage consumption and therefore control demand. Its abandonment therefore speaks to issues on the municipality side; possibly the economic infeasibility of maintaining these meters, which had significantly high failure rates, especially in light of reduced consumption to FBW allocation and therefore reduced revenue for the utility to offset these maintenance costs.

2.3 Nkomazi Prepaid Meter Project

This case study summary is based on a report by Marah et al. (2004).

Nkomazi Municipality is located approximately 350 km east of Gauteng, and consists of five local councils with an approximate population of 430 500 residents. The municipality had accrued debt of about R1.4 million from 1996 to 1998 and yet many residents were finding the flat rate of R50 per month (regardless of consumption) unaffordable. Prepaid meters were therefore installed in 1 374 households, most of which belonged to municipal staff, in an attempt to find a more affordable option to the flat-rate billing system in use, and therefore recover water costs.

On installation, a high failure rate of about 40% of installed units was experienced, forcing the municipality to try about four different metering technologies in an attempt to cope with, and alleviate, these failure rates. In spite of this, however, the community was accepting of the system and a significant reduction in consumption from about 40 kl per household to 7 kl per household was observed. Furthermore, financial benefits were achieved with the reversal of an annual loss of about R540 000 to an average income gain of about R320 000. With a more technically reliable prepaid meter, therefore, the future of this technology in Nkomazi was deemed feasible.

2.4 Burbank Advanced Metering Infrastructure (AMI) Project

This case study summary is based on a report by Fletcher (2013).

Burbank is a city in California. Its economy heavily relies on the entertainment industry. Its service provider; Burbank Water and Power, supplies about 45 000 residences and 6 000 businesses with water and electricity. In 2008, the city launched a sustainability plan meant to improve energy efficiency and reduce water losses in response to California's drought-induced water crisis. A smart grid initiative was put in place with installation of advanced electricity and water meters that could allow bi-directional communication through a wireless mesh network. The meter data management system that formed part of this AMI enabled verification of readings prior to the formulation of bills and so improved the monitoring ability of the utility; an aspect key to reduction of water losses. This smart grid system was supplied by a joint venture partnership of Siemens Energy, Inc and eMeter Corporation.

The major benefits realised from the AMI system were improved billing accuracy and thus shorter customer query response time. Regular interval data provided by the system could also enable the utility carry out leak detection and spot illegal connections. The system also enabled the utility to carry out updates to improve the functionality and scale of both water and energy infrastructure monitoring. New regulations and information requirements could thus easily be actualised.

2.5 Pinetop Water Advanced Metering Project

This case study summary is based on a report by Sensus (2013b).

Pinetop is a small town in Arizona whose economy relies heavily on summer tourists visiting its various lakeside retreats. Its winters are very cold, with snow covering most of the town's rivers and lakes. It has five main water supply sites, which consist of both tanks and wells. Pinetop Water, the utility responsible for water resource management and supply in the town, faced significant challenges in fulfilling their mandate. These included costly and time-consuming monitoring of water source levels and functionality, manual meter reading which could be hampered by the icy weather conditions or buried meters in winter; and consequent billing inaccuracies or water losses at source sites or at undetected leakage points. An automated water metering technology, which could allow the utility to better manage source and network monitoring was therefore sought, and the Sensus smart water network solution eventually chosen for installation.

The Sensus system used an open protocol system, known as the FlexNet communication network, for remote meter reading, and was also equipped with automation controls for monitoring the well and tank levels. It therefore freed up the utility staff's time for other tasks, since remote reading of all meters took five minutes as opposed to the previous four days per month. Furthermore, the risks to municipal staff in reading meters, particularly in winter, were now minimised, and valves at the supply stations could be opened and closed automatically instead of manually, depending on the system-monitored levels. Increased revenue from low flow detection and recording of the new water meters as well as reduced water consumption due to timely leak detection were other benefits realised from this system.

2.6 Melbourne AMI Case Study

This case study summary is based on a report by Nicholson et al. (2012).

Melbourne, Australia, has three main water and sewerage utilities, of which Yarra Valley Water is one. Yarra Valley Water supplies water and sewerage services to more than 1.6 million people, with 660 000 properties and 50 000 businesses within its operating areas to the south and east of Melbourne. Following the division of its network into about 140 distribution zones with multiple flow and pressure sensors, Yarra Water required an automated network monitoring facility that could better process and analyse the amount of data continually received, for identification of anomalies and consequent action. The utility chose a cloud-based AMI system, supplied by TaKaDu, for this purpose and within a three-month installation period from June to August, 2011, several large leaks were detected, with alerts received on average 14 days earlier than they would have in a manual monitoring situation. In fact, about 70 mega litres, which translated to AUD 60 000 were saved during this period. Meter faults and hydraulic malfunctions could also easily be detected and rectified with this system.

3. A MODELLING EXERCISE IN PREPAID METERING IN A TYPICAL LOW-INCOME AREA

While each system in the field is unique, typical parameter values were selected for a low-income system with 1 000 connections and used to investigate, through modelling, the feasibility of a prepaid water metering system. A sensitivity analysis was conducted to investigate the impact of different parameters on the feasibility of the system. A more detailed breakdown of this case study's evaluation inputs and results is provided in Appendix B of this report.

The system assumed that FBW is paid for through a government subsidy of R11.43/kl, thus ensuring an average water price of R12.72/kl compared to the water cost price of R6.00.

The current system (before installation of new water meters) was assumed to consist of 50% billed, metered connections, using 20 kl/property/month and with a 50% payment rate; 30% fixed rate connections using 30 kl/property/month and with a 40% payment rate; and 20% illegal or unbilled users, using 40 kl/property/month.

A proposed new system where all connections were supplied with either conventional or prepaid water meters was investigated. The prepaid meters were significantly more expensive to install (R2 000 per meter compared to R400 per meter for conventional), required an investment of R200 000 to pay for communication and payment infrastructure, and were more expensive to operate (R20/meter/month compared with R3/meter/month for conventional). This is an inevitable consequence of the higher sophistication of advanced meters, which have more components that can fail, and the higher skills required for installing and operating these meters.

The main financial benefit of the advanced meters was the billing cost that was assumed to be zero compared to R10/bill for conventional meters. Since prepaid meters assist users to manage their consumption, it was assumed that these meters will result in significant savings in consumption (11 kl/property/month compared to 20 kl/property/month for conventional). They were also assumed to ensure significantly better payment rates (75% compared with 50% for conventional metering).

The current system was calculated to run at a loss of around R100 000/month, which was reduced to a loss of around R10 000/month for conventional meters and R30 000/month for prepaid meters.

The results show that the capital payback period for implementing conventional meters is 4.4 months, which is much better than the 32 months required for the advanced metering system. Although both projects will give positive results with regards to effective surplus, the conventional meter system is again superior.

Thus, for this typical low-income application, it is clear that a conventional metering system is a better choice than the advanced metering system in all respects, except for consumption.

The main benefit of the advanced metering system is that user consumption can be better managed, and, in areas where water supply is under severe stress, this benefit may override the economic benefits of conventional metering. However, this comes at a significantly higher financial risk associated with a total capital cost of R2.2 million compared with R400 000 for conventional metering.

The sensitivity analysis showed that the economic feasibility of prepaid meters in low-income areas is threatened most by the following:

- A high payment rate for billed, metered consumption in the existing system; prepaid metering systems offer no economic advantage where the payment rate is already high.
- Low payment rates after implementation of the prepaid water metering system. This and the previous point show that advanced metering can only be economically viable if it increases payment rates substantially above the levels before the system is implemented.
- Low consumption levels in the existing system. If a system has low consumption levels, there is little scope for further reductions and the low-income levels make it difficult to recover the costs of new infrastructure.
- High number of consumers on billed, metered consumption in the current system, rather than on fixed rates or illegal connections.
- High failure rates for advanced meters.

4. WATER MANAGEMENT DEVICES IN CAPE TOWN

4.1 Introduction

According to the City of Cape Town Water By-law, a " 'water management device' means a device that controls the quantity of water flowing through a water meter over a certain time period" (City of Cape Town, 2010:6). Thus water management devices (WMDs) are a type of advanced meter. From 2006, WMDs have been rolled out by the City Council in several parts of Cape Town. The primary reasons for their use are to reduce debt and to save water by helping consumers manage their usage (Saayman, 2016).

The areas in which these devices are in use include the following: Du Noon(Environmental Monitoring Group, 2016), Khayelitsha (Nkomo, 2012), Lotus River (Booysen, 2016), Langa (Phaliso and Naidoo, 2010), Manenberg (news24, 2015), Mitchell's Plain (Donne, 2009), Samora Machel (PLAAS, 2015),Hanover Park (City of Cape Town, 2012a), Factreton (City of Cape Town, 2012a), Fisantekraal (City of Cape Town, 2013a), Ravensmead (City of Cape Town, 2013a), Bloekombos (De Sousa-Alves, 2013), Wallacedene (De Sousa-Alves, 2013), Mfuleni (De Sousa-Alves, 2013), Macassar (De Sousa-Alves, 2013), Wesbank (Pereira, 2009), Phillipi (Pereira, 2009), Atlantis (Donne, 2009) and Delft (Donne, 2009). It is also worth mentioning that, currently, when replacements are carried out of defective or aged conventional meters in most parts of Cape Town, the replacement meters installed in all cases are water management devices (Saayman, 2016). As such, the true magnitude of the presence of these WMDs in Cape Town is larger than just the areas above. This case study will therefore look at the roll out of WMDs in the City of Cape Town as a whole, instead of focusing on just one of the above areas.

The City of Cape Town Metropolitan Municipality is located in the southern peninsula of the Western Cape Province, stretching from Gordon's Bay to Atlantis. It has a coastline of 294 km and the adjacent municipalities to it are Swartland and West Coast to the north; Drakenstein, Cape Winelands and Stellenbosch to the north-east; and Theewaterskloof, Overberg and Overstrand to the south-east. It is bounded by the Atlantic Ocean to the south and west (The Local Government Handbook, 2012).

In 2011, the population of Cape Town was 3 740 025, and the number of households was 1 068 572 (Statistics South Africa, 2012).The average household size in Cape Town has declined from 3.72 to 3.50 since 2001, and, per the 2011 census results, the following socio-economic characteristics describe Cape Town. It is mainly comprised of a 42% Coloured and 39% Black African (42%) population. In terms of education, 46% of people aged 20 years and older have completed Grade 12 or higher. Of the labour force (aged 15 to 24), about 76% are employed, with approximately 47% of households living on a monthly income of R3 200 or less.

Since the WMDs are mainly being used in residential areas, as mentioned above, the meter sizes used typically vary from 15 mm to 25 mm (van Zyl, 2011) and were installed in line with the City's 2010 Water By-law, quoted here:

"***General Conditions of Supply"***

(6) *The Director may install a Water Management Device at any premises as part of the water meter and its associated apparatus to:*

(a) *to encourage water demand management; or*

(b) ensure implementation of an affordable approach in providing access to basic water services.

(7) Where a Water Management Device has been installed at any premises, a consumer may request to enter into an agreement with the Director to set the drinking water supply to their premises to a predetermined daily volume." (City of Cape Town, 2010: Clause 24, page 13)

Even as implementation of these devices precluded the aforementioned by-laws, their formulation gave lee-way for mass roll out of these devices in various areas of Cape Town for some of the reasons explained in the section below. A more detailed breakdown of this case study's evaluation inputs and results is provided in Appendix B of this report.

4.2 Reasons for Implementation

The initial installations were part of a pilot project to reduce some of the service delivery gaps in informal settlements, particularly for backyard dwellers living in the backyards of Council rental stock (City of Cape Town, 2012a). This programme was piloted in three areas, i.e. Hanover Park, Factreton and Langa, and included construction of a water-borne toilet structure in the backyard with a tap outside it to which a water management device was tagged. This WMD was to enable control of water dispensed to the unit based on the number of backyard units on each property and sum of FBW allotments to each (City of Cape Town, 2012a).

Another prompt for the city to embark on WMDs was the increasing arrears accrued on water and sanitation services. This technology was seen as a means for the city to pre-empt these arrears by restricting people to the FBW amount and what they could afford outside of it. WMD use would also provide a debt cancellation option for those who maintained their use within affordable limits and, to this effect, R61 million worth of arrears had been written off by CoCT by Feb 2009 (Papier, 2009).

Supply side management has resource sustainability issues attached to it that limit the extent to which the City can safely abstract from water resources to meet growing demand (Turton, 1999). Consequently, demand side management has gained increasing momentum in South Africa as well as the rest of the world.

Domestic consumption makes up about 47.8% of the overall water use in the CoCT, as per 2011/2012 figures (De Sousa-Alves, 2013). Technological advancements like the WMD are thus seen as one means to control and minimise domestic and, consequently, overall water demand as well as have the potential for use as monitoring and enforcement tools for water restrictions in the future.

A culture of “non-payment” for services is considered to be one of the historical results of the rent and service delivery boycotts during apartheid, particularly amongst previously heavily marginalised and unserved areas (McDonald, 2002). This history has impacted current service level delivery to these informal settlements whereby different service levels, that is basic, intermediate and full are designated to low-, middle- and high-income consumers (McDonald, 2002). This has, consequently, further entrenched non-payment attitudes by alienating low-income dwellers from the idea of citizenship attached to service provision, and its roles and responsibilities to the state (Rodina and Harris, 2016). As such, the self-disconnection or flow restriction capability of these WMDs endears them to the City as a move in combating the culture of non-payment and starting a dialogue in these areas about debt management and the value of water.

4.3 Project Implementation Process

The City of Cape Town, in a memorandum to representatives of the South African Communist Party and the African National Congress (ANC) and ANC alliance partners, dated 20 March, 2009 (Plato, 2009), clarified the salient issues with regard to the WMD implementation policy in CoCT as follows:

i. The water management devices were being implemented on a voluntary basis in homes across Cape Town.

ii. The WMDs would not require prepayment to deliver a free basic 6 000 litres of water per month to households, plus a further 4 000 litres to households registered on the indigency database.

iii. The WMDs could be set to deliver more if owners consent to paying a certain amount at the end of each month.

iv. At the time, the WMDs provided a minimum of 44 litres per person per day of free basic water, based on an estimated average household of eight people. Where more people live in a household, CoCT would increase the amount of free water accordingly.

v. In an attempt to save residents from accumulating unmanageable debt, especially through leaks, the City had fixed leaks free of charge in homes where the WMDs had been installed to enable them to manage consumption. Residents on the indigency database who have the device installed and, for six months, stick within their daily limit and pay a contribution towards their debts, would have their debts written off after this period, regardless of the amount.

vi. Where water was under WMD use, people who registered as indigent and made arrangements to pay their debt never had their water deliberately cut off, however big their debt was. Their water was only restricted to 6 000 litres per month in terms of the trickle and later WMD system; and 10 000 litres free if they were on the CoCT indigency database.

vii. If water was cut off in a household, this implied a problem which should immediately be reported to the City so that their 24-hour response team could go out and fix it.

According to Pereira (2009), qualification for indigency requires a person to be the registered owner of their property and to be earning less than R2 880 per month. Other salient issues regarding WMD implementation in CoCT, gleaned from CoCT promotional material and cited in the Pereira (2009) text, include the following:

i. Those not on the indigency register can pay a once-off fee for installation which allows them 6 000 litres per month free, and any additional amount they commit to pay for.

ii. The WMDs are configured to switch on at 04.00 am every morning, and to switch off only once one has used their set quota for that day. If a person utilises less than their daily quota for that day, the remaining amount which was not used will be carried over to the next day, but only until the end of the month, after which any unused allocation for that month is cancelled, and the next month's quota reset to the original amount.

iii. In case of any problems with a water management device already installed in one's home, or other appurtenant city water delivery infrastructure, one should send an SMS to the number 31373 at a cost of 80c per SMS.

iv. In a case where water has been interrupted for more than 24 hours, one is advised to contact the Technical Operations Centre on 0860 103 054, at the cost of a local call.

The above gives a summation of the current implementation procedures for WMDs in the CoCT. In addition, the current *Application for Water Management Devices* form is attached as an Appendix. It details the different device setting options and also includes the different liabilities and responsibilities taken up by both the City and the individual in the use of this device.

With regard to the more technical aspects of WMD procurement and installation, Chapter 7 of the *Service Guidelines and Standards for the Water and Sanitation Department of CoCT* (City of Cape Town, 2015b) details specifications for an electronic flow limiter valve fitted to a meter with its associated meter in box and fittings. This chapter includes specifications of features, the valve body, the meter in box, the after-assembly test, the electronic PCB controller, software and operating features, training, tamper proof, display functions, automatic meter reading (AMR) feature, battery, general and software/hardware (City of Cape Town, 2015b).

An issue worthy of note, already mentioned above, is that a once-off leakage repair and plumbing retrofitting programme later formed a preliminary aspect of WMD installation in CoCT. This is because significant losses of water prior to any consumer use had been noted to happen frequently in informal settlements and other areas, resulting in a huge public outcry against these meters and accusations that they excluded the poor from their rights to access water. For example, one resident in Mitchell's Plain, Tanya Smith, with a household of about six other family members, with one sick, complained that the WMD system caused frequent water cut-offs – sometimes for weeks at a time and for no apparent reason (Donne, 2009). Her objections were supported by residents from Atlantis, Delft and Mfuleni who said they were experiencing cut-offs after using only about 20 litres of water (Donne, 2009).

Leak repair and retrofitting, technical evaluation of these WMDs, and communication and awareness programmes about individual household leak detection therefore remain a critical part of the WMD implementation process and other water loss reduction programmes in CoCT.

The two main WMD meter makes currently used in Cape Town are Utility Systems and Aqualoc, with Aqualoc used mainly for 20 mm size meters and Utility Systems used mainly for 15 mm size (Pontia, 2016). The technical specifications of these meter types are given in the section below.

4.4 Technical Specifications of the Most Commonly Used WMDs

As stated above, the Aqualoc and Utility Systems WMDs, described below, form the majority of WMD meters currently installed in CoCT.

4.4.1 Aqualoc Water Demand Management Systems

The Aqualoc WMD manufacturer's brochure states that they offer two typical meter sizes of 15 mm and 20 mm. Per the manufacturer's claim, these WMDs have the following characteristics:

- "*Fully sealed housing with pop up lid. Easy leak detection in one piece moulded housing"*
- *"Mud and roots contamination free"*
- *"Repair and replacement of all components in situ, using unique non-standard tools"*
- *"Fundamental product that is easily upgraded from basic management (no meter) to 15 mm or 20 mm with/without flow regulating device"*
- *"Upgradable to automatic meter reading as and when required"*
- *"Pressure independent with IFRD (Intelligent Flow Regulating Device)"*
- *"Pressure management with IFRD"*
- *"Dual housing available offer cost savings in product and installationRef."*

Meter specifications in terms of nominal bore, flow rate, pressure, installation and class are also provided in the brochure with accompanying head loss and flow curve diagrams.

The dimensions table, also provided in the brochure, details the installation depth, meter box dimensions required and end connectors and compression fittings needed to successfully install these meters.

4.4.2 Utility Systems Water Management Devices

Per the manufacturer's claim, the Utility Systems WMD is a low-cost, intelligent, electronic control valve that is capable of controlling the flow of water for its full pressure range (See **Figure 4-1** below).

It can be installed in domestic as well as small commercial properties and, when linked to a pulse output water meter, the device is claimed to enable the following:

- "*Time and volume based control of water flow"*
- *"Leak and tamper detection"*
- *"Management of delinquent customers"*
- *"Remote data capture and meter control"*
- *"Automatic Meter Reading (AMR) with the ability to provide control of water flow, the essence of Advanced Metering Infrastructure (AMI)"*
- *"The implementation of standard transfer specification (STS) prepayment water metering"*

Figure 4-1: Utility Systems Water Management Device (courtesy of Utility Systems)

The manufacturer's claim is that the WMD configurations are multiple whereby it can be set to only dispense FBW, but also allows configuration to dispense other higher or lower quantities of water, either daily or monthly. The WMD settings also allow it to be linked to a flat tariff structure for consumers who voluntarily choose to limit their consumption.

The main features, technical specifications and benefits to the service provider of the WMD are provided in the manufacturer's brochure. With regard to conformance, these meters are claimed to be both SANS certified and STS approved; and have an average battery life of 10 years, dependent on use.

Of interest is that another WMD for bulk mains has been developed by this manufacturer, known as the Bulk WMD.

4.5 Benefits of Implementation of WMDs

The following benefits were realised by CoCT from installing WMDs in various areas throughout the city:

i. An estimated monthly saving of 156 000 000 litres of water, worth R519 000, was quoted by City of Cape Town as a result of the WMD installations in CoCT by March 2009 (Plato, 2009). Another water saving figure quoted as achieved with the retrofitting and leak-fixing project was approximately 10 Kl/month per targeted area, and a financial saving of between R1.2 and R1.7 million/year per targeted area (City of Cape Town, 2013). These figures indicate a potential for both financial sustainability and control of water demand growth in municipal water service provision when WMDs are installed (Saayman, 2016).

ii. Reduced consumption also contributes to municipal budgetary savings by deferring water infrastructure augmentation projects which would otherwise be needed to meet increased demand. Up to approximately two billion rands' worth of capital investment in desalination and other supply side solutions has been extended due to reduced consumption from WMD installation. (Saayman, 2016).

iii. For consumers, WMDs offer an opportunity for controlled and budgeted consumption. An example is Gideon Shubani in Sqekezana Street, Makahaza, who welcomed the implementation of WMDs on account of being able to control his water usage with them in place (Nkomo, 2012).

iv. A positive attitudinal shift in valuing water as a resource can be surmised from the WMD implementation and other concurrent conservation and demand strategies. A study in Khayelitsha, for example, found that some residents, in relating rural to urban experiences of water provision, evoked the improved water quality and infrastructural investments in water delivery made by the City as justification for the need to pay for water services (Rodina and Harris, 2016). Furthermore, many residents asserted that paying for water services incentivised individuals to value it as opposed to the irresponsible use that was rife with free water consumption (Rodina and Harris, 2016).

4.6 Challenges Encountered

Even as the above benefits of WMDs were realised, the implementation of these devices in Cape Town faced a number of challenges. These challenges are sub-divided into the technical, social and economic subsections below.

4.6.1 Technical Challenges

(a) Failure rates

A study of WMD implementation in four areas of Cape Town, i.e. Saxon Sea, Samora Machel, Umlazi and Umbubulu, was performed by Thompson et al. (2013). The study gave an average WMD technical failure rate of approximately 21% per annum (GIBB, 2015).The supporting harrowing narratives of sick residents and home business owners going for days without water verify this failure rate and can inflame resistance to these meters, making vandalism of them justifiable to some communities. One community leader in Mitchell's Plain, for example, was lobbying for mass action to "rip out" the WMDs due to the poor service delivery experienced with them (Donne, 2009).

(b) Slow response time

A significant lag in responding to some WMD complaints made by residents is highlighted in different studies. The length of time that some residents had to go without water due to WMD malfunctions and/or supply interruptions varied and ranged from one week (Pereira, 2009) up to a month (Phaliso and Naidoo, 2010). Unhealthy coping mechanisms, as well as interruptions to informal home industries, result from this, further discrediting WMDs in the consumer's eyes.

(c) Emergency water reserves

The lack of emergency water reserves in case of fires and medically related incidents is one of the major shortfalls of WMDs, with residents in areas like Kleinvlei worried about what will happen in case of such incidents (Pereira, 2009). Technological advancements that allow contingency supplies for emergency incidents are critical in alleviating risks and endearing these technologies more to consumers. An example of such risk management can be found in Hermanus, where prepaid meters, piloted as part of the Greater Hermanus Water Conservation Programme, were fitted with a panic button linked to a 24-hour volunteer group who would provide police or fire support in case of any such instances (Turton, 1999).

(d) Leakage

Leakages from old and poor-quality plumbing in informal settlements are another major cause of failure of WMD implementation. This is because significant losses of water from leaks result in premature cut-offs when only minimal amounts of water have been used by the consumer. For example, a 61-year-old in Makhaza complained about getting only about 20 litres of water a day (Donne, 2009). These frequent cut-offs not only debilitate the meters but also result in huge public outcries against these meters and their exclusion of the poor from their rights to access water. The Department of Water Affairs and Forestry (DWAF), in a water reconciliation strategy study for KwaZulu-Natal metropolitan areas, observed the need for use of more durable, high-quality pipes, meters and fittings in township areas due to the significant wear and tear they face from the more frequent usage in these areas (DWAF, 2009).

4.6.2 Social Challenges

The significant social challenges associated with these WMDs are summarised below.

(a) Political landscape

Significant bias and disparity in the hydro-political scope around the implementation of WMDs has oftentimes negatively impacted community attitudes to them. Derogatory terms like “water apartheid” (Carty, 2003), “weapons of mass destruction” (Donne, 2009) and “bucket system” (Donne, 2009) are rife in reference to WMDs and add to the apprehension of different communities about their installation. These attitudes are further reflected in suspicion around the credibility of the water scarcity assertion made by CoCT, with some residents attributing the implementation of these meters to financial scarcity for water infrastructure projects as opposed to physical scarcity of water (Pereira, 2009; Rodina and Harris, 2016). The extent of this intrigue even necessitated a memorandum on March 20, 2009, from City of Cape Town to SACP and ANC alliance partners who had conducted a march to the Civic Centre (Plato, 2009). The main subject of this memorandum was to request that these parties cease spreading misinformation about municipal services and, in particular, the implementation of WMDs in Cape Town (Plato, 2009).

Implementing these devices in communities that are already hostile to and pre-biased against the municipality presents challenges to the City.

(b) Mass action

South Africa has had numerous protests over basic services in recent years. In Wilson et al. (2008), it is stated that the Minister of Safety and Security released figures showing 5 085 legal and 881 illegal gatherings and demonstrations for the 2004/05 financial year, with many of them related to basic services. The ANC protest march cited in the paragraph above is one of a number of similar protests or rejections of WMDs in different communities in Cape Town. These incidents are exacerbated by minimal consultation prior to implementation and insufficient discussion between municipalities and consumers on the way forward after WMD installation (Wilson and Pereira, 2012).

(c) Indigency prerequisites

Another cause of contention in WMD installation is the indigency policy and how it is applied. Rodina and Harris (2016), in reference to a 2012 interview with a City official, mentions the challenging nature of indigent policy implementation as well as the low level of awareness of residents about it. Wilson and Pereira (2012) corroborate this by stating that even for the few residents of CoCT who are aware of the indigent policy, a complete understanding of the rebate system it entails has not yet been grasped. In the absence of this knowledge, therefore, the benefits of WMDs to many residents still remain unknown, further entrenching popular aversion to them.

(d) Litigation

The City of Cape Town water by-law (City of Cape Town, 2009) requires the CoCT to give two notices prior to disconnection of one's water supply, with each notice providing a time period for settlement of arrears. However, with WMDs, supply cut-offs outside of the FBW amount for inability to pay or non-payment are a foregone conclusion. This poses a seeming contradiction of the by-law and its practical implementation which can be used for litigation as well as incentivise mass action protests against the city. For example, in March 2009, the City received a memorandum highlighting grievances from the SACP and ANC delegation including the unconstitutional nature of WMD implementation (Plato, 2009).

(e) Consumption monitoring

One of the main issues with WMDs. which have resulted in their nickname "umfudo", which is isiXhosa for tortoise, regards their physical appearance (Wilson and Pereira, 2012). The opaque black shell cover in which these devices are contained, while serving a protective purpose, is also perceived by consumers as a deliberate way of making it impossible for them to monitor their consumption (Wilson and Pereira, 2012). This has served to increase the suspicion and level of distrust of these devices in some communities like Khayelitsha, and, thus, for the CoCT that installed them (Nkomo, 2012).

(f) Distrust

A 43% probability of failure per year due to vandalism and other causes was obtained from a study of the use of these devices in eThekwini (GIBB, 2015). High levels of vandalism of these WMDs also exist in CoCT and these failure rates can be attributed to the technical challenges which have resulted in supply cut-offs which increase the social burdens on residents. These burdens serve to alienate residents and perpetuate distrust between the City and its residents such that, in some instances, not only meter vandalism but active threats to harm CoCT employees working with the meters, were made (Saayman, 2016).

(g) Health risks

Due to the water supply interruptions and slow response times in addressing them, consumers have adopted unhealthy strategies in order to survive on the minimal water amounts that they obtain. These include sharing bath water, recycling dish water, going to the toilet in outside bushes to avoid flushing (Pereira, 2009; Kumwenda, 2006) and other unhealthy measures which pose health risks to these residents. The water-borne diseases and other health complications that arise from this place additional resource burdens on the municipal health sector.

(h) Social tensions

The water restrictions imposed by WMDs, both in their typical functioning and also in cases of malfunction, affect the social relationships of consumers. For instance, in situations of supply interruptions or shortages, an increased burden is placed on women and children to find alternative water sources, and ensure the safety of children when using outside toilets and other instances of this nature (McDonald, 2002). In other cases, begging for water from neighbours in order to survive causes embarrassment and also strains relations between community members (Phaliso and Naidoo, 2010; Nkomo, 2012).The Anti-Privatisation Forum's research, cited in GIBB 2015, found increased stress and tension within households on account of rationing individual member's water use, which resulted from flow restrictions of this nature (GIBB, 2015). These tensions can incite violence both amongst community members as well as against the City.

4.6.3 Economic Challenges

The negative economic impacts and challenges affecting WMD implementation are explained below:

(a) Affordability

The Department of Water Affairs report, titled *Water Boards as Regional Water Utilities,* mentions the affordability of water as a major problem in municipal cost recovery (DWA, 2014). A household income of R38 200 per annum is considered as the minimum income below which households are typically considered to be unable to pay for water (DWA, 2014). The Overberg Water Board, under which Cape Town falls, is listed as servicing an area in which 53% of households have incomes of less than R38 200 per annum (DWA, 2014). This implies that payment for water outside of the FBW allotted by WMDs is highly unlikely for the majority of people in these communities and, consequently, increased incidences of illegal connections to the water supply for additional water needs are to be expected. In Witsand, Atlantis, for example, where WMDs have been installed, households with leaks or other supply cut-offs and interruptions make use of an unmetered standpipe in a neighbouring informal settlement to collect water to meet their needs (Pereira, 2009).

(b) Increased investment costs

WMDs are usually installed as a supplementary component to a typical conventional meter. This means that the overall capital costs and operational costs of WMD metering systems are much higher in comparison to conventional metering systems (GIBB, 2015). Additionally, the operation and maintenance of these devices, owing to the increased failure rates alluded to in Section 3.6.1 above, places more resource strains on the City's operation and maintenance response teams. Nevertheless, when these meters are installed and activated in low-income areas, due to unaffordability, residents will typically reduce their consumption to remain within the FBW allotment or seek alternative water sources (Pereira, 2009). This suggests that the City's ability to recuperate the increased investment costs for these devices is diminished, and this affects the financial viability of these projects.

(c) Billing inconsistencies

There are a number of billing policy discrepancies that require attention in order for successful implementation of WMDs to be achieved. Disparities in billing frequency occur. For example, in Witsand, Atlantis, a family which had been residing there for 2.5 years had only received two bills in this duration, neither of which they could afford to pay (Pereira, 2009). Exorbitant bills for some and none for others are additional disparities that occur in CoCT. For example, interviews with City staff revealed that payment for water services for some residents in Site C of Khayelitsha, where WMDs have been installed in newly built RDP houses, would only be required after the formalisation process and associated upgrades had been completed (Rodina and Harris, 2016). In areas like Mitchell's Plain, residents believe that WMDs accrue higher bills, with some who are classified as indigent claiming to receive bills of up to U$100 per month for homes with only one tap (Donne, 2009). Varied reasons like leakages, inherited debt from previous owners or multiple persons using the water could explain these exorbitant bills (Wilson and Pereira, 2012). The above experiences with billing amplify the worry of residents and create mistrust and reluctance to accept WMD installations in homes. Also important to note is that due to low literacy levels in some implementation areas, consumers are unable to comprehend the bills they receive (Wilson and Pereira, 2012) and thus cannot act on them. The city's revenue streams from WMD implementation could prove inconsistent and difficult to track as a result.

(d) Debt cancellation

The policy and execution of debt write-offs as part of WMD installation has in some cases been found to be ineffective. Some Makhaza residents for instance expressed fear to go to the city and negotiate their debts due to stories that, going forward, they would be required to pay immediately or face instant disconnection of their water supply (Wilson and Pereira, 2012; Nkomo, 2012). More local authority involvement, and campaigns to improve awareness of the terms of the debt write-off, should be used to build trust and avoid even larger debt accruement by fearful consumers.

(e) Home industry

Informal home industries are affected by water restrictions imposed by WMDs. For example, a sixty-six-year-old crèche owner in Langa lost children she was taking care of to other crèches due to lack of water at her property for about a month (Phaliso and Naidoo, 2010). The stifling of this and other minor industries on which these low-income consumers sustain themselves therefore serves to further entrench them in a state of indigence.

4.7 Current Status of Water Management Device Implementation in CoCT

Continued roll out of WMDs is being carried out to date in CoCT, particularly of the standardised 20 mm Aqualoc and 15 mm Utility Systems WMDs. In fact, when conventional water meters are repaired or replaced, WMDs are installed, regardless of the area of Cape Town in which works are done (Saayman, 2016). The only divergence is that in more economically viable residential areas, these WMDs, when installed, are not activated (Saayman, 2016).

Some areas like Khayelitsha and Dunoon, however, still have significant political and community resistance to these devices and therefore the city continues to struggle to have WMDs fully rolled out there (Saayman, 2016).

5. PREPAID WATER METERS IN ILEMBE DISTRICT MUNICIPALITY

5.1 Introduction

iLembe District Municipality is located in KwaZulu-Natal along the north coast (65 km north of Durban) where it covers an area of approximately 1 455 km^2, comprised of four local municipalities (the water dialogues, 2008). The four local municipalities are Maphumulo and Ndwedwe in the west, Mandeni to the north and Kwadukuza to the east. Maphumulo, Ndwedwe, Mandeni and Kwadukuza are 80%, 80%, 60% and 20% rural respectively (Mthembu, 2016).

The 2011 Census results indicate a population of 606 809 in iLembe with 0.8% growth per annum (Statistics South Africa, 2012a). Trends indicate a high rate of migration of residents from the rural municipalities of Maphumulo and Ndwedwe to the more urbanised municipalities of Mandeni and Kwadukuza (Statistics South Africa, 2012a). This is no surprise considering that Maphumulo and Ndwedwe have the highest unemployment rates of 49% and 58% respectively relative to a district average unemployment of 31%, and 37% amongst the youth (Statistics South Africa, 2012a).

This municipality currently has a total length of mains of approximately 2 205 km, from 111 water schemes feeding about 34 632 consumer connections (iLembe District Municipality, 2015a). Of these consumer connections, a FBW allocation of 10 kl/month goes to indigent domestic consumers, with all the other domestic, industrial, commercial and institutional users required to pay for any and all water used (Mthembu, 2016).

However, in October 2013, bill accruement and an increasing debt book of about R211 million from unpaid water bills prompted the municipality to roll out prepaid water meters (iLembe District Municipality, 2013). Currently the coverage of these prepaid meters in each local municipality stands at approximately 25% for Maphumulo, 45% for Ndwedwe, 60% for Mandeni and 80% for Kwadukuza (Mthembu, 2016).

A more detailed breakdown of this case study's evaluation inputs and results is provided in Appendix B of this report.

5.2 Reasons for Implementation

The primary reason for introducing prepaid meters was to increase revenue collection by mitigating the various problems with billing (iLembe District Municipality, 2015b). These included meter data-capturing errors, discrepancies in meter records and time lags in updating meter records per field maintenance activities and/or new connections (iLembe District Municipality, 2015b).

It was thus hoped that the data cleansing done in the course of prepaid meter installation would reconcile and update the billing system records (iLembe District Municipality, 2015b). Furthermore, the drive-by approach to data capture was envisioned as a time-saving and error proof means of meter reading (iLembe District Municipality, 2015b).

As stated above, the municipal debt book was approximately R211 million, and growing, in 2013 (iLembe District Municipality, 2013). Prepaid meters were therefore seen as a means of arresting this debt. This municipal thinking around prepaid meters can best be illustrated by the statement by Mr Jean-Pierre Mas, the Operations Executive at Johannesburg Water, in regard to their installation in Orange Farm in 2000:

> "*Under the old system, people were billed for far less water than they consumed, and still they were not paying their bills. They had no incentive to lower their consumption. They had no incentives to pay. If we don't do anything about it, it will be an unsustainable setup. We will have a financial disaster.*" (Jean-Pierre Mas, quoted in Thompson, 2003).

The roll out of Utility Systems (USC) prepaid metering devices therefore commenced in iLembe in October 2013 with varying device sizes installed amongst different consumer types. The technical specifications of these devices are detailed in Section 4.3 below.

5.3 Technical Specifications of Utility Systems Prepaid Water Metering System

The elements of Utility Systems prepaid metering system can be grouped into four main components, namely:

- A water management device
- A user interface unit (UIU)
- Vending infrastructure
- Data collection hardware and software.

A brief description of each of these components, as per the manufacturer's brochure, is given in subsequent sections.

5.3.1 Water Management Device

The WMD is an electronically controlled valve typically connected to a pulse output water meter. The pulse output from the water meter is what typically triggers the WMD to monitor and control consumption via electronic pick-ups. Per the manufacturer's claim, this WMD has the following functions and features and a photograph of it is also provided below:

- Monitoring consumption and dispensing water accordingly. This could include dispensation of emergency or lifeline reserves in case of credit depletion (GIBB, 2015).
- Ability to communicate with field service units for data collection as well as with the UIU.
- Has a data logging function for monthly billing or longer duration analysis.
- Tamper and leak detection properties.
- Bi-directional communication abilities which can allow remote control of this device.

Figure 5-1: Utility Systems Water Management Device (courtesy of Utility Systems)

5.3.2 User Interface Unit (UIU)

This unit is typically installed inside the customer's premises and is the unit into which the consumer keys the credits/tokens bought, in the prepaid system. This UIU uses an RF radio link to convey the purchased unit information to the WMD above (personal communication with USC, cited in GIBB, 2015). Per the manufacturer's claim, this UIU has four main display functions, listed below, and an image of it is shown thereafter:

- Display of meter reading per the WMD installed
- Display of available water allocation (FBW or prepaid amount)
- Display of WMD serial number required to purchase a token
- Leak, tamper and other alarm detections.

Figure 5-2: Utility Systems User Interface Unit (courtesy of Utility Systems)

5.3.3 Vending Infrastructure

Per the manufacturer's claim, this prepaid metering system is Standard Transfer Specification (STS) approved. This implies that multiple vending options are available to the municipality, and to consumers who need to purchase credit for water.

For the municipality, billing is not required since revenue collected from consumers on this system is recorded through said vendors. On the consumer side, the STS system is claimed to enable multiple, and therefore more convenient, non-proprietary vending options. These, per the manufacturer, include use of already existing:

- *"electricity vendors"*

- *“internet-based vending”*
- *“cell phone vending”*
- *“points of sale”*
- *“bank hall vending.”*

5.3.4 Data Collection Hardware and Software Interfaces

Per the manufacturer’s claim, these data collection systems can be scaled from basic walk-by or drive-by to fully automated remote reading systems. This is dependent on whether the data collector receiving transmissions from the WMD is fixed or periodic. This data collector then relays the information to a central server through a secondary communication network.

The same network and process is used for reverse directional commands or configurations sent to a single or multiple WMDS in an area.

The software interface enables field data download, and interpretation into billing information or other meter data analysis records. According to the manufacturer, this system can support varying scales of area meter configurations, be they local, municipal or otherwise.

The figure below, from the manufacturer’s brochure, shows examples of the different vending and communication components of this system explained above.

Figure 5-3: Vending and communication infrastructure of USC prepaid metering system (courtesy of Utility Systems)

A list of other features, specifications and benefits to the service provider are also provided in the manufacturer’s brochure. With regard to conformance, these meters are claimed to be STS approved; and to have an average battery life of 10 years, dependent on use.

Due to the varied components and functionalities of the USC system described above, the more specific components chosen by the municipality will be included in the project implementation section 4.4 below.

5.4 Project Implementation Process

A number of steps were involved in the project implementation process, as described below.

Consumer awareness campaigns were carried out in which residents were informed of the upcoming works and briefed as to the preliminary processes that these roll outs would entail.

For example, during the weekend of 6th–7th July, 2013, the Mayor and members of the iLembe District Municipal Council were engaged in meetings in different wards to consult and address prepaid metering queries (iLembe District Municipality, 2013).

Amongst the preliminary processes were meter audits to update the customer list and identify illegal connections (Mathonsi, 2014). This audit involved field workers, typically hired by the municipality, carrying out door-to-door campaigns to collect the necessary information, detailed below, to update the meter database. Note that the database information required, as quoted below, was obtained from an iLembe District Municipality 2013 text:

- *"Stand or the "Erf/F" number"*
- *"Personal details and ID number of the home owner"*
- *"Marital status of the homeowner (A copy of the marital certificate will be required)"*
- *"Number of persons living in the household"*
- *"Proof of income for all those that are employed and/or receive a social assistance grant"*
- *Contact details, i.e. "telephone number; physical address and postal address"*
- *"Water meter number"*
- *"Details of next of kin/ one relative that does not live in the household"*
- *"Preferred mode of communication with the iLembe District Municipality."*

In addition to the above process, another data cleansing initiative was carried out by the municipality through a 2012/13 contractual agreement between the municipality and a data house tasked with carrying out database cleansing (iLembe District Municipality, 2015b).

Following the preliminary processes above, installation of the WMDs and the required communication infrastructure to enable a drive-by approach to meter reading was then carried out (Mthembu, 2016). Note that in most cases the conventional Elster Kent meters were left in the ground and the aforementioned infrastructure was added (Mthembu, 2016).

UIUs were provided to consumers and different vending options for purchasing water credits, similar to those for prepaid electricity, availed (Mthembu, 2016).

A one-year defects liability/warranty period formed part of the service level agreement for this Utility Systems prepaid metering system installed (Mthembu, 2016).

5.5 Benefits of the AMR System

Even though the overall project results fell far below municipal expectations, a few benefits were realised, included the following:

- During the meter audit and replacement phases, bypassed, vandalised and faulty meters within the area were identified and repaired or replaced, thus saving the utility further revenue losses.

- Short-term jobs were created for municipal youth as field workers during meter audits (iLembe District Municipality, 2013).
- An update and reconciliation of the city's meter database was one of the benefits realised and this was a step towards improving billing efficiency and revenue collection.
- An overall reduction in water losses was realised due to the improved metering and subsequent area zoning for leak detection.

5.6 Challenges Encountered

Although initially sold as a solution to many of the municipality's problems, it was soon realised that the prepaid metering system came with a significant number of challenges (Mthembu, 2016). In some instances, because sanitation system charges are tied to water consumption and thus both conventional and prepaid meter readings, the challenges in obtaining the prepaid meter consumption readings for sanitation charges have been highlighted. These challenges, divided into economic, administrative, technical and social subsections, are expounded below.

5.6.1 Economic Challenges

The economic challenges faced, during implementation as well as after it, included the following:

- Shortly after the roll out of prepaid meters, the iLembe Municipality embarked on a new way of charging for sanitation (Mthembu, 2016). Where previously a constant rate based on property value had been charged for sanitation, the municipality now opted to use a percentage of water consumed as the basis of sanitation charges (Mthembu, 2016). This meant that particularly large households whose water consumption had previously had no impact on their sanitation charges now faced increments of double or more (Mthembu, 2016). In some instances, these households struggled to pay these increased charges and thereby accrued municipal debt (Mthembu, 2016). It was therefore difficult to realise the reduction in debt accruement as a result of the prepaid meter installations and, in fact, an increase in the municipal debt book was instead realised (Mthembu, 2016).
- The maintenance cost of the prepaid system has been noted to be significantly higher than for a conventional metering system (Mthembu, 2016). This can be partly attributed to the significant number of failures just shortly after the warranty period that required the municipality to purchase new prepaid metering units (Mthembu, 2016). In instances where repairs are required, due to the increased number of components in these meters compared to conventional ones, the repair process is often more resource intensive and more frequent.
- In spite of the hope that behavioural change would occur whereby consumers would be forced to pay for their consumption, it was realised that, even where these prepaid meters had been installed, illegal connections were being made in many instances (Mthembu, 2016). As such, no drastic improvement in payment for water services could be realised (Mthembu, 2016).

- The increased logistical requirements needed to make this system work, for example, management of credit vendors (GIBB, 2015), manual checks of the system sometimes required for water balancing purposes (GIBB, 2015) and others, have also placed an additional cost burden on the municipality (Mthembu, 2016).

5.6.2 Administrative Challenges

Various administrative challenges were faced with implementation of this technology, including the following:

- To begin with, in choosing the prepaid metering scale, economic feasibility was taken into account. The fully automated system was prohibitively expensive and therefore the drive-by metering infrastructure was chosen instead (Mthembu 2016). As stated above, the use of water consumption amounts to calculate sanitation charges highlighted problems with this prepaid metering system; for example, time savings in billing were not realised as anticipated with the drive-by system. This is because the field data has to be sent to the supplier for interpretation before it can be fed into the municipal billing system and it can take up to three days for the supplier to respond (Mthembu, 2016).
- The added step described above in which the supplier is required to interpret field data collected has also resulted in a lengthier and less conducive process to identifying discrepancies in billing accounts (Mthembu, 2016). This is because this time lag limits the time available to the municipality to carry out field verification of any anomalies noted in the billing records and thus often results in these works not being done (Mthembu, 2016). As such, the level of confidence in the sanitation bills currently sent out is much lower for prepaid meters than conventional meters.
- Due to the change in sanitation policy, and, consequently, increased water and sanitation costs, more instances of illegal or bypassed connections have been encountered (Mthembu, 2016). This is particularly true in areas with no knowledge of free basic services and the indigent policy (Mthembu, 2016). As such, maintaining accurate statistics of the indigents in iLembe is still difficult since they retain the illegal connection and don't come forward to the municipality (Mthembu, 2016).
- The now lengthier process in sanitation billing with prepaid meters provides more opportunities for errors to occur in billing. This is because the municipality has to first wait for the service provider for interpretation (Mthembu, 2016). Then, when the report is returned from the service provider, the data then has to be reformatted into the municipal billing system template (Moonsoft) from the supplier’s format. Only after this reformatting and uploading onto the billing system can discrepancies be detected (Mthembu, 2016). By this time, not only has significant time passed but also various changes of hands and thus multiple opportunities for errors to be introduced in the data have occurred.
- Poor record keeping and out-dated municipal billing and metering records necessitated economic investment in data cleansing and meter audits before the roll out of these prepaid meters could be carried out (Mathonsi, 2014).

5.6.3 Technical Challenges

Some of the technical challenges experienced with this system are as follows:

- Constant break-downs due to technical faults with the prepaid meters have been experienced. It is particularly frustrating for the municipality when, as mentioned before, new meters have to be purchased where they fail after one year, because then their warranty /defects liability period has run out (Mthembu, 2016). This calls into question the value for money of these meters and has highlighted the need for the warranty period to last longer than one year (Mthembu, 2016).
- Due to the significant technical failure rates above, there has been a corresponding significant increase in the number of consumer complaints and queries over these meters (Mthembu, 2016). It is difficult to collect revenue or debt from consumers who have a multitude of complaints, particularly in cases where payment has been made and yet these consumers are unable to access their water due to technical issues or faults (Mthembu, 2016).The resource envelope to deal with these issues is therefore also constrained, meaning that there is a slow response time in attending to each consumer complaint (Mthembu, 2016).
- As explained above, the varied issues and increased consumer frustration with these prepaid meters has put them at risk of consumer tampering. This is especially true because even the current meter bypasses are largely being picked up in "guess mode", whereby only consumers who haven't purchased tokens or whose purchasing patterns are irregular are highlighted to be checked for illegal connections (Mthembu, 2016).This basing of illegal consumption on sales only means that those who continue to purchase water regularly but have bypasses and are thus consuming a lot more water than is purchased at home will never be captured by this system (Mthembu, 2016).
- Drive-by data collection has been observed to have significant challenges. Where cars or other obstructions are on top of meters, they can interrupt transmission from data collectors, so drive-by readings may not be taken (Mthembu, 2016).This, combined with the lengthy data interpretation and formatting process, means that the un-captured meter readings will only be picked up very close to billing time (Mthembu, 2016). This results in some houses not being charged their sanitation fees for long periods of time (Mthembu, 2016). Subsequent charging of these consumers with lump sums after long durations of time is not convenient in many instances and, instead, entrenches quarrels and refusal-to-pay attitudes amongst consumers (Mthembu, 2016).
- The prepaid meters have multiple components, each with significantly higher failure rates in comparison to conventional meters. For example, approximately 80% of the UIUs installed as part of this study were found to be faulty from the time of installation and in need of replacement, which the supplier did for free (Mthembu, 2016). Even a significant number of batteries were found to need replacement within the first year of installation in spite of the 10-year battery life claimed by the supplier (Mthembu, 2016). These high failure rates, coupled with a lack of satisfactory

reasons being provided for said failures, have resulted in an unwillingness to recommend this technology to other municipalities (Mthembu, 2016).

- Another widespread problem encountered in the use of these meters was the WMD automatic close off at the start of each month, regardless of the water credits still available (Mthembu, 2016). Widespread complaints were received in this regard necessitating a large number of meter repairs and/or replacements to be done as well as an inquiry from the municipality to the supplier as to why this technical fault was so rampant (Mthembu, 2016).
- Leakage from pipes, particularly where poor plumbing/installation work had been done, was another problem experienced, resulting in substantial background water losses being experienced (Mthembu, 2016).
- The vulnerability of prepaid meters to air in the pipe network is very high. In many instances, this has resulted in depletion of consumer credits by air instead of water in the system and thus premature cut off of consumer water supply in spite of the fact that water paid for had not actually been used (Mthembu, 2016).

5.6.4 Social Challenges

As is the case with most infrastructure projects, social impacts and engagements are inevitable. Some of the social challenges experienced were as below:

- Frustration of customers with the multiple failures of these meters and the consequent interruptions to their supply (Mthembu, 2016). In some instances, customers even demanded their old conventional meters back (Mthembu, 2016).
- Due to the increased bills, particularly from increased sanitation charges, high instances of vandalism and tampering were faced, particularly in instances where lump sum bills or high debts were difficult for consumers to pay off (Mthembu, 2016).
- In some cases, due to insufficient consumer education or awareness about the prepaid meters and how they worked, confusion persisted about their alignment with/dispensation of free basic water (the water dialogues, 2008).
- In some instances, a wrongful perception persisted that water had become more expensive with the installation of prepaid meters, and yet increments in consumption could just be attributed to improved meter accuracy (Mthembu, 2016).

5.7 Current Status of iLembe Prepaid Metering Project

The municipality currently has both prepaid and conventional metering systems running. Regardless of the significant issues faced with the prepaid meters, reversion back to the more reliable conventional meters would require significant investment in terms of retrofitting and reconfiguring the network back to its old state, since some of the system piping was modified to accommodate the prepaid WMDs (Mthembu, 2016). It is therefore not considered a cost-effective solution at this time (Mthembu, 2016).

Another counter to the idea of reverting back to the old system is the argument that the prepaid meters are working well in high-income gated communities (Mthembu, 2016). The implication of this is that the usage of these meter facilities in low- or middle-income areas is at fault as opposed to the technology itself (Mthembu, 2016).

Although both in-house as well as contracted-out teams are carrying out maintenance of the metering system, USC has, on occasion, been given a number of faulty meters and asked to explain why there were so many faulty meters (Mthembu, 2016). In these instances, they have often returned a portion of the meters fixed while returning others which had completely failed without repair, since the warranty period had ended, with no explanation for the failure or recommendation to the municipality (Mthembu, 2016). The municipality thus feels no closer to understanding why the units on the ground are failing and why they are failing with such regularity (Mthembu, 2016).

The municipality would thus prefer to have a competitor in the advanced meter market who will either offer a more durable product or alternatively force USC to improve their product, as opposed to going back to the conventional system, since consumers still do not want to pay for water (Mthembu, 2016).

6. PREPAID METER INSTALLATION IN OLIEVENHOUTBOSCH, TSHWANE

6.1 Introduction

The City of Tshwane is comprised of five administrative regions: the southern, north-west, eastern, north-east and central regions (City of Tshwane, 2010). Water and sanitation maintenance works are, however, divided into seven regions: regions 1 to 7 (Ngobeni, 2016). Of these regions, approximately 95% of water consumption is monitored by conventional meters and 5% by prepaid metering (Ngobeni, 2016).

The prepaid meter roll out started in 2003 with a total of about 6 000 prepaid meters installed to date (Ngobeni, 2016). The roll out started as a pilot project in Olievenhoutbosch Extension 36 and 37, located in Maintenance Region 4, and it is here that these meters remain focused to the present day (Ngobeni, 2016).

Olievenhoutbosch is located in the southern region of the City of Tshwane along with Centurion (City of Tshwane, 2010). It is one of the more formalised townships, with an area of about 11.39 km,[2] housing a population of approximately 70 863 residents, 98% of whom are Black African (Statistics South Africa, 2012 & wikipedia.org). Up to 87% of residents in the southern region have access to piped water within their households (City of Tshwane, 2010).

The prepaid meters installed are largely domestic meters located above ground and they are programmed to dispense a 12 kl/month FBW allocation to all users (Ngobeni, 2016). The main reason for installation of these prepaid meters was to assist in debt control by minimising the non-revenue water losses to only FBW allocation (City of Tshwane, 2012b). Additionally, prepaid meters would be able to circumvent billing inefficiencies caused by conventional meter readers' failure to take and/or report actual physical meter readings (Ngobeni, 2016).

The section below will delve into more details about the project implementation process. A more detailed breakdown of this case study's evaluation inputs and results is provided in Appendix B of this report.

6.2 Project Implementation Process

The three main prepaid meter systems to choose from included the communal standpipe type, the domestic wall-mount type and the domestic above-ground type (Ngobeni, 2016). This study focuses on the domestic above-ground meters used in Olievenhoutbosch which were chosen because they offered easy monitoring by the municipality as well as easy credit loading and consumption tracking by the user (Ngobeni, 2016).

The process involved complete removal of conventional units and their subsequent replacement with the prepaid units (Ngobeni, 2016). In addition, some of the supplier training options offered included:

- *"Full training for all aspects of system"*
- *"In field training for consumers"*

- *"Follow up training ensuring efficient operation of system by all levels of staff" (Ngobeni, 2016)*

However, before any particular meter was settled on, product specifications were formulated to guide the municipal procurement process. These requirements were made up of three main sections: legal, technical and warranty (Ngobeni, 2016). Amongst the legal requirements was compliance with the relevant SANS 1529 Trade Metrology Acts for Class C Meters, as well as JASWIC (Joint Acceptance Scheme for Water Services Installation Components) acceptance (Ngobeni, 2016).

The technical specifications included a requirement for 15 mm diameter units with above-ground plastic housing, compatibility with prepayment systems, inclusion of all appurtenant components, i.e. the battery, shut-off and non-return valves, computing unit and transmitting reed switch sensor, all connected to the volumetric meter unit as well as different tokens required (Ngobeni, 2016). Visibility of valve status, available allocation, battery life, leak detection and tamper detection on the remote display unit was also required (Ngobeni, 2016).

The warranty period specified for each unit was 1 year from delivery time (Ngobeni, 2016).

With the above requirements in mind, Elster Kent above-ground meters were eventually chosen for the prepaid meter roll out. The technical specifications of these chosen meters are given in the section below.

6.3 Technical Specifications of Elster Kent Prepaid Meters Installed

The Elster Kent prepaid metering system is a proprietary token-based vending system. The meter consists of several features each of which contributes to its overall use:

- Domestic water dispenser
- Above-ground meter box
- Tokens
- Hardware system components
- Cash-flow management system
- System requirements
- Management information
- Prepaid meter display

A brief description of the above feature characteristics, per the technical specifications used in procurement as well as the manufacturer's claims, are provided below.

6.3.1 Domestic Water Dispenser

Class C meters of 15 mm diameter and 114 mm body length with 0.5 litres/pulse pulse output facilities were required (Ngobeni, 2016). These dispensers were to have field replaceable lithium SAX1327L batteries as well as be fitted with Aquacity 25 mm valves [SAX1136] and actuated valve replacement diaphragm mains [SAX1347- 48] (Ngobeni, 2016). A replaceable control box and associated battery for the domestic water dispenser was also required (Ngobeni, 2016).

6.3.2 Above-ground Meter Box

The meter box was to be constructed from UV-stabilised plastic of at least 4 mm thickness, with approximate dimensions of ±800 mm height; ±250 mm width and ±100 mm depth (Ngobeni, 2016). Protection from soil ingress in the form of a base plate on the meter box was required as well as use of washers and O-rings to prevent leaks at the inlet and outlet box connections (Ngobeni, 2016). Ability of the box to withstand external sitting, tilting or standing pressures exerted by users was to be ensured as well as internal protection for the consumer valve (Ngobeni, 2016). To assist installation, the flow direction was to be indicated clearly on the box as well as a line showing the recommended installation depth (Ngobeni, 2016). For readability, the box was to have a slot at the lid top for taking meter readings and this lid was to be fixed with tamper-proof locks that allow only authorised municipal personnel to open them (Ngobeni, 2016).

A picture showing this meter box is provided below.

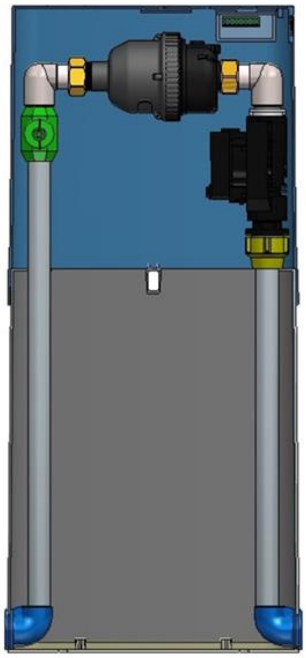

Figure 6-1: Prepaid Meter Above-ground Box (Elster Kent, 2014)

6.3.3 Tokens

Five different types of tokens can be used with the Elster Kent prepaid metering system:

- Consumer token
- Maintenance token
- Management token
- Engineering token
- Vendor token.

For this Pretoria case study, however, only three of these tokens were specified, i.e.

- Blue consumer tokens
- Green maintenance tokens
- Yellow engineering tokens.

Pictures of the tokens are shown below:

Figure 6-2: Consumer token (Elster Kent, 2014)

Figure 6-3: Maintenance token (Elster Kent, 2014)

Figure 6-4: Engineering token (Elster Kent, 2014)

It was also specified that the token touch port on the meter box be of stainless steel ring design to enable easy data/credits transfer (Ngobeni, 2016). The system was also required to be upgradable to a walk-by or fixed network AMR system with the ability to perform upgrades without removing the meter box from the installation (Ngobeni, 2016).

The token benefits claimed by the manufacturer include the following:

- *"Read/write token with non-volatile memory"*
- *"Encrypted token with cycle counter eliminates fraud"*
- *"Ensures transfer of up to date info of usage"*
- *"Data retention over 10 years"*
- *"Resistant to extreme environmental conditions i.e. shock and temperature (-20° to +70° C)"*
- *"Information stored includes: Account no., Credit Remaining, Consumption profile, Leak and tamper icons, Last meter reading, Programmed information." (Elster Kent, 2014)*

6.3.4 Hardware System Components

Per the manufacturer's claim, the main hardware system components are comprised of a tamper switch, isolating latching valve, pulse output meter and electronic module. The benefits of these components, according to the manufacturer, include (Elster Kent, 2014):

- *"Quality proven components"*
- *"Ease of installation (no fittings needed)"*
- *"Pulse output water meter approved to Class C"*
- *"Approval No. SA842"*
- *"Electronics water resistant to IP 67"*
- *"Electronic totaliser with 0.5l resolution"*
- *"Up to 7 years battery life."*

6.3.5 Cash-flow Management System

This can be quite a complex system depending on the size or extent of the prepaid meter installation project. According to the manufacturer, it is possible for this to be a central system that houses information on multiple villages/areas whose consumers make use of multiple work stations (Elster Kent, 2014). This can be by aggregating collected village/area databases, consumer databases and vendor databases (Elster Kent, 2014). The information contained therein can be used for generation of reports on consumer sales as well as other pertinent administrative and access control system information required (Elster Kent, 2014).

6.3.6 System Requirements

Specified hardware and software form the system requirements for vending, and for monitoring the installed meters. The hardware requirements, per the manufacturer's claim, include; "PC with Pentium or higher processor, 512 MB DDR2 memory, 80 GB hard-disc drive, VGA or higher resolution monitor, Microsoft mouse or compatible pointing device, a printer and keyboard, two open serial or USB ports and external drive/CD writer"(Elster Kent, 2014). The system software includes "Windows 95, 98, 2000 or NT" (Elster Kent, 2014). To make good use of these requirements, however, staff should be trained in the different aspects for use (Elster Kent, 2014).

6.3.7 Management Information

The information obtained from these prepaid metering systems that enables easy municipal monitoring and/or management includes: Monthly and daily sales analysis, consumer profiles of monthly consumption, reporting of discrepancies and logging of maintenance activities (Elster Kent, 2014).

6.3.8 Prepaid Meter Display

Before information is recorded and stored by the token and management systems, the meter display is able to indicate the following, according to the manufacturer's claims: "Credit remaining, leak detection, tamper detection, meter reading, free water and amount remaining, indication of tariff scale and R per m^3" (Elster Kent, 2014).

6.4 Benefits of the WMD Implementation

The benefits realised in the use of these prepaid meters include the following:

i. Wide-scale community acceptance of the system, largely because lower fixed rates were charged for consumers on prepaid meters. This acceptance resulted in minimal vandalism of this infrastructure, comparable to conventional meters (Ngobeni, 2016).

ii. Reduced consumption was observed as a result of the prepaid meter installations and this aided water demand management (Ngobeni, 2016).

iii. There was a reduction in the resources required for meter reading since the prepaid meters rendered this process irrelevant (Ngobeni, 2016).

iv. No billing was required and this, in tandem with upfront payment for water, resulted in improved credit/debt control (Ngobeni, 2016).

v. New consumers connected to prepaid meters were exempt from a deposit for water consumption, further endearing these meters and the City to the community (City of Tshwane, 2015).

However, in spite of the above, a number of challenges were experienced, as discussed in the sections below.

6.5 Challenges Encountered

The challenges experienced are sub-divided into technical, social and economic.

6.5.1 Technical Challenges

(a) Failure rates

The prepaid system has multiple components susceptible to failure. As such, the failure rate of these prepaid meters was significantly higher than that of conventional meters (Ngobeni, 2016).

(b) Repair and replacement works

The prepaid system has a higher level of complexity, compared to conventional meters. As such, even though modular units with batteries replaceable in the field were obtained, in some instances the whole unit had to be replaced when one component was damaged. This was because there were instances where damage to other components was caused in the course of replacing a faulty component (Ngobeni, 2016).

(c) Water losses

Meters in some instances failed in the open position. This resulted in large volumes of unrecorded water being availed to the consumer, particularly since failures of this nature would rarely be reported to the municipality as opposed to instances where meters failed in closed position (Ngobeni, 2016). Increased NRW was therefore realised in these open position failure scenarios.

(d) Health and safety risks

In instances where meters failed in the closed position, increased fire risks were imposed on consumers (Ngobeni, 2016).

(e) Leak and tamper detection

Since meter readings were not required, field detection of leakages, tampering and vandalism on site was not being done, further increasing water losses (Ngobeni, 2016).

Furthermore, the tampering detection facility, as was the case in iLembe, works based on sales whereby only consumers whose pattern of water purchases reduces or varies dramatically will be flagged for an illegal use or tampering check (Ngobeni, 2016). This leaves the system vulnerable to abuse in other ways.

(f) Consumption monitoring

Since tokens are used to purchase water, it is difficult to monitor the consumption patterns of consumers since this would require tracking individuals' token purchases, their frequency of use and then conversion of these purchases to consumption values (Ngobeni, 2016). Since this type of exercise has not been embarked on, accuracy in demand monitoring and water balancing has been affected.

6.5.2 Social Challenges

The different social challenges faced in the use of these prepaid meters are explained below.

(a) Vending

There is only one vending station and due to the working hours of municipal vendors employed therein, consumers are unable to purchase water credits after hours or during weekends (Ngobeni, 2016). They would therefore have to interrupt their schedules to purchase water during business hours or do without water in cases where it runs out after these times (Ngobeni, 2016). Health and safety risks were therefore inevitable in these cases as well as unsatisfied consumers with multiple complaints.

(b) Operations and maintenance capacity

There was insufficient staff to handle the increased meter failures and consequent maintenance requirements, resulting in delayed responses to customer complaints (Ngobeni, 2016). At one stage, only one team was trained to carry out repairs to the prepaid meters, and therefore no back-up capacity for this team was available (Ngobeni, 2016). An effort to have more teams that can deal with these repairs was therefore being made (Ngobeni, 2016).

6.5.3 Economic Challenges

Some of the economic challenges encountered in use of the prepaid meters are highlighted below:

(a) Limited purchases

The presence of only one vending station, with limited working hours, restricted the amount of water credit purchases made (Ngobeni, 2016). This therefore reduced the revenue stream that would otherwise be obtained from these prepaid meters if multiple vending options were available.

(b) Tariff application

Application of a rising block tariff to prepaid meters was found to be problematic. This is because consumption measurements are not made for payments made upfront and yet these measurements form the basis of rising block tariff application (Ngobeni, 2016). As such, a fixed rate was applied, regardless of volumes purchased, resulting in the prepaid meters being cheaper than conventional ones. The revenue that would otherwise have been made from water, as well as sanitation charges levied at 10% of the water consumed, was thus curbed (Ngobeni, 2016).

(c) Maintenance intensive

Given the increased complexity of prepaid meters, more staff and resources are required to adequately maintain the meters, increasing operation and maintenance costs at municipal level (Ngobeni, 2016).

(d) Capital costs

The capital costs of the prepaid meters are significantly higher than those of conventional meters, imposing an additional cost burden on the municipality (Ngobeni, 2016).

(e) Open position failure

As mentioned in 6.5.1 above, device failure in the open position results in large volumes of water being supplied to the consumer regardless of credit availability (Ngobeni, 2016). Significant revenue is lost from this unregistered water (Ngobeni, 2016).

In light of the aforementioned benefits and challenges, a status update on the current prepaid meter situation in Olievenhoutbosch is given in the section below.

6.6 Current Status of Prepaid Meter Installation in Olievenhoutbosch

Continued roll out of smart meters is being carried out in Olievenhoutbosch due to popular demand (Ngobeni, 2016). This is largely due to the fact that the tariffs, since the time of the first pilot in 2003, have not been changed to date making water dispensed by these meters significantly cheaper than water via conventional meters whose tariffs are typically revised every year (Ngobeni, 2016). As such, planned changes to these tariffs with R2-3 increments may cause a social outcry since the current preference for these prepaid meters is largely tagged to water affordability (Ngobeni, 2016).

Regarding operation and maintenance, currently only one team has been trained to manage these meters, and thus no stand-by team is available to work when this team is off-duty. Efforts to train at least two to three teams in dealing with the prepaid meter issues are thus being made to provide the necessary assistance (Ngobeni, 2016).

In Section 5.3 above, some of the specifications used for prepaid meters at the time of the tender in 2003 were given. Innovations/improvements in the advanced meter industry mean that they can currently offer more robust technologies to utilities that were not available in 2003.New specifications that require STS compliance to diversify the vending options available, as well as IP68 water resistance and other more durable meter characteristics are now used when purchasing newer models of these prepaid meters (Ngobeni, 2016).

7. AUTOMATIC METER READING IN EPPING INDUSTRIAL AREA

7.1 Introduction

Advanced meters are gaining increasing importance in the management of water resources today. The City of Cape Town, from February 2008 to May 2010, rolled out a pilot project to test the economic and technical efficacy of using advanced meter reading technology to measure water consumption and manage demand, while improving customer service.

Under AMR Pilot Project: Tender 30S 2007/2008 for the City of Cape Town, three pilot project areas were chosen, each with unique characteristics, in order to test this technology's functionality under different conditions. These areas were Sunset Beach, a residential suburban area, Epping, a major industrial area, and N2 Gateway, another residential area housing several high-density blocks of flats (De Beer, 2010).

The focus of this case study will be Epping industrial area situated to the south of Thornton, east of Pinelands and north of Langa. As one of Cape Town's largest industrial hubs, manufacturing contributes about 43% of the activity in Epping industrial area (City of Cape Town, 2016). The products manufactured range from fabricated metal work, machines and equipment, wood products and chemical and plastic products (City of Cape Town, 2016). It can therefore be expected that water consumption in this area is higher than in a typical residential area. The scope of the pilot project in Epping was an area of 6.8 square kilometres comprising approximately 430 water meters of sizes varying between 15 mm and 200 mm (De Beer, 2010).

A more detailed breakdown of this case study's evaluation inputs and results is provided in Appendix B of this report.

7.2 Reasons for Implementation

Automatic Meter Reading (AMR) involves the capture of consumption data from a customer's premises and the relaying of this data to a remote central location (De Beer, 2010). This type of advanced metering system was chosen by the City of Cape Town for implementation in Epping industrial area and the two residential areas mentioned above.

AMR systems have benefits such as obtaining readings at any time on demand, real-time leak detection, no need for property access, reduced billing cycles and rapid client dispute resolution (De Beer, 2010). In addition, managing water demand and conservation is greatly assisted by effective metering, monitoring and control of the water reticulation system, functions that are supported by AMR technologies (De Beer, 2010). Given these benefits, the pilot project was implemented in order to determine the feasibility of AMR system use, and its ability to achieve these benefits, in different areas of Cape Town.

On 18th February 2008, a tender was awarded to Hydrometrix Technologies/Cape Digital Solutions Joint Venture (JV).

Radio frequency technology for AMR systems can vary from low-power, pulse-activated (for “walk-by” or “drive-by” systems) to high-power, licensed, fixed radio networks, or alternatively to low-power, licence-free, two-way communication, integrated radio mesh networks (De Beer, 2010). Of the two remote reading types, i.e. high-power, licenced fixed RF networks and the integrated low-power, licence-free RF mesh networks, the latter was preferred by the contractor due to its cost-effectiveness, flexibility, scalability and low maintenance needs. Additionally, its low power requirements result in longer battery life and, due to the absence of licensing conditions, it is geographically unlimited (De Beer, 2010).

The contractor’s RealSens AMR system was thus based on a two-way, licence-free, 868 MHz radio frequency communication system. This system transmits meter reading data via a GSM (GPRS) network to a system server where data is inserted automatically into a MySQL database (De Beer, 2010).

For data transmission to occur, the water meter is fitted with a pulse output device (reed or inductive switch), a radio transceiver (meter interface unit - MIU) connected locally to the water meter, a low-power radio repeater network and GSM device(s). Data logging is done by the MIU facility until a request is received to upload the meter readings to the database. To upload, the MIU sends the stored readings via the repeaters to a GSM device, which in turn forwards the data to the remote database (De Beer, 2010).

The scope of the pilot project was to equip each meter in the pilot area with the AMR communication components from which the meter data logged could be sent at predefined intervals to a MySQL database server. This upgrade was to be followed by a three-month evaluation period during which meter readings obtained from the AMR system would be compared with manual readings to determine the success of the system (De Beer, 2010).

Figure 7-1: Epping Industrial Pilot Area (De Bruyn, 2009)

7.3 Project Implementation Process

Prior to the AMR installation, the two preliminary processes explained below had to be undertaken:

7.3.1 Consumer Awareness

An AMR project, like any other city infrastructure implementation, affects numerous parties whose usual operations will be impacted by the works to be done. In this case, checks and consequent upgrades had to be done on individual consumer's meters, some of which were located inside the consumer's properties. In addition, intermittent shut down of the water supply to some consumers had to be done where meter repairs or replacements were required. All affected parties thus needed to be given notice of the project's aim and implications, including approximate time schedules of when field personnel should be expected in or near their properties. Various awareness strategies, ranging from local newspaper articles, notices in their utility bills and hand-delivered notices, were employed prior to installation (De Beer, 2010).

7.3.2 Meter Audits

The aim of meter audits is to verify the utility's meter database by ensuring that field meter details such as property reference, serial number, size and type match utility office records. This audit, in this case, had the additional aim of determining which meters could be replaced with AMR compatible ones. This comprehensive process involved field data capture, comparison of field and municipal data, data clean up involving both office and field verification and finally compilation in GIS and data tables (De Beer, 2010). A total of 439 properties in Epping were visited, of which 315 had meters that were not compatible with AMR, 87 had meters that were compatible and, for 19, AMR compatibility could not be determined due to the meters not being found (De Beer, 2010).

Figure 7-2: Actaris Combination meter with two-channel MIU (De Beer, 2010)

The above two processes formed the basis of the meter replacement activity, in which AMR-incompatible meters were replaced with new AMR-compatible ones, while the meters that could not be found were reported in a snag list to the CoCT.

Following the replacement activity, reed switch and MIU installations were carried out on all meters (De Beer, 2010). With all the upgraded meter locations marked on maps, the radio network planning regarding the placement of repeaters and GSM devices could be done on a map background. Repeaters were placed as high above the ground as possible, for communication and safety reasons, while GSM devices, which require a permanent power source, had differing positions from initial map placements dependent on the availability of these power sources (De Beer, 2010).

Figure 7-3: GSM unit mounted with Isolating switch (De Beer, 2010)

Once the above installation process was complete, a snag list including pilot area meters that were not fitted with AMR due to incompatibility, inaccessibility and any other reasons was compiled and reported to the City of Cape Town. A post-audit and data integration process then formed the final stages of the AMR implementation process (De Beer, 2010).

7.4 Benefits of the AMR System

As initially anticipated, a number of benefits were observed as a result of this pilot project and these included the following:

i. During the meter audit and replacement phases, bypassed and vandalised meters within the area were identified and repaired or replaced thus saving the utility further revenue losses (De Beer, 2010).

ii. Oversized meters and old meters which had exceeded their service lives were identified and replaced (De Beer, 2010).

iii. Tampering, leakages and improperly functioning meters could be detected timeously with the AMR technology in place (De Beer, 2010).

iv. On-demand meter readings and consumption monitoring could be done with the central database thus reducing hazards to meter readers such as traffic, where meters were in hard-to-read locations (De Beer, 2010).

v. An update and mapping of the city's meter database improved billing efficiency and eased customer service query handling (De Beer, 2010).

7.5 Challenges Encountered

A number of challenges, however, were also encountered by the City of Cape Town, during the implementation phase of this pilot project and the subsequent operation and maintenance phases. These challenges are expounded below, divided into administrative, technical, operational and social challenges.

7.5.1 Administrative Challenges

The administrative shortfalls which negatively impacted this project included the following:

- Delays in the city procurement process resulted in delays in the delivery of meters which extended the project implementation timeline (De Beer, 2010).
- Poor coordination between the different parties involved in the implementation process also caused delays; for instance where the meter supply contractor upgraded existing meters which had already been recorded in the meter audit by the AMR contractor; and thus the upgrade materials that the AMR contractor had initially planned for based on the audit results needed to be updated and reordered too (De Beer, 2010).
- Some of the AMR components (repeaters and GSM devices) require permanent power sources to run. Their mounting therefore required notification and approval from electricity and street lighting authorities in some instances. The administrative processes required to get these approvals lengthened the project time schedule (De Beer, 2010).
- The City had a three-year meter procurement tender in place from which only a particular make of meter could be ordered. Because AMR had not been anticipated at the time the meter tender was instigated, no consideration had been given to meters with pulse outputs. Consequently, for the 25 mm domestic meters on tender, a significantly more expensive pulse device compared to a standard reed switch was required to ensure compatibility, thus inflating the initial contract price (De Beer, 2010).

7.5.2 Technical Challenges

The technical setbacks experienced are summarised below:

- Incompatibility whereby some of the existing meters were not pulse upgradable and thus needed to be replaced before AMR could be installed (De Beer, 2010).
- Battery failure of the different AMR components making it impossible to obtain meter readings (Wendell, 2016).
- Meter box sizes restricted the meter body lengths that could be used, and since in many instances, this was only discovered on site, it resulted in cancellation of the orders of longer-body length meters and replacement with ones of shorter body length. This replacement process caused unnecessary delays (De Beer, 2010).
- Other delays were caused by the need to close zonal valves in instances where meters to be worked on couldn't be isolated due to defective shut off valves (De Beer, 2010).
- In the course of some meter replacements, it was observed that some meter flange types were not compatible with the existing fittings, thereby triggering another procurement process before the replacement could be concluded (De Beer, 2010).
- It was observed that electric streetlights in very close proximity to repeaters could cause radio interference and so great care needed to be taken with AMR component installation procedures to avoid this (De Beer, 2010).
- Defective meters whereby a specific type of meter installed during the project produced such a weak magnetic field that the reed switch struggled to operate accurately resulting in large reading errors (De Beer, 2010).
- Meter chambers with metal lids and buildings with excessive metal cladding and/or steel reinforcing were found to be a challenge to the AMR communication systems since they affected the transmission of radio frequency waves (De Beer, 2010). Relocation or other contingency measures had to be taken in these cases.

7.5.3 Operational Challenges

The pilot project maintenance and operation challenges included the following:

- Buried and/or broken valves and meters increased replacement needs and caused delays in meter replacement scheduling (De Beer, 2010; Wendell, 2016).
- In some cases, when manhole covers were being removed or replaced during maintenance operations, they fell into the manhole thereby breaking the AMR components installed (De Beer, 2010; Wendell, 2016).
- Poor record keeping and updating of meter and AMR system damage or upgrade activities made coordination of maintenance activities difficult (De Beer, 2010; Wendell, 2016).
- Poor meter chamber construction whereby some meter chambers had to be completely demolished to create the necessary working space to perform

- replacements and/or upgrades. These, once reported by the AMR contractor, were either exempted from the project or incurred undue time and cost burdens for the City of Cape Town (De Beer, 2010).
- Some meter locations were difficult to access and this factor, as well as poor record keeping, resulted in difficulties in reconciling the field and office meter databases (De Beer, 2010).
- Flooded meter chambers due to leakages and/or groundwater ingress necessitated dewatering of chambers which increased the time needed for meter auditing and upgrades (De Beer, 2010).

Figure 7-4: Flooded meter chamber (De Bruyn, 2009)

7.5.4 Social Challenges

A number of social challenges had to be addressed, both during and after the AMR pilot project. Some of these issues are highlighted below:

- Vandalism of existing and newly installed meters and AMR components which incurred losses to the City of Cape Town (De Beer, 2010; Wendell, 2016). About 5.6% of the newly installed meters in Epping were vandalised during the evaluation period, according to the audit summary report (De Beer, 2010).
- Poor solid waste disposal practices whereby some meter chambers were filled with rubbish and so time-consuming efforts were required to empty them before meter characteristics and replacement needs could be ascertained (De Beer, 2010).

Figure 7-5: Meter chamber filled with rubbish (De Bruyn, 2009)

- A major labour concern that the City of Cape Town had to contend with was reallocation of the conventional meter readers once the AMR system was operational. This required additional logistics (re-assignment) and fund allocation (for training) on the part of the City of Cape Town (De Beer, 2010; Saayman, 2016).

Other social challenges stemmed from the attitudes of some consumers whose meters were part of the AMR pilot:

- In some cases, consumers who experienced minor plumbing problems long after their meters had been replaced blamed the contractor for these problems. The contractor, in an attempt to maintain good relations, fixed these consumers' plumbing problems at his own cost, incurring even more unanticipated delays (De Beer, 2010; Saayman, 2016).
- Some consumers disagreed with the advanced meters due to the notion of privacy invasion through the continual meter monitoring aspect of AMR systems, and these consumers were prone to vandalising the installations (De Beer, 2010).
- In instances where meters had been installed in customer driveways, breaking up and reinstatement of the driveway was required as part of the meter upgrade process. However, many customers remained dissatisfied with the reinstatement works done, regardless of their quality on completion (De Beer, 2010).
- There were some cases where consumers, in spite of prior notification of the project, resisted and/or refused to grant the contractor access to meters located on their properties. The consequent dialogue and negotiations required to obtain this access resulted in further project delays (De Beer, 2010).
- One of the more genuine delays imposed on the contractor was that factories limited their working times in order to minimise disruption to their operations. The low volumes of work achievable within these time slots, usually only weekends, therefore lengthened the overall project completion time (De Beer, 2010).

7.6 Current Status of Epping Pilot Project

The remote reading functionality of the Epping AMR system is not currently being used. Instead a walk-by approach, typical of conventional meter reading, is being used. This is because the financial investment required to operate and maintain the communication infrastructure for the remote read is high and above municipal operational capacity for the time being (Saayman, 2016).

The Epping pilot and its lessons, which are discussed further below, was therefore successful in informing the city's current stand on the use of advanced water meter reading technology. This stand is summarised below:

- The City currently only chooses to use AMR technology in the following areas:
  - Industrial and residential areas where it is difficult for municipal staff to obtain access to meters and/or where the distance between meters is large, making walk-by methods ineffective (Saayman, 2016).
  - Areas with high-income consumers (Saayman, 2016) since recuperation of the costs invested is more feasible with such consumers.

A phased approach to install AMR in the above type of areas in Cape Town is therefore underway (Saayman, 2016).

8. CONCLUSIONS AND LESSONS LEARNED

8.1 Introduction

This chapter details the lessons that were learned from implementing each of the field case studies described in Chapters 3 to 7 above. These lessons can be used as recommendations and/or points of caution to consider when proposing new advanced metering projects.

8.2 Social Considerations

8.2.1 Community Involvement

Consumer education and awareness is required to improve community attitudes towards advanced meters. Shortfalls in clarifying how billing, the indigency policy and debt rebate or cancellation would apply in advanced meter implementation still exist, and to prevent the consequent worry and rejection of these meters in communities, extensive awareness campaigns should be in place before these devices are rolled out (Wilson et al., 2008). Where differing levels of service and metering technologies are in use, this awareness and transparency will avoid confusion and consumer distrust of utility providers (the water dialogues, 2008).

8.2.2 Multipronged Method

A multi-faceted approach – education of adults and children, water-saving device usage and employment of local labour to assist in conservation measures such as clearing alien vegetation – should be adopted concurrently with advanced meter implementation (Turton, 1999). This would serve to permeate information on several levels and instil the sense of ownership that makes an advanced metering project sustainable, consequently minimising incidents of mass protest and vandalism.

8.2.3 Stakeholder Engagement

Many of the studies done on WMDs imply that acceptance of paying for services does exist in many of these areas (Rodina and Harris, 2016). This implies a need to extensively engage with local leaders and community members to identify and mitigate social burdens on the especially vulnerable in these areas, to build a sense of ownership for these devices in the community.

Engagement with other stakeholders of the utility is required. For example, in the AMR case, particular requirements like line of sight, no traffic obstructions and continuous power sources needed by the different AMR components meant that multiple locations were required in which to mount these components (De Beer, 2010). Obtaining ideal locations and approval for their use required alliances and liaison between different municipal authorities to ease this work.

8.2.4 Labour Reallocation

Municipalities, particularly those with highly unionised staff, should ensure that re-assignment or training programmes are in place so that meter readers' jobs are not threatened when remote meter reading systems are put in place.

8.2.5 Notification of Upcoming Works

An advanced metering project affects numerous parties whose usual operations will be impacted by the works to be done. Notifications of the upcoming works and their planned timeline are critical to minimise interruptions to scheduled activities and so reduce complaints during contract implementation (De Beer, 2010). Municipalities should take this into account in planning their community awareness approach and in setting realistic project timelines

8.3 Environmental Considerations

8.3.1 Water Savings

Some advanced meters are able to monitor consumption patterns and thus detect illegal connections and leakages. Their installation on large consumer meters as well as bulk and zonal meters should be encouraged to ensure saving of large volumes of water which might otherwise be lost within the network as well as reduce power requirements during the production stage of these lower volumes (De Beer, 2010).

8.3.2 Energy Use and Battery Disposal

Significant battery replacement needs have been observed for advanced metering technologies. The environmental impact of disposing of these batteries, if advanced meters are rolled out on a wide scale, therefore needs to be considered and planned for accordingly. Additionally, some AMR communication components require a permanent power source to work and so the higher electricity requirements for operation of these systems and the environmental impact of this will also need to be weighed up during the advanced meter planning phases.

8.4 Technical Considerations

8.4.1 Policy Formulation

Due to lack of experience in using these meters at the time of the pilot studies, no policy regarding their use had been previously formulated in most municipalities. As such, the experiences obtained should be used to formulate policies that guide future installations (Ngobeni, 2016).

8.4.2 Procurement

Stricter procurement specifications which combat some of the technical issues experienced in using some of the advanced metering systems should be insisted on. These include STS compliance and bi-directional communication, accommodation of step/multi-tier tariffs and billing systems, IP68 resistance of meters and multi-drilled flanges. Municipalities should also insist on durable products and write a maximum failure rate that is acceptable into the contract with the service provider.

In the Epping case study, it was observed that current meter supply contracts have a three-year tenure. A one-year tenure would allow the city to access the advantages of new, improved technologies in the rapidly growing advanced meter industry, and minimise the cost surcharges that piece-meal AMR component purchasing may entail (De Beer, 2010).

8.4.3 Disaster Preparedness

The ability to immediately respond to fire and other medical emergencies is critical to saving life and property (Pereira, 2009). Alternative water sources for emergency cases where self-disconnecting meters are installed, or configuration of these meters to allow for emergency reserves, are thus critical to their safe implementation.

8.4.4 Institutional Capacity

Some advanced meters, due to their self-disconnection function, place significantly higher demands on the maintenance and operation capacity of the municipality. Investment into improvement of the utility's institutional capacity to operate and maintain these devices, prior to their roll out, is critical to their success and will also prevent disease outbreaks from the unhealthy coping mechanisms adopted in the absence of water (Ngobeni, 2016). This is particularly important in prepaid metering cases where prepayment raises user expectations of service delivery.

8.4.5 Plumbing and Retrofitting

As mentioned in some of the case studies above, water losses due to leakage in low-income areas is very high. As a result, retrofitting and leakage repair projects, prior to implementation of the advanced meters, should be done with use of durable, high-quality pipes, meters and fittings encouraged in all aspects of low-income water infrastructure upgrades. This will also enable municipalities to more accurately ascertain the impact of advanced meters on consumption without errors due to leakage.

8.4.6 Maintenance and Operations

Meter audits, maintenance of updated meter records, meter chamber and valve inspection and preservation as well as continual field inspections to identify leakages and vandalism should be done to both ease future advanced meter implementation works as well as save the city the losses accrued from damaged meters and unrecorded consumption (De Beer, 2010).

In cases like the Epping AMR system, where more advanced skill sets are needed, the need to have maintenance contracts in place and municipal staff trained and equipped to handle these systems, was realised (Saayman,2016).

8.4.7 Compatibility Issues

Incompatibility was one of the major causes of the increased logistical requirements during AMR project implementation in Epping industrial area. Innovative systems of meter auditing as well as municipal policies clarifying how future advanced meter installations will be synchronised with existing municipal infrastructure should be formulated before any future roll outs are carried out (Saayman, 2016). The quality controls, security and privacy issues around the advanced metering information obtained also need to be clarified prior to new implementations.

8.5 Economic Considerations

8.5.1 Financial Analysis

Advanced metering systems incur both high capital investment and operating costs. However, the water tariff restrictions that municipalities face mean that their main revenue source to recuperate advanced meter system costs is limited (Saayman, 2016; De Beer, 2016). A more holistic financial and cost analysis over the entire project lifecycle of these systems, which incorporates more than just their direct and short-term outcomes, should therefore be done before large-scale implementation is carried out.

An example of high capital cost is that existing water meters can be upgraded to AMR systems, and yet the unit cost of some of the additional components, for example, MIUs, can vary from R65 to R650, which eclipses the cost of some conventional meters (Saayman, 2016). Another example of high operating cost is that continual monitoring of these systems is often restricted to particular clusters, for example in parts of Europe, to minimise the increased infrastructure running costs (Saayman, 2016).

8.5.2 Vending Infrastructure

Large-scale roll out of proprietary-based systems is not feasible for some areas since the risk of being locked into a system that may not work is high and the reinvestment into an all-new advanced system infrastructure not viable. These proprietary systems should therefore only be piloted on a small, and therefore manageable, scale in a few areas, and any new advanced meter procurements should require STS compliance for bid consideration (Saayman, 2016).

8.5.3 Legal Considerations

he legality of using some advanced meter records, for example AMR records, for billing purposes is restricted to six months, after which time, physical readings and a meter audit must be conducted (Pontia, 2016). The cost implications of this, as well as its policy restrictions on the municipality particularly in cases of customer complaints/bill disputes. should consequently be considered.

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APPENDIX A

AN EVALUATION FRAMEWORK FOR ADVANCED METERING SYSTEMS

Water Research Commission Project K5/2370
"State-of-the-Art in Advanced Metering Technology and Application"

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ABBREVIATIONS

AADD	Average Annual Daily Demand
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
CDMA	Code-Division Multiple-Access
GSM	Global System for Mobile for communication
HAN	Home Area Network
LAN	Local Area Network
NIST	United States National Institute for Standards and Technology
PLC	Power Line Communication
RF	Radio Frequency
SEP	Smart Energy Profile
UMTS	Universal Mobile Telecommunications System (UMTS)
USC	Utility Systems
WAN	Wide Area Network
WCDMA	Wideband code-division multiple-access
WMN	Wireless Mesh Network
WRC	Water Research Commission of South Africa
WBKMS	Web-based Knowledge Management system

1. INTRODUCTION TO EVALUATION FRAMEWORK

This appendix describes the application of an evaluation framework for advanced water metering projects. The framework itself is provided as a separate spreadsheet which can be downloaded at http/www.wrc.org.za/software/AdvancedMetering.

It is important to stress that the evaluation framework is meant as a guide to help designers make appropriate decisions on the implementation of advanced metering projects. Advanced metering projects are highly complex and no evaluation tool can replace the engineering analysis and judgement required to make sensible decisions on their implementation.

The framework evaluates projects in four areas:

- technical
- social
- economic
- environmental.

The technical and economic evaluations lend themselves well to calculated parameters and thus make up most of the evaluation framework. Social and environmental evaluations are less amenable to analytical measures, consequently, only a few input and calculated parameters are included in the framework. These are meant to flag issues that might negatively affect the implementation of the project and should not be used as decision variables.

The input parameters are described in table format for each section. Information on the range of values that each parameter can adopt is then presented based on a literature search, survey and case studies. These values can assist users to select appropriate model values where local information is not readily available.

The model is implemented for several case studies in Appendix B, including typical low- and high-income supply areas. The case studies may be consulted for further information on the application of the evaluation framework.

The survey referred to in this section was developed to obtain relevant information from water metering practitioners with experience in advanced metering projects. The survey was conducted at a workshop on advanced metering held in Midrand in November 2015 and further through approaching practitioners individually. The response rate to the survey was low, but the results were still considered useful in determining a typical range of values. More details on the survey can be found in Malunga (2017) and Mwangi (2017).

It was seen as important to keep the evaluation framework as simple as possible to make it easy to use and understand. It should be stressed again that the framework is not intended to be used as a black box, but as a tool to help decision-makers identify potential problems and benefits, and thus make rational decisions.

This document is structured as follows;

Chapter 2:- This chapter describes the different input parameters used in the evaluation framework. For each group, i.e. system, global, current and proposed, a brief definition of each parameter is given. Literature which includes typical values for each parameter is also given as a guideline to assist the designer to pick an appropriate value for areas where limited information is available.

Chapter 3:- This chapter describes the four different categories of framework results. It gives a brief description of the key parameters under each indicator category.

Note that the spreadsheet tools can be downloaded at http/www.wrc.org.za/software/AdvancedMetering

2. INPUT PARAMETERS

2.1 System Parameters

The system parameters describe the advanced metering project to be analysed. The system parameters are summarised in **Table 2-1**

Table 2-1: System parameters

No.	Parameter	Description
1.1	Analysis ID	Unique ID for the analysis
1.2	System name	Name of the system analysed
1.3	Suburb(s)	Suburb the system is located in
1.4	City	City or town the system is located in
1.5	Date	Date of analysis

2.2 Global Parameters

The global input parameters describe the basic system parameters used throughout the analysis. A summary description of each input parameter is given in **Table 2-2** and discussed in the rest of the section.

Table 2-2: Global parameters

No.	Parameter	Description
2.1	No of properties	The number of consumer connections included in the project.
2.2	Water cost price (R/kl)	The production cost of water. Ideally, this should include all raw water and water purification costs. Where a bulk supplier is used, this will be the price paid to the supplier for the water.
2.3	Applicable water tariff (R/kl)	The tariff used for consumption-based billing, i.e. billed metered consumption. Most municipalities use rising block tariffs and a representative water tariff should be selected from this structure. It is important to consider the inclusion of a cross-subsidy or government subsidy as payment for free basic water in the model.
2.4	Billed unmetered tariff (R/month)	The tariff used for fixed monthly water billing (i.e. unbilled metered consumption) where this is applicable.

2.2.1 Number of Properties

The number of properties (Item 2.1) gives the number of user connections that exists in a supply area. These include formal and informal connections directly to the system, irrespective of whether they are currently legal connections, metered or paying for the water consumed. However, backyard dwellers that should obtain water from the main dwelling and not from the distribution system should be excluded.

2.2.2 Water Cost Price

The water cost price (Item 2.2) is the cost the municipality incurs in the abstraction and treatment of water before it is supplied to the system. For municipalities that use their own treatment and abstraction facilities, this will be the cost of production. For municipalities that use a bulk water supplier, this is the purchase price of the bulk water. This value excludes distribution system costs such as operation, maintenance, metering, meter reading and billing costs.

According to Eberhard (2003), individual water charges vary widely across South Africa due to the large number of links in the water supply chain that are regulated in different ways and by different entities. Figure 11 shows water cost prices for different municipalities in 2003.

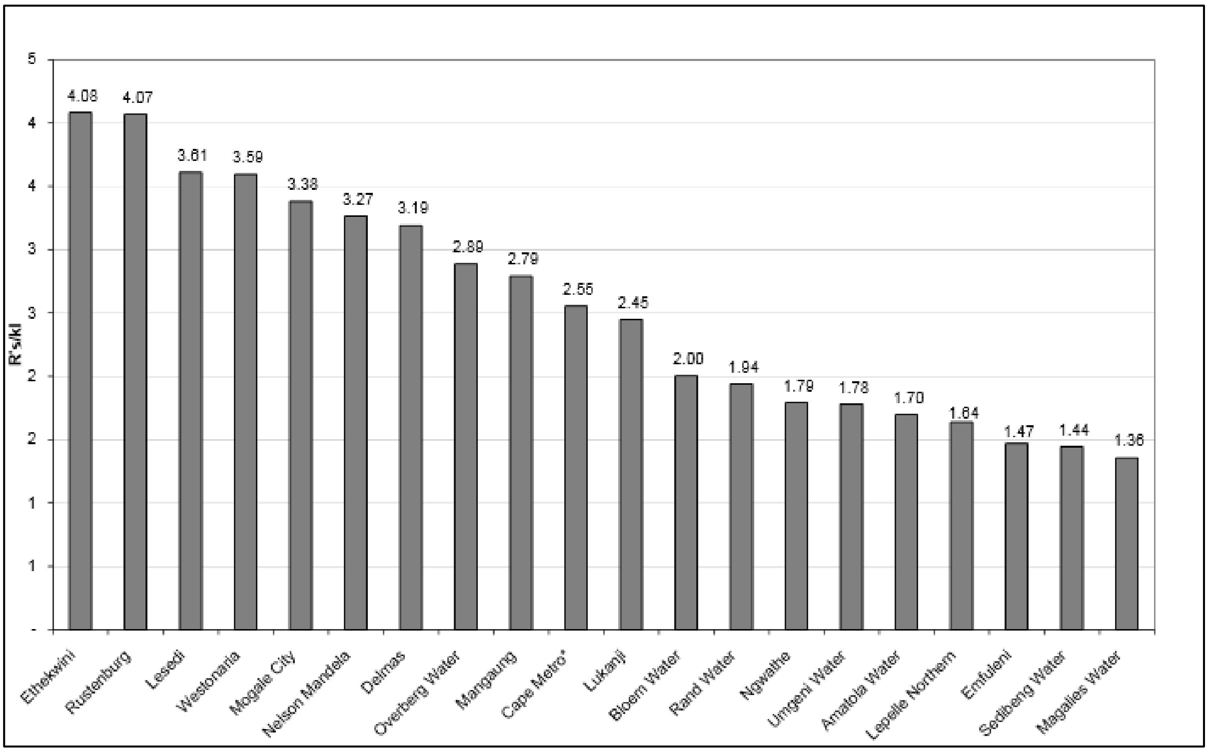

Figure 6: Bulk Water Prices in 2003(Eberhard)

The cost prices were adjusted for inflation to 2016 values using an inflation calculator for South Africa, showing them to vary between R2.65 and R7.96 (Crause, 2016). However, Eberhard (2003) found the annual nominal increases in bulk water tariffs to be significantly higher than inflation between 1997 and 2001. Thus, these inflation-corrected values are likely to underestimate the true production price.

In the practitioner survey, four correspondents reported prices between R6/kl and R10/kl, which corresponds reasonably well with the inflation-adjusted values from Eberhard (2003). Through data acquired from De Sousa-Alves (2013) and GIBB (2015), the cost of water in 2016 in Cape Town and Durban was found to be R10 per kl and R5 per kl respectively. Water Boards in South Africa vary in their average bulk portable water tariff with the Department of Water Affairs' report on water boards (DWA, 2014) giving a range of R3.20/kl to R7.55/kl.

In Australia, the production cost of water in New South Wales was AUD 0.75/kl in 2014 (Beal & Flynn, 2014), which is approximately R8.40/kl in South African currency.

2.2.3 Applicable Water Tariff

The applicable water tariff (Item 2.3) is the average price that consumers pay to the municipality for water consumed. Since municipalities use different tariff structures and rising block rates, this value should be the weighted average price paid by consumers in the study.

According to a study on average water demand by suburb (Griffioen & van Zyl, 2014) the daily demand from properties is a function of stand size, but also of a large number of other factors such as income and climate. For the smaller property size range that is typical in low-income urban areas, unit consumption varied between 6 and 30 kl/month.

In low-income areas, average consumption is often found to be substantially higher due to a lack of maintenance and high on-site leakage rates. However, since these high consumption rates are invariably associated with non-payment for the service, they were not considered when estimating the tariff range paid.

As indicated by Muller (2008), municipalities have to set the tariffs in such a way that high-volume users cross-subsidise the free basic water allocation. However, with municipalities that are too poor to be able to do that, the Constitution provides for an inter-governmental transfer, the "equitable share of revenue" from national level. Findings of the feasibility study in eThekwini indicate that the value of the free basic water allowance, as provided by the National Treasury, is R11.43/kl (GIBB, 2015).

In South Africa, increasing block tariffs are favoured for domestic, metered consumption and non-domestic consumption (i.e. institutional, commercial and industrial). A block tariff comprises of different prices for water based on the amount of water consumed. However, in South Africa each municipality utilises different water tariff structures.

Table 2-3 compares the water tariff structures for 2015/16 for domestic consumption in the different South African metropolitan municipalities. Although all municipalities use an increasing block tariff structure, each municipality charges different water prices for different quantities consumed. **Table 2-3** also indicates the different water tariffs for non-domestic consumption. The City of Johannesburg has different rates for industrial and commercial users. The rates for industrial users are given in brackets.

Table 2-3: Water tariff structures FY2015/16 for domestic and non-domestic consumption in different South African metropolitan municipalities

Quantity Consumed (kl/month)	Water Tariff by Municipality (R/kl)				
	eThekwini	Johannesburg	Cape Town	Tshwane	Ekurhuleni
Domestic Consumption					
0					
6		0	0	7.73	0
9	14.27				
10		6.86			
10.5			11.07		
12				11.03	
15		11.17			13.54
18				14.49	
20		16.17	15.87		
24				16.76	
25	16.86				
30	22.46	22.92		19.17	16.58
35			23.57		
40					
42				20.71	
45	34.63				20.63
50			29.03		
72				22.17	
> 72	38.1	28.33	38.3	23.73	25.44
Non-domestic Consumption					
0					
200		19.00 (26.25)			13.82
2500					15.28
10000				16.53	
100000				15.5	
>100000	21.19	19.87 (27.47)	17.10	14.45	18.82

In order to select an appropriate tariff bracket it is imperative to determine the consumption range for high-income areas in South Africa. Griffioen and van Zyl (2014) addressed this matter in a study looking to propose a guideline for modelling water demand. This study indicated that the factors having the greatest impact on domestic consumption were household size, prolonged high temperatures, stand area and income. Of these, stand area was the predominant factor. Griffioen and van Zyl (2014) demonstrated the correlation between average annual daily demand (AADD) and stand area. This is illustrated in Figure 15 and Figure 16 below.

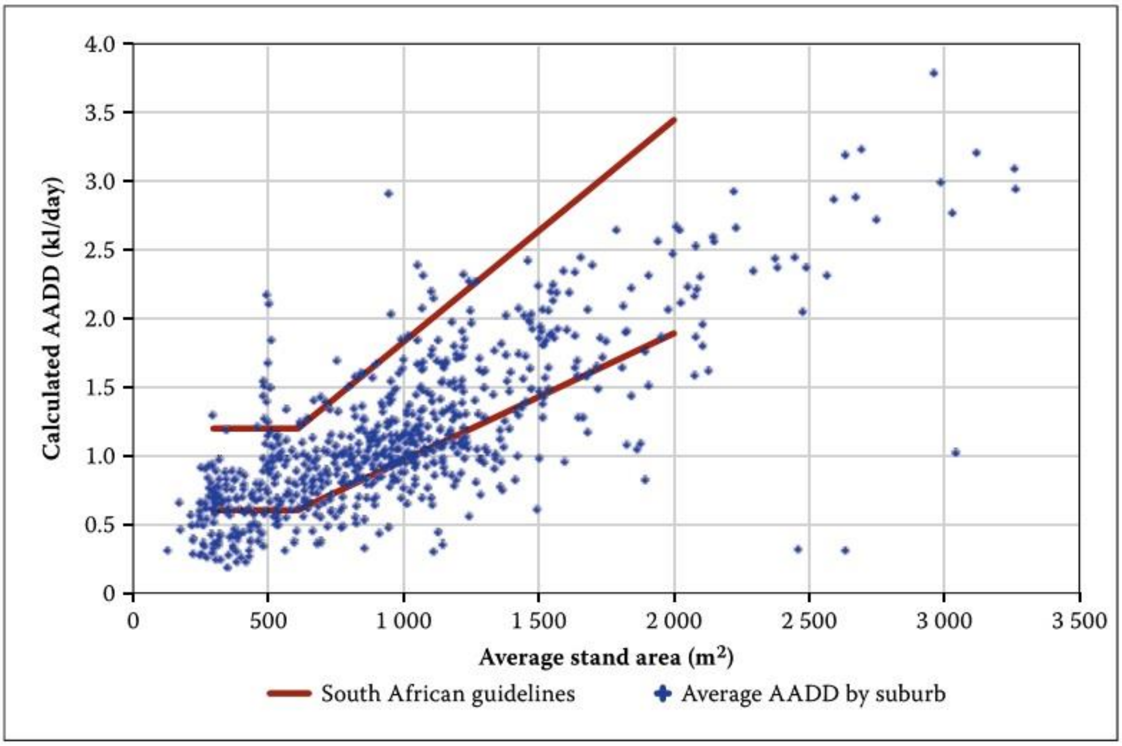

Figure 7: Average demand and stand area of 739 suburbs throughout South Africa and current South African guidelines (Griffioen & Van Zyl, 2014)

Figure 15 shows the consumption range of 739 suburbs against the upper and lower limit of the South African design guidelines. However, 4% were above and 38% were below the upper and lower limits respectively. As such, Griffioen and van Zyl (2014) proposed new design envelope curves, as illustrated in Figure 45.

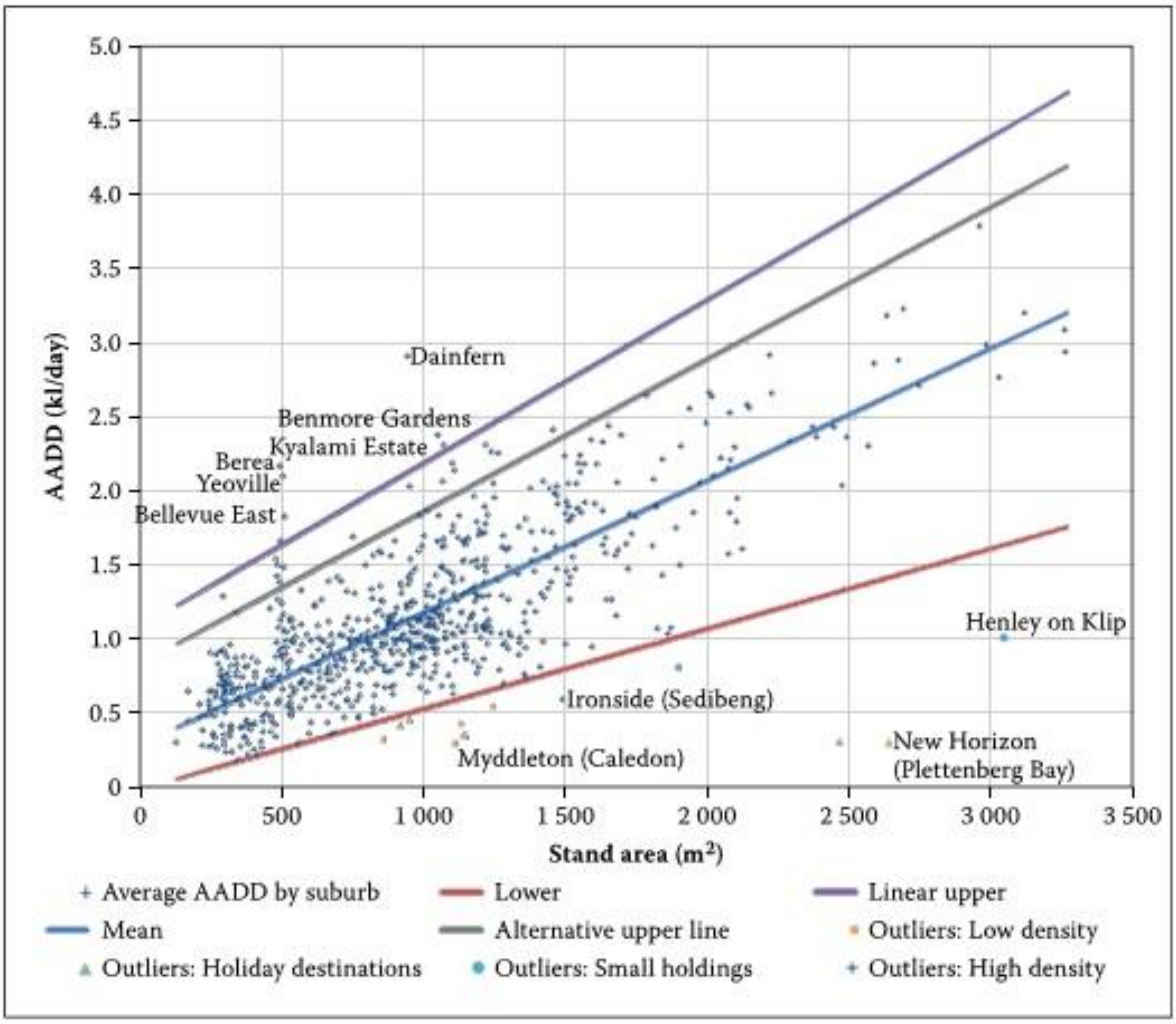

Figure 8: Proposed new design envelope curves for estimating the AADD of properties (Griffioen & Van Zyl, 2014)

Figure 16 illustrates that most of the data samples were within the design curve. The data above the upper limit represents very high-income consumers and data below the lower limit represents either coastal holiday homes or small, low density rural settlements.

Once the average consumption has been determined, the applicable average water tariff can be determined through a weighted average calculation. This method uses a cumulative procedure where tariff brackets are multiplied by the respective quantities consumed in the bracket. The resulting products are summed up until the accumulative quantity consumed equates to the total quantity consumed. The summations of the products are then divided by the total quantity consumed to get an average rate.

Finally, it should be noted that many municipalities also bill sewer services based on water consumption, normally assuming the sewer flow to be 75% of the water used. Sewer charges can be included in the analysis, when appropriate, to give a more complete picture of the project. However, if sewer charges are included in the analysis, it is expensive to operate and maintain and the sewer system cost must also be included in the analysis.

2.2.4 Billed Unmetered Tariff

The billed unmetered tariff (Item 2.4) is the flat-rate tariff charged to consumers who are not billed based on metered consumption. This is normally a monthly figure that the municipality charges its consumers, based of parameters such as stand size or land use type and consumer category.

The City of Johannesburg charges a flat water rate of R192.19/property for indigent consumers (City of Johannesburg, 2014). Marah et al. (2004) found tha,t prior to installation of prepaid meters, a flat rate of R50 per month was charged in 2004, which is R97.43 in 2016 terms.

Table 2-4 below shows the flat-rate tariffs for Ekurhuleni Municipality

Table 2-4: Ekurhuleni unmetered consumption (Ekurhuleni Metropolitan Municipality, 2014)

Tariff Summary	Tariff R 2013/14	Tariff R 2014/15
Fixed rate per month (estimated consumption less than or equal to 15 kl / month)	91,00	98,00
Fixed rate per month (estimated consumption exceeding 15 kl / month, but less than or equal to 30 kl / month)	275,00	297,00
Fixed rate per month (estimated consumption exceeding 30 kl / month)	588,00	636,00

2.3 Current Situation Parameters

This section deals with the system before any intervention is implemented. It is discussed in three sections:

- Current consumption
- Current payment rate
- Other parameters.

2.3.1 Current Water Consumption

Three types of current consumption are used:

- billed metered,
- billed unmetered
- illegal or unbilled consumption.

A summary description of the required input parameters is given in **Table 2-5**. The input parameters (with suggested typical, low and high values) are discussed in more detail in the rest of this section.

Note that a significant fraction of consumption may consist of on-site leakage, which should be included in the consumption values entered in the model. See the discussion of Parameter 3.9 for more information on on-site leakage.

Table 2-5: Current situation: consumption parameters

No.	Parameter	Description
3.1	Billed metered consumption: no. of properties	Billed metered consumption includes all properties that are metered and billed based on their actual consumption.
	Billed metered consumption: Unit consumption (kl/property/month)	The average monthly consumption of properties billed on metered consumption.
3.2	Billed unmetered consumption: no of properties	Billed unmetered consumption includes all properties that are not metered but are billed for water consumption, or are metered but not billed based on their actual consumption. This category is also know as flat-rate billing.
	Billed unmetered consumption: Unit consumption (kl/property/month)	The average monthly consumption (in kL/month) for billed unmetered consumption.
3.3	Illegal or unbilled consumption (kl/property/month)	Illegal or unbilled connections include all properties that have illegal or unregistered connections to the distribution system. The number of illegal connections is calculated in the model as the total number of properties minus the number of billed metered and billed unmetered properties.
3.4	Total/ average	The total number of properties included in the analysis is calculated as the sum of the billed metered, billed unmetered and illegal connections. The number of properties has to equal the number of properties entered under global input parameters.

(a) Billed, metered consumption

The billed metered consumption range for systems in a reasonably good condition and where consumers pay for their consumption is discussed in Section 2.3.1. In a study on prepaid meters by Marah et al. (2004) in Nkomazi, the average unit consumption was found to be 40 kl per household per month before implementation of prepaid meters and 7 kl per household per month after installation (Marah et al., 2004). The survey indicated the value to range from 3 kl/property/month to 15 kl per month.

(b) Billed, unmetered consumption

According to the feasibility study on prepaid meters in eThekwini, consumption is reduced from 1 kl/day (30 kl per month) to 0.5 kl per day (15 kl per month) after installing water meters (GIBB, 2015), implying unmetered consumption of 30 kl/property/month. In Phiri (Soweto), the water consumption was reported to be 66.7 kl/property/month prior to installation of prepaid meters when consumers were charged a flat rate for services (Singh & Xaba, 2006).

(c) Illegal or unbilled consumption

In a study on the feasibility of a prepaid metering system in eThekwini, the extent of illegal connections in low-income areas was found to range between 0% and 52% (of the connections) (GIBB, 2015). The results of the practitioners' survey indicate that the fraction ranges from 0 to 70% (from six respondents).

Illegal connections are seen to be less prevalent in high-income areas, although the survey results showed that it does occur. An assumed range for this parameter ranges from 0% to 10% with a typical value of 3%.

2.3.2 Current Payment Level

Payment levels are of critical importance for economic evaluation of advanced metering systems. A summary description of the payment level input parameters (with suggested typical, low and a high values) is given in **Table 2-6**. The input parameters are discussed in more detail in the rest of this section.

Table 2-6: Current situation parameters: payment level

No.	Parameter	Description
3.5	Fraction paying for water: billed metered consumption (%)	Fraction of billed metered properties currently paying their full water bill
3.6	Fraction paying for water: billed unmetered consumption (%)	Fraction of billed unmetered properties currently paying their full water bill

The current situation regarding payment levels of billed metered consumption (Item 3.5) reflects on payment levels where conventional meters are used (the experience with advanced meters is discussed in Section 2.6.3). From literature, it is clear that numerous factors play a role in consumers' ability to pay for water. However, the predominate one is poverty, according to the Department of Water and Sanitation (formerly the Department of Water Affairs and Forestry) which states that poverty is the root challenge to the ability to pay for water services. (DWAF, 2004)

A study in eThekwini (GIBB, 2015) showed that only about ten of low-income residents with conventional metering had their account in arrears. The eThekwini municipality is strict with non-payment for water; an annual 12% interest is charged on arrears and flow restrictors are installed on consumers' points where the account has been unpaid for 60 days (GIBB, 2015). According to this study, approximately 20% of the connections have been disconnected due to non-payment in low-income areas of eThekwini.

A study by Marah et al. (2004) indicates that before prepaid meters were installed in Umzimvubu Municipality, the collection levels were approximately 30% and the results of the practitioners' survey indicate that the fraction ranges from 0% to 50% (from two respondents).

The payment levels of billed unmetered consumption (Item 3.6) reflects payment levels in low-income areas where fixed water charges are used. The study on cost recovery by Marah et al. (2004) found that the Letsemeng Municipality experienced a very low rate of payment for fixed-rate and unmetered water services of 1%.

2.3.3 Other Current Parameters

A summary description of the other current parameters is given in Table 2-7 below. The input parameters (with suggested typical, low and high values) are discussed in more detail in the rest of this section.

Table 2-7: Other current parameters

No.	Parameter	Description
3.7	Fraction of demand that is on-site leakage (%)	The fraction of the estimated demand that is made up of on-site leakage. This parameter is not used in the calculations, but is meant as a flag of this issue as its impact on current and future water demand and the cost of project implementation should be considered.
3.8	Ave time between meter readings (months)	The average time between water meter readings.
3.9	Meter reading cost (R/meter reading)	The cost of taking a water meter reading, including transport, labour and equipment.
3.10	Billing cost (R/bill)	The cost of entering the meter reading data into the billing system, generating, printing and mailing a water bill.
3.11	Meter operation and maintenance cost (R/meter/month)	The cost of operating and maintaining the water meter.
3.12	Meter failure (/year)	The fraction of existing meters that needs replacement due to failure of the meter itself.
3.13	Vandalism and other (/year)	The fraction of existing meters that needs replacement due to tampering or vandalism damage to the meter.
3.14	Total (%/year)	The total fraction of meters that needs to be replaced per year due to failure or vandalism.

No.	Parameter	Description
3.15	Average household income (/month)	The average household income of properties in the study area. This parameter is used as a flag for the designer to consider the affordability of the water supply in low-income areas.
3.16	Unemployment rate	The average unemployment rate in the study area. This parameter is used as a flag for the designer to consider the affordability of the water supply in low-income areas.
3.17	Volatility of community (No. of protest or mass action incidents per year)	The average number of incidences of protest or mass action occurring in the study area per year. This parameter is used as a flag for the designer to consider the volatility of the community and the likelihood of the water metering project being politicised and rejected by the community, particularly in low-income areas.

(a) Fraction of demand that is on-site leakage

The fraction of demand that is on-site leakage (Item 3.7) is the fraction of estimated demand that is made up of on-site leakage. On-site leakage includes leaks from elements such as pipe fittings, taps, toilet cisterns and other household appliances (Lugoma et al., 2012).

In a study on the extent of on-site leakage in selected middle- and high-income suburbs of Johannesburg, it was found that 64% of residential properties had measurable on-site leakage with a median flow rate of 12 kl/month (Lugoma et al., 2012). In the same study, it was found that the average on-site leakage can be reduced by almost two thirds by fixing leaks in the 10% of the properties with the most leakage.

In a similar study in selected middle- and high-income suburbs of Cape Town, it was found that 16.4% of domestic properties had an on-site leakage and with a median flow rate of 10 litres/hour or 7.2 kl/month/property (Couvelis & van Zyl, 2015).

According to the same study, the prevalence of on-site leakage in low-income areas of Cape Town ranged from 17% in Mandela Park in Khayelitsha to 42% in Langa. In Bloemfontein (Mangaung) the percentage of properties with on-site leakage ranged from 3% in Motlatla to 62% in Freedom Square.

In another study, Frame et al. (2009) indicated that 62% of 8 000 low-income properties of Cape Town had on-site leakage prior to the implementation of a leakage repair programme. This programme reduced consumption from 19 kl/month/property to 11.5 kl/month/property (a 40% reduction). The practitioners' survey indicated that in low-income communities the fraction of demand that is on-site leakage ranges from 5% to 70% (from four respondents).

A study in Spain of 64 households (Arregui et al., 2006) found that most measurable on-site leakage rates ranged between 2 and 40 ℓ/h, with some leaks being as high as 100 ℓ/h. Gascón et al. (2004) found an average residential leakage rate of 17 ℓ/h per property while studying water consumption patterns in four different Spanish cities. The on-site leaks represented 8.9% of the average daily consumption.

In Australia, Beal and Flynn (2014) and Blom et al. (2010) found, through case studies, that the fraction of consumption that is on-site leakage ranges from 6% to 20%.

The results from practitioners suggested that on-site leakage ranges from 5% to 70%.

(b) Average time between meter readings

The average time between meter readings (Item 3.8) is the frequency with which water meters are currently being read. Ideally, meters should be read once a month, but not less that once every three months.

Heymans et al. (2014) advise that it is important that the monthly manual meter reading is carried out as a way to inspect the possibilities of illegal connections (Heymans et al., 2014). The practitioners' survey indicated that the average time between meter readings ranges from monthly to quarterly (from four respondents).

(c) The cost of meter reading

The meter reading cost (Item 3.9) is the cost of taking a manual water meter reading, including transport, labour and equipment.

The results of the practitioners' survey indicate that the cost of manual meter reading ranges from R4.00 to an unreasonable sounding R100.00. In a study of the economic feasibility of advanced metering technology in Melbourne, it was established that the cost of meter reading is 60 Australian cents per meter per reading (Blom et al., 2010), which is equivalent to R4.40 in South African currency in 2010, and R6.18 in 2016. A study in eThekwini established that the cost ranged from R1.74 to R4.00. R1.74 is the cost of reading a meter in informal settlements, while R4.00 is the cost of reading a meter in rural areas, as the properties are clustered together in informal settlements but remotely located leading to increased traveling expenses in rural areas.

International studies done by Arregui et al. (2003) and Sternberg and Bahrs (2015) also found that the meter reading cost ranged from approximately R5.50 per meter to R12.69 per meter, in 2016.

(d) Billing cost

The billing cost (Item 3.10) is the cost of entering the meter reading data into the billing system, and generating, printing and mailing a water bill to the consumer.

From a feasibility study on prepaid meters in eThekwini, the cost was assumed to be R10 per month per meter (GIBB, 2015) made up of a R6 administrative cost, R1 printing cost and R3 postage cost.

(e) Meter operation and maintenance cost

The meter operation and maintenance cost (Item 3.11) is the cost of operating and maintaining the water meter. This cost is dictated by the maintenance requirement of a water meter; that is through specified maintenance intervals of a meter and a strainer.

According to SGS Economics and Planning (2011), the annual maintenance cost of a meter is expected to be 15% of the purchase cost.

(f) Meter failure

Meter failure (Item 3.12) is the fraction of existing meters that needs replacement due to failure of the meter itself (i.e. excluding vandalism or other reasons). This number should reflect the ideal situation where meters that fail are replaced immediately. Thus, even if all failed meters are not currently replaced, the value should reflect the ideal fraction of replacements rather than the actual one.

Couvelis and van Zyl (2015), in a study on apparent losses, investigated the meters installed in eThekwini in the period 6 June 2005 to 28 March 2010 (five years). As part of the study it was observed that, in that period, approximately 19% of the meters were replaced, which translates into a fraction of approximately 4% per year. Based on a study done by Mutikanga et al. (2011), the failure rate is 6.6 %/year. Thus, Mutikanga et al. deemed the failure rate to be higher.

In one study in eThekwini, it was cited that from 1 July 2013 to 30 June 2014 (1 year), 8.8% of conventional meters in the database were replaced (GIBB, 2015). The practitioners' survey indicated that the fraction of meters failing ranges from 5% to 50%. The high value of 50% was in Johannesburg and Mangaung where prepaid meters were installed.

(g) Meter vandalism

The fraction of meters failing due to vandalism (3.13) and other reasons is the fraction of existing meters that needs replacement due to vandalism of the meter. This number should reflect the ideal situation where meters that fail due to vandalism are replaced immediately. Thus, even if all vandalised meters are not immediately replaced, the value should reflect the ideal fraction of replacements rather than the actual one.

(h) Average household income

The average household income (Item 3.15) is the average monthly income of properties in the study area. This value may be obtained from census data or other income studies. This parameter is used as a flag for the designer to consider the affordability of the water supply to the community.

Willingness to pay for water consumption is a major factor that has to be taken into consideration when it comes to provision of service; and this is directly influenced by social factors such as income level, household size, and education (Moffat et al., 2002). At municipal level, this willingness to pay can be predicted through establishing the correlation between level of payment for services and social factors such as unemployment rate, average family income, and level of education. Studies also indicate that stand ownership plays an important role in willingness to pay for water services.

To get further indication on the expected level of payment for services, average family income should be considered. As cited by Littlefair (1998), payment for services can be estimated using the 5% rule.

The 5% rule commonly assumes that there is an elastic demand for the purchase of water with a cost of less than 5% of a household's income and an inelastic demand where the cost exceeds 5% of the household's income.

(i) Unemployment rate

The unemployment rate (item 3.16) is the average number of people without formal employment and the figure can be obtained from census data or other employment studies of the area of study. This parameter is used as a flag for the designer to consider the affordability of the water supply to the community.

(j) Community volatility

The volatility of the community (Item 3.17 – the number of protest or mass action incidences per year) is the average number of incidences of protest or mass action occurring in the study area per year. This parameter is used as a flag for the designer to consider the volatility of the community and the likelihood of the water metering project being politicised and rejected by the community.

2.4 Proposed Parameters: System Parameters

This section deals with the proposed new conventional and advanced metering system to be installed. An option of using conventional instead of advanced water meters in the scheme is included as this option should always be considered as an alternative. This is important since advanced metering schemes are considerably more complex and costly than conventional metering. The complexity, the electronics and the additional components, such as communication and billing systems, of advanced metering results in a higher failure rate and makes increases in operation and maintenance costs inevitable. This means that advanced metering schemes will not be suitable in all situations.

The key parameters for the evaluation of advanced and new conventional metering technology are summarised in **Table 2-8** and are discussed in more detail in the subsequent text.

Table 2-8: Proposed system parameters

No.	Parameter	Description
4.1	Meter make	The make of the meters proposed for conventional and advanced meters.
4.2	Meter model	The models of meters proposed for conventional and advanced meters.
4.3	SANS 1529-1 compliant?	Do all the meter models comply with SANS 1529 Part 1?
4.4	SANS 1529-9 compliant?	Does the advanced meter model proposed comply with SANS 1529 Part 9? (This document does not apply for most conventional water meters.)
4.5	Mean battery life (years)	The mean battery life of the advanced water meters.
4.6	Battery replaceable in field?	Can the battery be replaced in the field or should the meter be replaced when the battery runs flat?
4.7	Meter service life (years)	Expected service life of the water meter, including all components except for the battery.
4.8	Effective service life (years)	If a meter uses a battery that cannot be replaced in the field, the effective service life is determined as the shortest of the meter and battery service lives. If the meter doesn’t use a battery, or has a battery that can be replaced in the field, the effective service life is set to the meter service life.
4.9	Water meter failure (%)	The expected fraction of meters that will need replacement annually due to failure of the meter itself.

No.	Parameter	Description
4.10	Electronics and other components (e.g. valve) failure	The expected fraction of meters that will need replacement annually due to failure of the electronic components of the meter (advanced meters only).
4.11	Vandalism	The expected fraction of meters that will need replacement annually due to damage caused by vandalism.
4.12	Fraction of meters needing replacement annually due to other reasons (/year)	The expected fraction of meters (for conventional and advanced meters) that will need replacement annually due to other reasons.
4.13	Total (/year)	The total fraction of meters(for conventional and advanced meters) that needs to be replaced per year due to all possible causes.

2.4.1 SANS 1529-1 Compliance

SANS 1529-1 compliance (Item 4.3) refers to whether the mechanical meter part conforms to the national standards for mechanical water meters for potable water. This is a legal requirement for all meters installed in South Africa and thus a meter should be disqualified if the answer is "No".

2.4.2 SANS 1529-9 Compliance

The SANS 1529-9 compliance (Item 4.4) refers to whether the electronic components of the metering system conform to the national standards for electronic components of water meters. This is a requirement for all advanced meters installed in South Africa and thus a meter should be disqualified if the answer is "No".

2.4.3 Mean Battery Life

The mean battery life (Item 4.5) is the average time the meter battery is expected to last. This is not applicable to conventional meters since they do not have batteries.

The expected battery service life is normally specified by the manufacturers. Manufacturers sometimes claim a battery life exceeding 10 years. These numbers should be treated with scepticism since the test conditions tend to differ from operating conditions.

Studies in low-income areas indicate that battery life can be as short as 1 year and as high as 10 years (Heymans et al., 2014). The practitioners' survey indicated that the mean battery life ranged from 2 to 10 years (from three respondents).

Dittrich (n.d.) found that most batteries will have a lifespan ranging from 10–20 years. However, he also noted that some batteries have a lifespan of 5 years. Blom et al. (2010) support these findings as they found, in an Australian case study, that batteries have a lifespan ranging from 5 to 15 years.

2.4.4 Meter Service Life

The meter service life (Item 4.7) is the expected service life of the water meter, including all components except for the battery. The results of the practitioners' survey indicate that the meter service life of conventional and prepaid meters range from 5 to 25 years and 5 years to 15 years respectively (6 respondents). Heymans et al. (2014) indicate that conventional meters can be in operation for up to 30 years, while prepaid meters can be in operation up to 20 years but are only effective for 10 and 7 years respectively.

2.4.5 Effective Service Life

For the effective service life (Item 4.8), if a meter uses a battery that cannot be replaced in the field, the effective service life is determined as the shortest of the meter and battery service lives. If the meter doesn't use a battery, or has a battery that can be replaced in the field, the effective service life is set to the meter service life.

2.4.6 Fraction Failed due to Meter Failure

The fraction of meters expected to fail due to water meter failure (Item 4.9) is the fraction of meters that will need replacement annually due to failure of the meter itself.

The fraction of prepaid meters failing due to the meter failing itself can be expected to be similar to that of conventional meters especially when a conventional water meter is used as part of the advanced meter. The results of the practitioner survey indicate that the fraction of prepaid meters failing due to the meter failure itself ranges from 1% to 60% (from seven respondents).

2.4.7 Fraction Failed due to Electronic or Component Failure

The fraction of meters expected to fail due to electronics and other components failure (Item 4.10) is the expected fraction of meters that will need replacement annually due to failure of the electronic and other components of the meter.

Though all components have a chance of failing, literature indicates that batteries are the most critical and have the highest chance of failure. Shirley et al. (2014) indicate that an advanced meter and components with a failure rate of 10%/year or more, within the first 10 years, could be considered as catastrophic. Seifried & Converse (2009) found, from a study on a meter replacement project, that the failure rate of an advanced water meter can range from 4.8%/year–11.3%/year due to battery failure.

A study of cost recovery by Marah et al. (2004) indicated that the failure rate of prepaid meters can be as high as 40% per annum (meter, vandalism and electronics). The practitioners' survey indicated that the fraction of prepaid meters failing due to electronics and other components ranges from 1% to 70% (from six respondents). Heymans et al. (2014) report that a performance audit of prepaid meters in Mogale, eight years after installation, showed that 90% of the meters were faulty due water meter failure, vandalism, failure of electronics and other components.

2.4.8 Failure due to Vandalism

The fraction of meters expected to fail due to vandalism (Item 4.11) is the expected fraction of meters that will need replacement annually due to damage caused by vandalism.

The fraction of prepaid meters failing due to vandalism has been reported as 30% in Johannesburg and 7.5% in eThekwini (GIBB, 2015).

2.5 Proposed System Parameters: Costs

The proposed scheme input parameters comprise information on costs related to the proposed advanced metering installation as well as conventional metering installation. This information is useful in determining the financial viability of the proposed metering solution compared to the financial viability of conventional metering.

The key cost parameters for the evaluation of advanced metering technology are presented in **Table 2-9** and the parameters are discussed in more detail in the rest of the section.

Table 2-9: Proposed scheme parameters: cost

No.	Parameter	Description
4.14	Meter price (R/meter)	The price of the meter.
4.15	Installation cost (R/meter)	The cost of installing the meter including transport, labour, meter box and auxiliaries.
4.16	Communication infrastructure cost (R)	The total cost of communication infrastructure, if included in the advanced metering installation.
4.17	Payment infrastructure cost (R)	The total cost of payment infrastructure, including vending terminals, billing software, computer hardware and additional staff that will be required.
4.18	Battery replacement cost (R/meter)	The cost of replacing a battery in the advanced meters, including the cost of the new battery, disposal cost of the old battery and labour.

No.	Parameter	Description
4.19	Meter reading cost (R/meter)	The cost of reading the meter. The cost should include all related costs, such as transport, labour and equipment.
4.20	Meter operation and maintenance cost (/meter/month)	The cost of operating and maintaining the water meters.
4.21	Billing cost (R/bill)	The cost of entering the meter reading data into the billing system, generating, printing and mailing a water bill.
4.22	Additional billing system operating cost (R/month)	Additional billing system operating costs not already included in the model.
4.23	Additional communication system operating costs (R/month)	Additional communication system operating costs not already included in the model.

2.5.1 Meter Price

The meter price (Item 4.14) is the cost of purchasing a water meter. This is the actual price that the municipality pays for the water meter.

GIBB (2015) states that the cost of purchasing a conventional water meter is R150/meter. This price appears low as the six practitioners surveyed state that the price ranges between R300/meter and R750/meter. In Australia, a study in 2010 showed that the cost of a conventional water meter was AUD 36 (Blom et al., 2010). In 2016, this price equates to approximately AUD 40.61/meter (Reserve Bank of Australia, 2016) which is R426.33/meter in South African currency.

With regards to advanced meters, six practitioners state that the price ranges from R500/meter to R2 500/meter, with the most commonly stated value being R2 000/meter. In Australia, the cost of an advanced water meter in 2010 was AUD 750 (Blom et al., 2010). In 2016, this price equates to approximately AUD 846/meter which is R8 881.35/meter in South African currency.

2.5.2 Installation Cost

The installation cost (Item 4.15) is the cost of installing the water meter. For conventional meters, this cost encompasses the labour costs incurred in installing the meter. GIBB (2015) states that the cost of installing a conventional water meter is R1 000/meter. From the survey, five practitioners state that the cost of installing a conventional meter ranges from R150/meter to R1 000/meter with the majority of the values ranging from R400 per meter to R1 000 per meter. In Australia, in 2010, the cost was AUD 25 per meter (Blom et al., 2010).

This equates, in 2016 values, to AUD 28.20 per meter, which is R296.05 per meter in South African currency.

With regards to advanced meters, the cost of installing a meter will consist of the cost of installing and setting up the necessary software and communication system per meter, the highly qualified technician labour costs as well as payment infrastructure.

In Australia, water meters were installed with transmitters at each home. The cost, in 2010, was stated as AUD 200. These values translate to AUD 225.60 per meter in 2016 which is R2 368.39 per meter (Blom et al., 2010).

2.5.3 Communication Infrastructure Cost

The communication infrastructure cost (Item 4.16) is the total cost of the communication infrastructure required for the metering system. This varies greatly from application to application, as there is a large range of possible technologies and systems.

The costs consist of installing the home user interface, purchasing communication equipment, purchasing the necessary communication software and establishing a communication infrastructure (e.g. via mobile/cellular, radio frequency, etc.)

There are different water metering communication protocols available. It is important that, when selecting a water meter, the suitability of the communication protocol used for the meter in the wider municipality be taken into consideration. Different manufacturers generally use their own communication protocols that are incompatible with that of other manufacturers. The utility will be forced to stick to the same supplier when upgrading meters in the future (KEMA, 2012).

Some manufacturers use open protocols, which enable a water utility to switch from one manufacturer to another without replacing the meters and its support infrastructure together with the vending system while others use proprietary software that require replacement of the whole system in a case where the water utility wants to switch from one manufacturer to another (Sneps-Sneppe et al., 2012).

Communication protocols that use standardised infrastructure like STS enable interoperability of utility meters; water and electricity (Sneps-Sneppe et al., 2012). Metering technologies that use this technology have an advantage over technologies that use proprietary communication protocols and software.

Sackett and Lake (2014) conducted a feasibility study on the implementation of an AMR water metering system for approximately 500 households. From this study, they established that the cost of installing either a mobile communication system or fixed (e.g. radio frequency) communication system would range from $21 500 to $76 586. In 2016 values, this equates to approximately $21 890.70 to $77 977.73. In South African currency, these costs range from R290 468.59 to R1 034 686.

2.5.4 Payment Infrastructure Cost

The payment infrastructure cost (Item 4.17) is the total cost of payment infrastructure, including vending terminals, billing software, computer hardware and additional staff that will be required. This varies greatly from application to application due to the large range of possible technologies and systems.

2.5.5 Battery Replacement Cost

The battery replacement cost (Item 4.18) is the cost of replacing a battery in advanced water meters, including the cost of the new battery, the disposal cost of the old battery and labour. Based on a study done in eThekwini, GIBB (2015) states that the cost of replacing a battery is R197 per meter. Two surveyed practitioners stated that the cost of replacing a battery was R200 per meter and R300 per meter. Using America as a high-income area proxy, it was found that the cost of a battery, in 2013, was $15 per meter. This equates, in 2016 values, to $15.52 per meter which is R205.59 per meter in South African currency. However, as this is only the cost of the battery and doesn't include the other costs associated with replacing the battery, this value is expected to rise and exceed R300 per meter.

2.5.6 Meter Reading Cost

The meter reading cost (Item 4.19) is the cost of reading a meter. The cost includes all related costs, such as transport, labour and equipment. The cost of reading conventional meters has already been discussed under item 3.10.

With regards to advanced water meters, meter reading costs vary based on the type of advanced metering used, whether automatic meter reading (AMR) or advanced metering infrastructure (AMI).

For AMR, the meter reading cost would consist of fuel and labour costs as readings are taken through drive by or walk by. Sackett and Lake (2014) conducted a feasibility study in Oak Creek, Colorado, of the costs associated with implementing different types of advanced water metering systems. In this study, they found that the cost of AMR ranged from $0.50 to $0.80 per meter per month. In 2016 values, these equate to $0.51 to $0.88 per meter per month which is R6.76 to R11.66 per meter per month in South African currency. Mott-MacDonald (2007) proposed that the cost of reading an advanced meter would be £0.25 per meter per month. In 2016 values, this equates to £0.30 per meter per month which is R5.19 per meter per month in South African currency.

With regards to AMI, literature such as Blom et al. (2010) indicates that meter reading costs could be eliminated due to technologies such as wireless communication networks. However, Blom et al. (2010) state that the cost would be replaced by the cost of maintaining these networks. In addition, it is recommended that meters in AMI systems are read manually at least once a year to verify the readings.

2.5.7 Meter Operation and Maintenance Cost

The meter operation and maintenance cost (Item 4.20) is the cost of operating and maintaining the water meters after installation. This cost is dictated by the maintenance requirements of a water meter.

As mentioned earlier, in item 3.12, according to SGS Economics and Planning (2011), the annual maintenance cost of a water meter is expected to be 15% of the purchase cost. For instance, taking a cost price of R1 500.00 for prepaid meters, a typical monthly operation and maintenance cost of R 18.75 is estimated.

2.5.8 The Billing Cost

The billing cost (Item 4.21) is the cost of entering the meter reading data into the billing system, and generating, printing and mailing a water bill if conventional and advanced meters are installed respectively.

This cost was assumed to be R10 per meter per month in the eThekwini system (GIBB, 2015). This component of the operations cost is said to be applicable to all metering technology that involves delivery of a bill to the consumer, therefore prepaid systems carry a zero cost for this component.

2.6 Proposed System Parameters: Expected New Consumption

This section deals with the expected consumption after replacing all meters with either conventional or advanced meters. A summary description of the input parameters is given in **Table 2-10**. The input parameters are discussed in more detail in the rest of the section.

Table 2-10: Proposed system consumption levels

No	Parameter	Description
4.24	Billed metered consumption (kl/property/month)	The estimated average monthly consumption for properties billed on actual metered consumption.
4.25	Billed unmetered consumption (kl/property/month)	The estimated average monthly consumption for properties in the billed unmetered consumption category
4.26	Illegal consumption (kl/property/month)	The estimated average monthly consumption for properties with illegal connections.
4.27	Total/average	The total number of properties included in the analysis is calculated as the sum of the billed metered, billed unmetered and illegal connections. The number of properties has to equal the number of properties entered under global input parameters.
4.28	No of meters installed	The number of meters to be installed in the proposed scheme. It is assumed that existing billed metered consumers will have their meters replaced and that all other consumers will move to the billed metered consumption category.
4.29	Fraction of billed metered properties paying for water	Fraction of billed metered properties currently paying their full water bill for the conventional and advanced meter options.
4.30	Fraction of billed unmetered properties paying for water	Fraction of billed unmetered properties currently paying their full water bill for the conventional and advanced meter options.
4.31	Ave time between meter readings (months)	Average time between meter readings.

2.6.1 Expected Billed Metered Consumption

The expected billed metered consumption (Item 4.24) includes all properties that are metered and billed based on their actual consumption. It is assumed that all consumers will have new meters installed and thus that all will move to this category.

If on-site leakage is reduced as part of the implementation of new meters, an equivalent reduction of registered water consumed should be considered.

For advanced water meters, reduction in unit consumption may incorporate the reduction of leakage and also reduction in consumption due to consumption feedback. Sønderlund et al. (2016) conducted a study to review the existing literature showing the correlation between reduction in consumption and advanced metering feedback. The study concluded that reduction in consumption due to advanced metering feedback ranges from 2.5% to 29%, with an average of 12%.

2.6.2 Number of Meters Installed

The number of meters installed (item 4.28) is the number of meters to be installed in the proposed scheme. It is assumed that existing billed metered consumers will have their meters replaced and that all other consumers will move to the billed metered consumption category.

2.6.3 Fraction of Billed Metered Consumers Who Pay

The fraction of billed metered consumers paying for water (Item 4.29) is the fraction of consumers that is expected to pay for their water after the new meters are installed. For conventional meters installed the values are expected to be similar to the situation in item 3.5.

Prepaid metering can increase payment levels by making payment unavoidable (unless consumers tamper with or bypass the prepaid meter) and maximising collection by removing human error from conventional billing (Heymans et al., 2014). This has been demonstrated to be the case by case studies on cost recovery in places like Beaufort West (Marah et al., 2004). According to case studies, the impact that prepaid water metering had was to make consumers reduce their consumption to free basic water, with a very few exceeding free basic water with a little amount which they could easily pay, making it a reasonable assumption that prepaid metering can achieve up to 100% payment. However, since prepaid metering shuts off consumers' water supply, it makes it susceptible to tampering in which case payment level can be assumed to be 100% minus illegal connections.

2.6.4 The Average Time Between Meter Readings

The average time between meter readings (Item 4.31) is the frequency at which the meters will be read in the new scheme. Ideally, meters should be read every month, and the frequency should not be less than every three months.

3. EVALUATION FRAMEWORK: RESULTS

3.1 Introduction

This section describes the results of the advanced meter evaluation system provided in the accompanying excel spread sheet model. These evaluation results are shown on the "Results" tab and several calculations are presented in the results in four categories: technical, social, environmental and economic.

The approached followed in this evaluation framework was to estimate critical performance parameters aimed at assisting the designer to make rational decisions. To assist the designer, certain cells are formatted to highlight particularly good or bad values.

As a general rule, a result highlighted as "very bad" indicates a critical failure that should result in the system being rejected. Results formatted as "unrealistic" indicate that the result should not be trusted and that the input parameters should be checked to correct this problem.

Table 3-1: Key to project evaluation results

Very Bad
Bad
Neutral
Good
Very Good
Unrealistic
Take Note of Value

The results of the analysis are discussed in the rest of this chapter under the four analysis categories.

3.2 Technical

The technical results of the metering technology evaluation are an indication as to whether the robustness of the technology makes the technology suit the application. Compliance to national standards is used as a flag for the technical feasibility of any project. Full technical compliance is much more complex and should be carefully investigated, based on the manufacturer's information, requirements of the project, success of field implementations of the technology and sound engineering judgement.

It is a legislative requirement that all water meters installed in South Africa comply with national standards. Conventional meters are expected to comply with SANS 1529-1 while electronic and prepaid meters are also expected to comply with SANS 1529-9. Meters that don't comply with these standards should be rejected.

3.3 Social

The social results of the technology evaluation do not reflect detailed analysis, but only highlight certain issues as flags for the designer to consider social issues in the project. If a community does not accept a metering scheme it is bound to fail. Social acceptance is highly complex and it is important that the designer gets expert input and the support of all interested and affected parties in the community for the project before implementation.

3.4 Environmental

Only two key parameters are considered in the environmental impact of the proposed scheme, i.e. the number of batteries to be replaced and safely disposed of and the reduction in water consumption. Efficient water consumption is an essential component of sustainable management.

Batteries are made of various chemicals including nickel and cadmium that are toxic and can cause damage to humans and the environment. For example, cadmium can cause damage to soil micro-organisms and affect the breakdown of organic matter. It also bio-accumulates in fish, which reduces their numbers and makes them unfit for human consumption (AlAbdulkarim et al., 2012). The extent of the damage is greatly influenced by the battery type and its capacity (AlAbdulkarim et al., 2012), and this should be considered in the design phase of the project.

3.5 Economic

The economic result of the evaluation framework gives an indication of the financial viability of the metering system to be implemented. This is achieved through determining the payback period for the technology and the effective surplus to be expected from the implementation.

The economic results are given relative to the current situation and thus the project. This means that to succeed economically, a new project doesn't necessarily have to run at a surplus, but can achieve this by saving more money compared to the current situation than it costs to implement.

3.5.1 Capital Payback Period

The capital payback period is how long it would take to recover the money spent on implementing the new system through the money saved by installing it. It is calculated by dividing the total capital cost by the increased operational surplus (or decreased loss) of the new system.

A system with a shorter capital payback period is better than a system with a longer one. Generally, a capital payback period of four years would be considered acceptable, but this is a decision that should be made in consultation with the municipality.

A negative capital payback period means that the system investment costs cannot be paid back and thus the scheme is infeasible.

3.5.2 Effective Surplus

The effective surplus is the average annual increased surplus (or reduced loss) over the service life of the metering system after the capital has been recovered. It allows meters with different service lives to be compared on the same basis. For instance, a more expensive type of meter may result in higher monthly income from water sales. Thus, even though these meters may be more expensive to install, have shorter service lives and a longer capital payback period, the increased income may be sufficient to make this the preferred system.

The effective surplus is an additional measure to the capital repayment period and both should be considered when evaluating the feasibility of a system. It is also important to consider the risks associated with different systems. For instance, an advanced metering system might have a higher effective surplus than a conventional system, but at the same time it represents a greater financial risk due to the higher capital outlay required and risks of the more sophisticated meters not performing as expected.

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APPENDIX B

APPLICATION OF EVALUATION FRAMEWORK TO CASE STUDIES

Water Research Commission Project K5/2370
"State-of-the-Art in Advanced Metering Technology and Application"

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ABBREVIATIONS

AADD	Average Annual Daily Demand
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
CDMA	Code-Division Multiple-Access
GSM	Global System for Mobile Communication
HAN	Home Area Network
LAN	Local Area Network
NIST	National Institute for Standards and Technology (United States)
O&M	Operations and Maintenance
PLC	Power Line Communication
RF	Radio Frequency
SEP	Smart Energy Profile
UMTS	Universal Mobile Telecommunications System
USC	Utility Systems
WAN	Wide Area Network
WCDMA	Wideband code-division multiple-access
WMN	Wireless Mesh Network
WRC	Water Research Commission of South Africa
WBKMS	Web-based Knowledge Management system

1. INTRODUCTION

This appendix describes the application of the evaluation framework to the five different case studies in South Africa introduced in Report 2. It explains the different model input parameters fed into the evaluation models for each of the case studies, and the results obtained are discussed in terms of their overall feasibility under both conventional and advanced meter implementation scenarios. The framework model for each is provided as a separate Microsoft ® Excel spreadsheet file.

2. EVALUATION OF PREPAID METERING IN A TYPICAL LOW-INCOME AREA

2.1 Model Input Parameters

The input parameters for the evaluation framework are discussed in **Appendix A**. Typical parameter values were selected from the information in **Appendix A**, as well as low and high values to provide a range for each parameter used in the sensitivity analysis. A detailed discussion of the input parameters used in the study is available in Malunga (2017).

The system assumed that free basic water (FBW) is paid for through a government subsidy of R11.43/kl, thus ensuring an average water price of R12.72/kl compared to the water cost price of R6.00.

The current system (before installation of new water meters) was assumed to consist of 50% billed metered connections using 20 kl/property/month and with a 50% payment rate; 30% fixed rate connections using 30 kl/property/month and with a 40% payment rate; and 20% illegal or unbilled users using 40 kl/property/month.

A proposed new system where all connections were supplied with either conventional or prepaid water meters was investigated. The prepaid meter system was significantly more expensive to install (R2 000/meter compared to R400/meter for conventional), required an investment of R200 000 for communication and payment infrastructure costs and was more expensive to operate (R20/meter/month compared with R3/meter/month for conventional). This is an inevitable consequence of the higher sophistication of advanced meters with more components that can fail, and the higher skills required for installing and operating these meters.

The main financial benefit of the advanced meters was the billing cost that was assumed to be zero compared to R10/bill for conventional meters. Since prepaid meters assist users to manage their consumption, it was assumed that these meters will result in significant savings in consumption (11 kl/property/month compared to 20 kl/property/month for conventional). They were also assumed to ensure significantly better payment rates (75% compared with 50% for conventional metering).

A summary of the input parameters for a typical system, as well as the low and high values uses is given in the table below.

Table 2: Input parameters for a typical low-income system

EVALUATION FRAMEWORK FOR ADVANCED WATER METERING

1. SYSTEM

No.	Parameter	Value	Comment
1.1	Analysis ID	Test 1	
1.2	System name	Test system	

1.3	Suburb(s)	Test suburb	
1.4	City	Test City	
1.5	Date	Today	

2. GLOBAL PARAMETERS

No.	Parameter	Value	Comment
2.1	Number of properties	1 000	
2.2	Water cost price (R/kl)	6	
2.3	Applicable water tariff (R/kl)	12.72	
2.4	Billed unmetered tariff (R/month)	200	

3. CURRENT SITUATION

Current water consumption

No.	Parameter	No of properties	Unit consumption (kl/property/month)	Total consumption (kl/month)	Comment
3.1	Billed metered consumption	500	20	10 000	
3.2	Billed unmetered consumption	300	30	9 000	
3.3	Illegal or unbilled connections	200	40	8 000	
3.4	Total/average	1 000	27.00	27 000	

Current payment rate

No.	Fraction of properties paying for water	Fraction	No of paying properties	Income from water sales (R/month)	Comment
3.5	Billed metered consumption	50%	250	63 600	

3.6	Billed unmetered consumption	40%	120	24 000	
3.8	Total/average	37.0%	370	87 600	

Other current parameters

No.	Other parameters	Value	Comment
3.9	Fraction of demand that is on-site leakage	40%	
3.10	Ave time between meter readings (months)	2	
3.11	Meter reading cost (/meter)	R2.50	
3.12	Billing cost (/bill)	R10.00	
3.13	Meter operation & maintenance cost (/meter/month)	R3.00	
Fraction of meters failing due to:			
3.15	Meter failure (/year)	5%	
3.16	Vandalism and other (/year)	3%	
3.17	Total (/year)	8%	
3.18	Average household income (/month)	R3 000.00	
3.19	Unemployment rate	50%	
3.20	Volatility of community (No. of protest or mass action incidences per year)	3.0	

4. PROPOSED SCHEME

Proposed system parameters

No.	Parameter	Conventional metering (baseline)	Advanced metering	Comment
4.1	Meter make	framework	Prepaid	

4.2	Meter model	Positive displacement	Unknown	
4.4	SANS 1529-1 compliant?	TRUE	TRUE	
4.5	SANS 1529-9 compliant?		TRUE	
4.8	Mean battery life (years)		6	
4.9	Battery replacable in field?		TRUE	
4.10	Meter service life (years)	15	10	
4.11	Effective service life (years)	15	10	
Fraction of meters expected to fail due to:				
4.12	Water meter failure (/year)	5%	10%	
4.13	Electronics and other components (e.g. valve) failure (/year)		10%	
4.14	Vandalism (/year)	3%	7%	
4.15	Other (/year)	0%	0%	
4.16	Total	8%	27%	

Costs

No.	Parameter	Conventional metering (baseline)	Advanced metering	Comment
4.17	Meter price (R/meter)	200	1 500	
4.18	Installation cost (R/meter)	200	500	
4.20	Communication infrastructure cost (R)		120 000	
4.21	Payment infrastructure cost (R)	0	80 000	
4.22	Battery replacement cost (R/meter)		R350.00	
4.23	Meter reading cost (R/meter)	R3.00	R5.00	

4.24	Meter operation & maintenance cost (/meter/month)	R3.00	R20.00	
4.25	Billing cost (R/bill)	R10.00	0	
4.27	Additional billing system operating cost (R/month)	R0.00	0	
4.28	Additional communication system operating costs (R/month)		0	

Expected new consumption		**No. of properties**			
4.28	Billed metered consumption (kl/property/month)	1 000	20	11	
4.29	Billed unmetered consumption (kl/property/month)	0	30	30	
4.30	Illegal consumption (kl/property/month)	0	40	40	
4.31	Total/average	1 000	20.00	11.00	
4.32	No of meters installed	1 000			
Fraction of properties paying for water					
4.33	Billed metered consumption		10%	75%	
4.34	Billed unmetered consumption		25%	50%	
4.36	Ave time between meter readings (months)		2	6	

2.2 Results

The typical low-income scenario is a situation in which the low-income scheme is evaluated using typical values for the input parameters.

2.2.1 Technical Result

The technical results of the evaluation are summarised in **Table 2** showing compliance with SABS standards for both conventional and advanced meters. However, the average number of meters to be replaced per month is more than three times higher for advanced metering due to the higher meter failure rates.

Table 3: Technical result for typical low-income scheme

1.TECHNICAL			
No.	**Property**	**Conventional Metering (Baseline)**	**Advanced Metering**
1.1	SABS compliance	Yes	Yes
1.2	Number of meters to replace (/month)	**7**	**23**

2.2.2 Social Result

The social results will depend on local conditions and thus the results shown in **Table 3** are only given as an example. In this example case, the affordability of the system is not assured, with the water bill making up 13% of the average income in the community. This, as well as the high unemployment rate and past incidents of volatility in the community, shows that the proposed system is highly unlikely to be accepted by the community. In this case, alternatives should be considered that will have a lower financial impact on the community, while still allowing basic water supply to be provided in an efficient way.

Table 4: Social result for typical low-income community

2. SOCIAL		
No	**Property**	**Value**
2.1	Current rate of meters vandalised (/year)	3.0%
2.2	Unemployment rate	50.0%
2.4	Volatility of community (No of protest or mass action incidences per year)	3
2.5	Average water bill (/month)	R394.32
2.6	Average property income (/month	R3 000.00
2.7	Water bill as a fraction of income	13.1%

2.2.3 Environmental Result

The environmental results are also highly system dependent and are only given as an example in **Table 4**. The important environmental results are the number of meters to dispose and the savings in water consumption, shown as items 3.7 and 3.8.

The example results show that both the conventional and advanced metering systems are likely to save significant quantities of water, but the advanced metering system is likely to perform much better than the conventional system. On the other hand, the advanced system will generate 167 batteries per year that should be safely disposed of.

Table 5: Environmental results for low-income community

3. ENVIRONMENTAL

No.	Consumption	Units	Current	Conventional metering (baseline)	Advanced metering
3.1	Billed metered consumption	(kl/month)	10 000	20 000	11 000
3.2	Billed unmetered consumption	(kl/month)	9 000	0	0
3.3	Illegal consumption	(kl/month)	8 000	0	0
3.4	Total consumption	(kl/month)	27 000	20 000	11 000
3.5	Unit consumption	(kl/property/month)	27	20	11
3.6	Reduction in consumption	(kl/month)		7 000	16 000
3.7	Fractional reduction in consumption	-		25.9%	59.3%
3.8	No of batteries to dispose of	(/year)			167

2.2.4 Economic Result

The economic results of the proposed scheme indicate the financial viability of the proposed scheme. The key parameters indicating the financial viability of the proposed scheme are capital payback period and effective surplus, given as items 4.28 and 4.30 in **Table 5**.

Table 6: Economic viability of a proposed scheme in typical low-income scheme

4. ECONOMIC

No.	Income	Units	Current	Conventional metering (baseline)	Advanced metering
4.1	Billed metered consumption	(/month)	R63 600.00	R25 440.00	R104 940.00
4.2	Billed unmetered consumption	(/month)	R24 000.00	R0.00	R0.00
4.4	Total income	(/month)	R87 600.00	R25 440.00	R104 940.00
4.5	Unit income	(/property/month)	R87.60	R25.44	R104.94
4.6	Increased income	(/month)		-R62 160.00	R17 340.00
4.7	Fractional increased income			-71%	20%
	Capital cost				
4.8	Water meters		R0.00	R200 000.00	R1 500 000.00
4.9	Installation		R0.00	R200 000.00	R500 000.00
4.11	Communication infrastructure cost		R0.00	R0.00	R120 000.00
4.12	Payment infrastructure cost		R0.00	R0.00	R80 000.00
4.13	Total capital cost		R0.00	R400 000.00	R2 200 000.00
4.14	Unit capital cost	(/property)	R0.00	R400.00	R2 200.00
	Operational cost				
4.15	Water production	(/month)	R162 000.00	R120 000.00	R66 000.00
4.16	Meter reading	(/month)	R625.00	R1 500.00	R833.33
	Meter operation & maintenance	(/month)	R1 500.00	R3 000.00	R20 000.00
4.17	Billing cost	(/month)	R8 000.00	R10 000.00	R0.00
4.18	Billing system operating cost	(/month)		R0.00	R0.00
4.19	Communication system operating costs	(/month)			R0.00
4.21	Failed meter replacement cost	(/month)	R16 000.00	R2 666.67	R45 000.00
4.22	Battery replacement cost	(/month)			R4 861.11
4.23	Total operating cost	(/month)	R188 125.00	R137 166.67	R136 694.44
4.24	Unit operating cost	(/property/month)	R235.16	R137.17	R136.69
4.25	Decreased operating cost	(/month)		R50 958.33	R51 430.56

	Summary				
4.26	Operational surplus	(/month)	**-R100 525.00**	**-R111 726.67**	**-R31 754.44**
4.27	Increased operational surplus	(/month)		**-R11 201.67**	**R68 770.56**
4.28	Capital payment period	(months)		-35.7	32.0
4.29	Expected service life	years		15	10
4.30	Effective surplus	(/year)		-R161 086.7	R605 246.7

The current system was calculated to run at a loss of around R100 000/month, which was reduced to a loss of around R10 000/month for conventional meters and R30 000/month for prepaid meters.

The results show that the capital payback period for implementing conventional meters is 4.4 months, which is much better than the 32 months required for the advanced metering system. Although both projects will give positive results with regards to an effective surplus, the conventional meter system is again superior.

Thus, for this typical low-income application, it is clear that a conventional metering system is a better choice than the advanced metering system in all respects except for consumption.

The main benefit of the advanced metering system is that user consumption can be better managed, and in areas where water supply is under severe stress this benefit may override the economic benefits of conventional metering. However, this comes at a significantly higher financial risk associated with a total capital cost of R2.2 million compared with R400 000 for conventional metering.

2.3 Sensitivity Analysis

A sensitivity analysis was conducted to investigate the robustness of the solution. This was done by changing each parameter at a time from its typical value to its low and high values as given in the tables in **Appendix A**. The values used in the sensitivity analysis are given in Table 6 below. Only the results for capital payback period are discussed in this section.

Table 7: Sensitivity Analysis for a Typical Low-Income Area with Prepaid Metering

SENSITIVITY ANALYSIS PARAMETERS

2. GLOBAL PARAMETERS

No	Parameter	Typical	Low	High
2.1	Number of properties	1 000	200	10000
2.2	Water cost price (R/kl)	6	4	10
2.3	Applicable water tariff (R/kl)	12.72	11.43	13.14
2.4	Billed unmetered tariff (R/month)	200	**0**	300

3. SITUATION BEFORE ADVANCED METER IMPLEMENTATION

Water consumption before Advanced Meter Implementation

No	Parameter	Typical	Low	High
3.1	Fraction of properties: Billed metered consumption	50	30	80
3.2	Fraction of properties: Billed unmetered consumption	30	30	20
3.3	Fraction of properties: Illegal or unbilled connections	20	40	0
3.1	Unit consumption: Billed metered consumption (kl/month)	20	6	40
3.2	Unit consumption: Billed unmetered consumption (kl/month)	30	15	50
3.3	Unit consumption: Illegal or unbilled connections (kl/month)	40	20	60

Payment rate before advanced meter implementation

No	Fraction of properties paying for water	Typical	Low	High
3.5	Billed metered consumption	50%	10	90
3.6	Billed unmetered consumption	40%	0	75

Other parameters before advanced meter implementation

No	Other parameters	Typical	Low	High
3.7	Fraction of demand that is on-site leakage	40%	5	70
3.8	Ave time between meter readings (months)	2	1	3
3.9	Meter reading cost (/meter)	R2.50	1.5	3
3.10	Billing cost (/bill)	R10.00	5	15
3.11	Meter operation & maintenance cost (/meter/month)	R3.00	1	5
Fraction of meters failing due to:				
3.12	Meter failure (/year)	5.0%	3	10
3.13	Vandalism and other (/year)	3.0%	1	7
3.15	Average household income (/month)	R3 000.00	1500	10000
3.16	Unemployment rate	50%	30	70
3.17	Volatility of community (No of protest or mass action incidences per year)	3.0	1	5

4. PROPOSED SCHEME

Proposed system parameters

No	Parameter	Typical	Low	High
4.5	Mean battery life for advanced meter (years)	6	3	9
4.7	Meter service life for conventional (years)	15	10	20
4.7	Meter service life for advanced (years)	10	6	15
Fraction of conventional meters expected to fail due to:				
4.9	Water meter failure	**5.0%**	3.0%	10
4.11	Vandalism (/year)	3.0%	1.0%	7
Fraction of advanced meters expected to fail due to:				
4.9	Water meter failure (/year)	**10.0%**	5.0%	15
4.10	Electronics and other components (e.g. valve) failure (/year)	10	5.0%	35
4.11	Vandalism (/year)	7.0%	5.0%	10

Costs

No	Parameter	Typical	Low	High
4.14	Meter price (R/meter)	1500	1000	2000
4.15	Installation cost (R/meter)	300	250	500
4.16	Communication infrastructure cost (R)	120000	80000	160000
4.17	Payment infrastructure cost (R)	80000	40000	120000
4.18	Battery replacement cost (R/meter)	300	200	350
4.19	Meter reading cost (R/meter)	R3.00	1	5
4.20	Meter operation & maintenance cost (/meter/month)	R20.00	15	30

Expected new consumption		Typical	Low	High
4.24	Billed metered consumption for conventional (kL/property/month)	20	6	40
4.24	Billed metered consumption for advanced (kL/property/month)	11	6	20
Fraction of properties paying for water				
4.29	Billed metered consumption for conventional	50	10%	90
4.29	Billed metered consumption for advanced	50	0%	100

Figure 1 shows the sensitivity analysis results for the capital payback period for the implementation of prepaid water meters. As in the earlier discussion, the capital payback period for the typical case is 32 months. The sensitivity analysis results show which parameters are critical for the economic feasibility of the system. It is clear that the feasibility is threatened most by five variables, all increasing the capital payback period above 50 months:

- High billed metered consumption payment rate in the existing system. This means that prepaid metering systems are not feasible in low-income areas where the payment rate is already high.
- Low payment rates after implementation of the prepaid water metering system. This and the previous point show that advanced metering can only be economically viable if it increases payment rates substantially above the levels before the system is implemented.
- Low consumption levels in the existing system. If a system has low consumption levels there is little scope for further reductions and the associated low-income levels makes it difficult to recover costs for new infrastructure.
- High number of consumers in the current system on billed metered consumption rather than fixed rates or illegal connections.
- High advanced meter failure rates.

Figure 2 shows how the sensitivity analysis results for the capital payback period if conventional meters are installed instead of advanced meters. As in the earlier discussion, the capital payback period for the typical case is 4.4 months. The sensitivity analysis results show that the following parameters are critical for the economic feasibility of the system:

- Low payment levels for the new conventional meters. Since there is no system that will automatically disconnect users when they don't pay for water, there is a significant risk that non-payment levels will be very high.
- A high billed metered consumption payment rate in the existing system. This means that prepaid metering systems are not feasible in low-income areas where the payment rate is already high.
- Low consumption levels in the existing system. If a system has low consumption levels there is little scope for further reductions and the associated low income levels makes it difficult to recover costs for new infrastructure.
- A high number of consumers in the current system on billed metered consumption rather than fixed rates or illegal connections.

The results show that the critical factors for the feasibility of replacing meters with conventional meters are essentially the same as for prepaid meters (consumption and payment levels), but that the capital payback period is much lower than for the advanced meters in all cases.

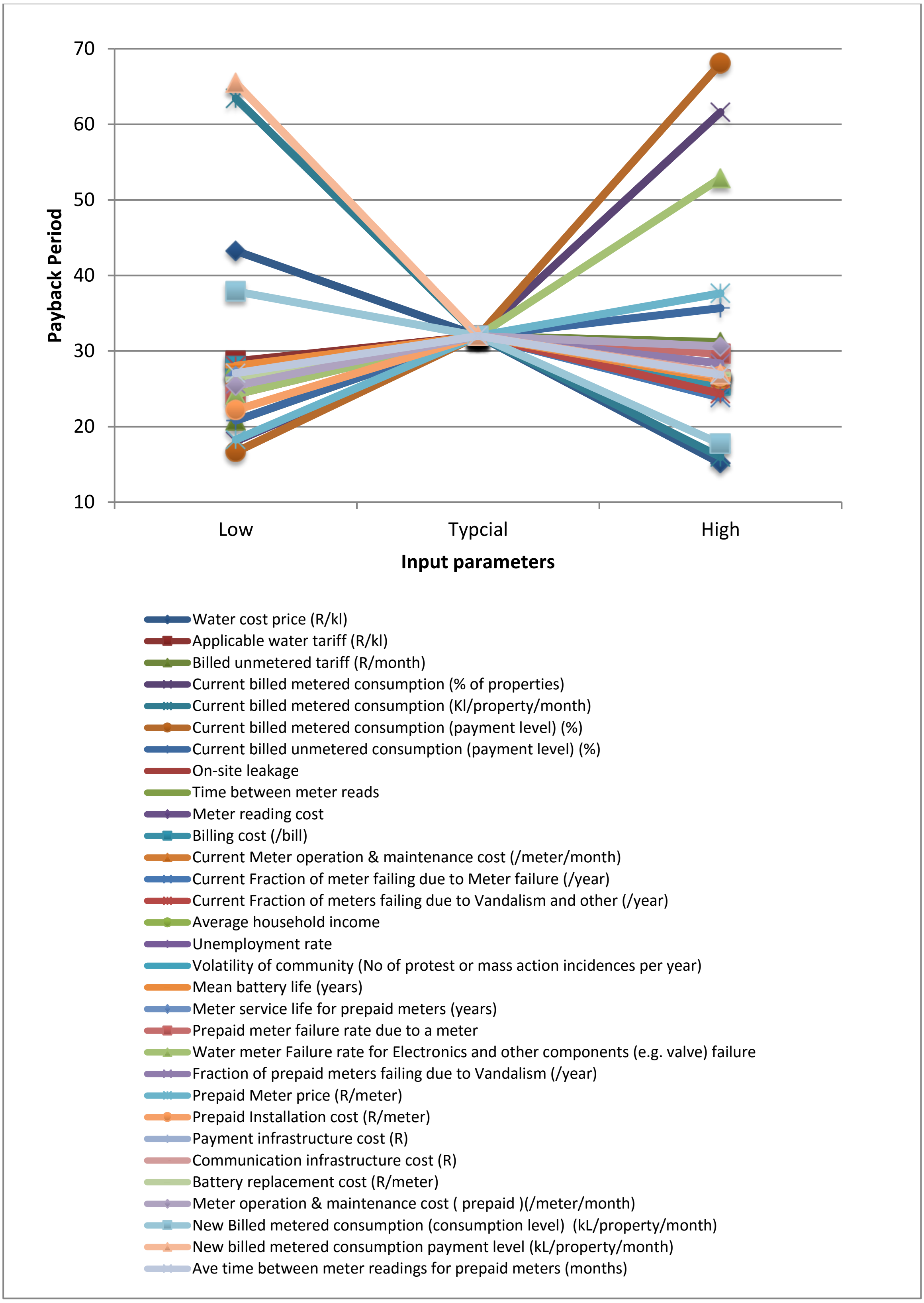

Figure 9: Sensitivity analysis results for the capital payback period if advanced (prepaid) water meters are installed in a low-income area

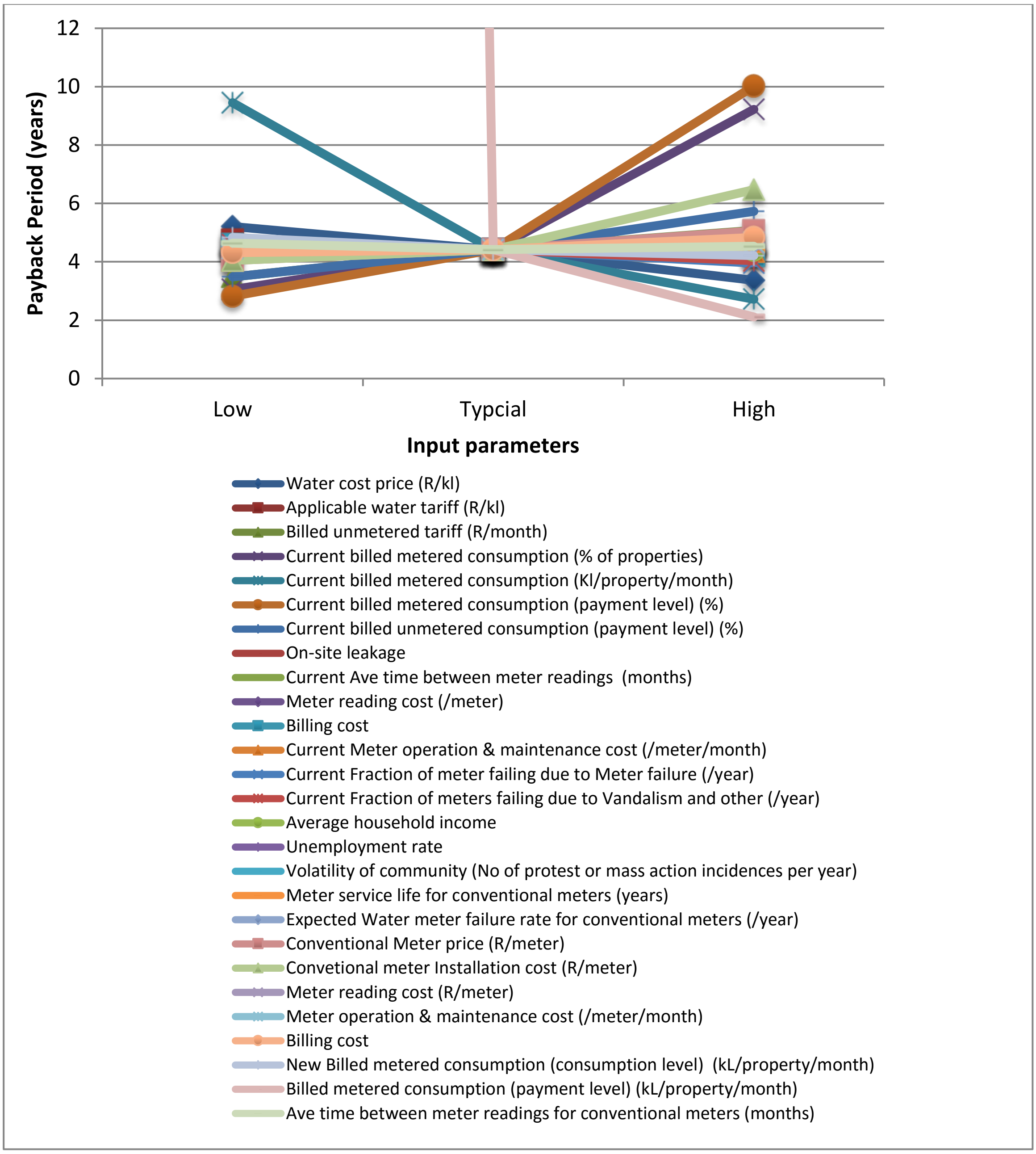

Figure 10: Sensitivity analysis results for the capital payback period if conventional water meters are installed in a low-income area

2.4 Summary of Findings

The analysis of implementing advanced (prepaid) meters in low-income areas shows that in virtually all aspects it is better to use conventional rather than advanced meters.

3. EVALUATION OF WATER MANAGEMENT DEVICES – CASE STUDY IN CAPE TOWN

The subsequent section delves into the different input parameters used to generate the evaluation model for the water management device (WMD) roll-out project in the City of Cape Town. As explained in the evaluation framework in Appendix A; two scenarios are taken into account, conventional and WMD advanced technology implementation.

3.1 Model Input Parameters

The input parameters used to calculate the indicators for the evaluation factors were obtained from various sources and are discussed in this section under the headings of:

- global parameters
- the existing system (which caters for the situation before new meter implementation)
- the proposed scheme (which caters for both the new conventional and new advanced metering systems proposed)

The input parameters are given in tables linked to the evaluation framework, which is provided in **Appendix A**.

3.1.1 Global Parameters

The global parameters used in the analysis are summarised in Table 7, with the values chosen, sources of information and a brief comment. A more detailed explanation of how these model values were selected is provided in the subsequent paragraphs. The roll out of 160 000 WMDs in Cape Town to date (Saayman, 2016) was taken to be the project scope for this study.

Table 8 : Global parameters

No.	Parameter	Value	Source	Comment
2.1	Number of properties	160 000	Saayman, 2016	
2.2	Water cost price	R8.00/kl	De Sousa-Alves, 2013	
2.3	Applicable water tariff	R8.33/kl	City of Cape Town, 2015	CoCT water and sanitation tariffs: 6 kl= free 4.5 kl at R11.07/kl = R49.82 5 kl at R15.87/kl = R79.35 Thus the total cost for 15.5 kl is R129.17, which gives an average tariff of R8.33/kl.
2.4	Billed unmetered tariff (R/month)	R0/month	City of Cape Town, 2015	This denomination does not currently exist under the city tariff structure

The ***number of properties*** is based on the total number of WMDs in Cape Town in June 2016 (Saayman, 2016).

The ***water cost price*** is the water production cost and includes only raw water and purification costs. It was adopted as R8.00 as a fraction of the water reticulation cost provided in the De Sousa-Alves (2013) Cape Town report.

The applicable ***water tariff*** of R8.33/kl is based on a weighted average of the 1st FBW tier, and the 2nd and 3rd tier tariffs for2015–2016 for CoCT for the domestic consumer category (City of Cape Town, 2015).

Per City of Cape Town (2011), for domestic controlled areas, no charge was levied on the FBW amount. Water in excess of this amount was previously charged a flat rate based on the average historical cost of water (AHCW). Currently, however, no such denomination exists under the city tariff structure and therefore 0 was adopted as the representative ***billed unmetered tariff*** value for CoCT

3.1.2 Existing System (Situation Before Metering System Upgrade)

This section describes the situation before the metering system upgrade. The values used are summarised in Table 8 as follows:

Table 9: Water consumption before advanced meter implementation

No.	Parameter	Value	Source	Comment
3.1	Billed metered consumption	150 400 properties	Sivatho & De Sousa-Alves, 2016	Based on 94% of overall 160 000 properties
3.1	Billed metered unit consumption	15.5 kl/property /month	Viljoen, 2015	Domestic consumption estimates
3.2	Billed unmetered consumption	1 600 properties	Sivatho & De Sousa-Alves, 2016	Based on 1% of overall 160 000 properties
3.2	Billed unmetered unit consumption	15.5 kl/property /month	Viljoen, 2015	Same consumption estimates as 3.1 above
3.3	Illegal or unbilled connections	8 000 properties		Based on remaining 5% of overall 160 000 properties
3.3	Illegal connections unit consumption	15.5 kl/property /month	Viljoen, 2015	Same consumption estimates as 3.1 above
	Fraction of properties paying for water			
3.5	Billed metered consumption	40%	Papier, 2009	
3.6	Billed unmetered consumption	0%	N/A	Same as 3.5 above

No.	Parameter	Value	Source	Comment
	Other parameters before advanced meter implementation			
3.8	Fraction of demand that is on-site leakage	6%	De Sousa-Alves, 2013	Table showing opportunities for reducing demand
3.9	Ave time between meter readings (months)	1	Saayman, 2016	Adopted since congruent with monthly billing cycles
3.10	Meter reading cost	R8/meter	Saayman, 2016	
3.11	Billing cost	R10/bill	GIBB, 2015	Inclusive of administrative, printing and postage costs
3.12	Meter operation and maintenance cost	R16/meter/ month	N/A	Estimated as a ratio of overall capital cost
	Fraction of meters failing due to			
3.13	Meter failure (/year)	5%	Wendell, 2016	
3.14	Vandalism and other (/year)	2%	Wendell, 2016	
3.16	Average household income (/month)	R3 200 /month	Statistics South Africa, 2012	Based on Census 2011 City of Cape Town Results
3.17	Unemployment rate	24%	Statistics South Africa, 2012	Based on Census 2011 City of Cape Town Results
3.18	Volatility of community (No. of protest or mass action incidences per year)	129	Centre for Civil Society, 2016	Social Protest Observatory records, 2016

The figure of 150 400 properties under ***billed metered consumption*** was based on applying a fraction of 94% to the total WMDs as per the Domestic User Connection Profile 2014/15 category for billed metered consumption in Cape Town (Sivatho & De Sousa-Alves, 2016).

In the absence of ***billed metered unit consumption*** data for these areas, an estimate had to be made. Viljoen (2015) contains a figure showing average daily water consumption of properties with main and additional households in low-income areas of Cape Town. Since service delivery to backyarders was a key issue in the implementation of WMDs (City of Cape Town, 2012), it was assumed that these devices were installed both on main and backyard dwellings. In addition, even though these devices are being installed in different low- and middle-income areas across the city, their flow restriction function is usually only activated in low-income areas with debt management backlogs (Saayman, 2016). It is why the unit consumption value of 0.5 kl/day for the low-income category of single households surveyed as in Figure 6 of the study (Viljoen, 2015) was adopted and applied over a period of 31 days to get an average monthly unit consumption of 15.5 kl/property/month.

The 1 600 value for ***billed unmetered consumption*** properties was obtained by applying a fraction of 1% to the overall 160 000 properties as per the Domestic User Connection Profile 2014/15 category for billed unmetered consumption in Cape Town (Sivatho & De Sousa-Alves, 2016).

A similar ***billed unmetered unit consumption*** of 15.5 kl/property/month, as in the billed metered unit consumption case, was adopted in the absence of more conclusive information from the City of Cape Town.

The 8 000 value ***for illegal or unbilled connections*** was obtained by applying the remaining fraction, of 5%, to the overall 160 000 properties on the assumption that this uncaptured fraction represents these types of connections in Cape Town.

A similar ***illegal connections unit consumption*** of 15.5 kl/property/month as in the billed metered unit consumption case was adopted in the absence of more conclusive information from the City of Cape Town.

A ***fraction of billed metered properties paying for water*** of 40% was adopted as a representative value based on the fact that high arrears are accrued in low-income areas from non-payment for water services (Papier, 2009).

CoCT was assumed to have a poor collection efficiency for unmetered properties since difficulty in collection from billed properties was already rampant. A ***fraction of billed unmetered properties*** paying for water of 0% was therefore adopted.

The ***fraction of demand that is on-site leakage*** of 6% was based on an estimate of on-site leakage in residential areas made by the City of Cape Town (De Sousa-Alves, 2013).

The R8/meter value for ***meter reading cost*** was obtained from City of Cape Town municipal personnel (Saayman, 2016).

It was not possible to get the ***billing cost*** from City of Cape Town. However, from a feasibility study for eThekwini, billing costs were estimated as R10 per month per meter (GIBB, 2015), made up of R6 administrative cost, R1 printing cost and R3 postage cost. This estimated R10 /bill was thus adopted as the ***billing cost*** for Cape Town.

To estimate the typical ***meter operation and maintenance costs***, a ratio of 15% of the overall capital cost of the conventional meter per annum was used in the absence of more conclusive information. An estimate of about R195 per annum and thus R16.25/month was obtained, which value was rounded off to approximately R16 /meter/month.

The ***meter failure rate*** of 5% for conventional meters in Cape Town was obtained from the City of Cape Town (Wendell, 2016).

The failure rate due to ***vandalism and other reasons*** of 2% for conventional meters in Cape Town was also obtained from the City of Cape Town (Wendell, 2016).

As stated above in the discussion of the socio-economic characteristics of Cape Town , the ***average household income*** of R3 200/month reported in Census 2011 City of Cape Town Results (Statistics South Africa, 2012) was adopted.

Similarly, an ***unemployment rate*** of 24%, based on the Census 2011 City of Cape Town Results (Statistics South Africa, 2012), was adopted.

About 43 protest/mass action incidents have been recorded in the Centre for Civil Society Social Protest Observatory as having occurred in the Cape Town area in just the course of January to April of the year 2016 (Centre for Civil Society, 2016). This indicates a high ***community volatility*** of about 129 protest incidents per year.

3.1.3 Proposed Scheme for Conventional Metering (Baseline)

In the evaluation framework, the proposed scheme consists of two parallel categories, i.e. conventional and advanced metering. This is useful in evaluating the benefits of replacing the existing meters with advanced meters over conventional meters.

The parameters for the proposed conventional metering scheme are summarised in Table 9 and discussed in the rest of the section under the headings of "proposed system parameters", "failure rates", "costs" and "expected consumption".

Table 10: Conventional metering scheme parameters

No.	Parameter	Value	Source	Comment
Proposed system parameters				
4.1	Meter make	Variable, including Elster Kent, Actaris, Sensus	De Beer, 2010	Similar residential meters assumed
4.2	Meter model	Variable including rotary piston, single-jet and multi-jet meters	De Beer, 2010	See 4.1 above
4.3	SANS 1529-1 compliant?	True	N/A	Meets legal requirements
4.7	Meter service life (years)	18	Van Zyl, 2011; De Sousa-Alves, 2013	
Fraction of meters expected to fail due to				
4.9	Water meter failure (/year)	5%	Wendell, 2016	As in Section 3.1.2 above
4.11	Vandalism (/year)	2%	Wendell, 2016	As in Section 3.1.2 above
4.12	Other (/year)	N/A	N/A	Included in 4.11 above
Costs				
4.14	Meter price	R500/meter	De Beer, 2016; WRP Consulting Engineers, 2009	Same as Section 6.1.3 of Epping Pilot Project
4.15	Installation cost	R800/meter	Ngobeni, 2016	

No.	Parameter	Value	Source	Comment
4.17	Payment infrastructure cost	R0	N/A	Absorbed within billing cost
4.19	Meter reading cost	R8/meter	Saayman, 2016	
4.20	Meter operation and maintenance cost	R16/meter/month	N/A	Based on capital cost of the meter
4.21	Billing cost	R10/bill	GIBB, 2015	Inclusive of administrative, printing and postage costs
Expected new consumption				
4.24	Billed metered consumption	160 000 properties	Saayman, 2016	
4.24	Billed metered Unit Consumption	15.5 kl/property/month	N/A	No change assumed
4.26	Illegal consumption or unbilled connections	N/A	N/A	Illegal connections are assumed to have been identified and metered
4.26	Illegal connections unit consumption	N/A	N/A	Based on above
	Fraction of properties paying for water			
4.29	Billed metered consumption	40%	Papier, 2009	Same as Section 3.1.2
4.31	Ave time between meter readings	1 per month	Saayman, 2016	Congruent with monthly billing cycle

(a) Proposed system parameters

CoCT has different types of meters in different areas per the various contractors who were awarded tenders for water infrastructure delivery. In the absence of aggregated information on all meter types in Cape Town, the ***meter make and model*** stated were based on the De Beer (2010) AMR report since it referred to a water meter supply tender for the whole City of Cape Town and also stated some of the existing meter types in a few residential areas of the pilot study in Cape Town.

The value for ***SANS 1529-9 compliance*** was omitted from Table 3 since it deals with requirements for electronic indicators that in most cases are not part of a typical conventional meter.

A conventional ***meter service life*** of 18 years was adopted as explained in Section 6.1.3 of the Epping Industrial AMR case study.

(b) Failure rates

In assessing the water ***meter failure rate,*** a value of 5% meter failure per year was used (Wendell, 2016).

The value of 2% ***failure per year due to vandalism and other*** causes was used.

(c) Costs

The typical conventional ***meter price*** used was R500/meter, based on the original conventional meter price adopted by comparison of two sources explained in Section 6.1.3 of the Epping Industrial AMR pilot project.

No information on the ***installation cost*** of conventional meters could be found. As such, an estimate of R800/meter, based on municipal staff experience in the Tshwane case study, was adopted here to account for all the materials and labour required for meter installation.

Since the administrative portion of the billing cost is expected to cover all payment system operational costs, no ***payment infrastructure costs*** are expected.

The ***meter reading, billing and meter operation and maintenance costs*** were adopted from the existing values discussed above.

(d) Expected consumption

All 160 000 properties were assigned to ***billed metered consumption*** as part of the new meter implementation process.

Since the proposed meter type here is the same as the existing conventional one, the ***consumption*** was assumed to remain unchanged, as in Section 3.1.2 above.

A ***fraction of billed metered consumption properties paying for water*** of 40% as in the Section 3.1.2 above was maintained since the same meters are used.

3.1.4 Proposed Scheme for Advanced Metering

The parameters for the WMD advanced metering scheme in Cape Town are summarised in Table 10 and are discussed in the rest of the section under the headings of "proposed system parameters", "failure rates", "costs" and "expected consumption".

Table 11: Proposed advanced metering scheme parameters

No.	Parameter	Value	Source	Comment
Proposed system parameters				
4.1	Meter make	Water Management Devices	Saayman, 2016	

No.	Parameter	Value	Source	Comment
4.2	Meter model	Variable, including Aqualoc and Utility Systems	Pontia, 2016; Booysen, 2016	
4.3	SANS 1529-1 compliant?	True	N/A	Meets legal requirements
4.4	SANS 1529-9 compliant?	True	N/A	Meets legal requirements
4.5	Mean battery life (years)	7 years	Pontia , 2016	Adopted from field experience
4.6	Battery replaceable in field?	True	Not available	Preference for modular units assumed
4.7	Meter service life (years)	7 years	Pontia, 2016	
Fraction of meters expected to fail due to				
4.9	Water meter failure	21%	Thompson et al., 2013 & GIBB,2015	From Cape Town WMD experience in four areas
4.10	Electronics and other components (e.g. valve) failure	See above	See above	Assumed to be included in above water meter failure rate
4.11	Vandalism	10%	GIBB, 2015	
4.12	Other	See above	See above	Assumed to be included in above vandalism failure rate
Costs for advanced metering				
4.14	Meter price	R1 500/meter	GIBB, 2015	
4.15	Installation cost	R1 000 /meter	GIBB, 2015	
4.16	Communication infrastructure cost	N/A	N/A	Meters not automatically read
4.18	Battery replacement cost	R220/meter	Made in China.com, 2016; GIBB, 2015	Estimate from product price list as in Epping Industrial case study.
4.19	Meter reading cost	R2/meter	Saayman, 2016	Meters can be present so advantageous over conventional
4.20	Meter operation and	R31/meter/month	N/A	Based on capital cost of meter

No.	Parameter	Value	Source	Comment
	maintenance cost			
4.21	Billing cost	R10/bill	GIBB, 2015	
Expected new consumption for advanced metering				
4.24	Billed metered consumption	160 000	Saayman, 2016	
4.24	Billed metered unit consumption	10.5 kl/property/month	Marah et al., 2004	FBW allotment
4.26	Illegal consumption	N/A	N/A	All assumed to have been identified and removed
4.26	Illegal connections unit consumption	N/A	N/A	See above
	Fraction of properties paying for water			
4.29	Billed metered consumption	90%	Sivatho & De Sousa-Alves, 2016; GIBB, 2015	
4.31	Ave time between meter readings (months)	1	N/A	Congruent with monthly billing cycle

(a) Proposed system parameters

- WMDs are the advanced ***meter type*** considered in this case study (Saayman, 2016).
- The ***meter models*** listed above were obtained from some of the WMD area implementation articles (Booysen, 2016) as well as information from Cape Town on the current implementations (Pontia, 2016).
- Both ***SANS 1529-1*** and **SANS 1529-9** compliance are applicable to advanced metering technology and therefore it is a legal requirement for the advanced meters to comply with these standards. The system and meters installed complied with these standards in all cases.
- A ***mean battery life*** of 7 years obtained from City of Cape Town (Pontia, 2016), as in Section 6.1.4 of Epping Industrial case study, was adopted here.
- A modular unit which allows the ***battery to be replaceable in the field*** was input as the typical characteristic of the WMD system proposed since this was considered to be the preferred option for maintenance and operational cost management.
- A ***meter service life*** of 7 years for advanced metering systems was obtained from the City of Cape Town (Pontia, 2016).

(b) Failure rates

- GIBB (2015) contains a section on case studies done on WMD implementation in Cape Town, carried out by Thompson et al. (2013). WMD project experience in four areas of Cape Town, i.e. Saxon Sea, Samora Machel, Umlazi and Umbubulu, is given. The technical failure rates of the WMDs in each area were thus used to obtain the average WMD ***meter failure rate*** of 21% given above.
- The ***electronics and other components*** (e.g. valve) ***failure rate*** parameter was omitted since this value was deemed to be included in the meter failure rate value from the 4 CoCT case studies in item 4.9 above.
- Per GIBB's (2015) study in eThekwini, there is an increased probability of tampering of conventional systems with water management devices in low-cost housing areas. A 2015 value of 43% probability of failure per year due to vandalism and other causes was given for eThekwini (GIBB, 2015). In the absence of information on vandalism of these devices from CoCT; an estimate of 10% ***failure per year due to vandalism and other causes*** was adopted as an average for roll out in all the various areas of Cape Town.

(c) Costs

- In the absence of information from CoCT on this, the typical WMD ***meter price*** adopted was R1 500 based on the complete cost value for a conventional domestic meter with WMD in eThekwini (GIBB, 2015).
- In the absence of information from CoCT on the ***installation cost*** of WMDs, R1 000 per meter for labour for installation, as in the GIBB (2015) report value for WMDs, was adopted.
- For ***communication infrastructure costs***, since these meters in most cases are not automatically read, the value for this has been omitted.
- The ***payment infrastructure cost*** was also omitted from the table since the WMDs use a post payment system similar to that of conventional meters thus no vending infrastructure was required.
- The ***battery replacement costs*** for this WMD system were based on comparison of two source values as explained in the Epping case study.
- Although the typical manual meter reading cost from CoCT is R8/meter; this was adjusted to a ***WMD meter reading cost*** of R2/meter. This fraction of the entire meter reading cost represented the fact that WMDs allow predetermined volumes of consumption to be provided to consumers therefore negating the need for manual meter reading to be carried out in many instances.
- Similar to the conventional case, to estimate the typical ***advanced meter operation and maintenance costs***, a ratio of 15% of the overall capital cost of the advanced meter per annum was used. An estimate of about R375 per annum and thus

R31/meter/month was obtained and adopted in the absence of more conclusive information from CoCT.

- The **billing cost** of R10/bill, as adopted from GIBB (2015) in the Epping industrial case study, section 6.1.4, has been maintained for this WMD metering system since conventional billing systems were retained for these WMDs.
- No additional ***communication system operating costs*** are expected in this WMD system for similar reasons to those in Section 6.1.4 of the Epping case study.

(d) Expected consumption

- All 160 000 properties, as in Section 3.1.1 above, were assumed to be under ***billed metered consumption*** as part of the new WMD project implementation.
- It has largely been found that consumption decreases where WMDs are installed, particularly in areas where communities were previously not paying for their consumption (Marah et al., 2004). The FBW allotment in CoCT of approximately 10.5 kl/property/month is therefore used here to represent the ***billed metered unit consumption*** reduction in the areas where these devices were used to combat the culture of non-payment for water services.
- All illegal connections, and consequently their ***illegal unit consumption,*** are assumed to have been identified and removed as part of the new WMD process and were thus omitted from the table.
- A 90% ***fraction of billed metered consumption properties paying for water*** was assumed due to the automatic flow restriction properties of WMDs which consequently force consumers to pay for continuous water supply or restrict their use to within the FBW amount.

3.2 Results

The four tables below provide the technical, social, environmental and economic results for the WMD case study in Cape Town, using calculations based on the input parameter values above.

3.2.1 Technical Result

The technical results of the evaluation are summarised in Table 11, showing compliance with SABS standards for both conventional and advanced meters. However, the advanced meters had over four times the failure rate of conventional meters. In fact, these high failure rates were one of the reasons for the initial rejection of the WMDs in most areas in Cape Town.

Table 12: Technical result for WMD case study in Cape Town

1. TECHNICAL

No	Property	Conventional metering (baseline)	Advanced metering

1.1	SABS compliance	Yes	Yes
1.2	Number of meters to replace (/month)	**933**	**4 133**

3.2.2 Social Result

The social results are shown in Table 12 below. In this case study, the affordability of the system is not assured, given that the water bill makes up 6.8% of the average income in the community. This, together with the high unemployment rate and past incidents of volatility in the community, shows that the proposed system is highly unlikely to be accepted by the community. The case study report indicates several social challenges and consequently a number of protests in implementing these devices in many of the Cape Town areas. However, with more efficient water use learned by the community over time as well as improved community awareness campaigns and customer query response times, these meters exhibited the potential to meet the key objectives, i.e. debt management and water demand management.

Table 13: Social result of the WMD case study in Cape Town

2. SOCIAL

No.	**Property**	**Value**
2.1	Current rate of meters vandalised (/year)	2%
2.2	Unemployment rate	24%
2.3	Volatility of community (no. of protest or mass action incidences per year)	129
2.4	Average water bill (/month)	R216.58
2.4	Average property income (/month)	R3 200.00
2.5	Water bill as a fraction of income	6.8%

3.2.3 Environmental Result

The environmental results are shown in Table 13 below.

A 32.3% reduction in consumption was realised with 22 857 batteries requiring disposal per year, as shown as items 3.7 and 3.8 of Table 14 below. This reduction in consumption in Cape Town fulfilled the consumption management objective.

Table 14: Environmental result of the WMD case study in Cape Town

3. ENVIRONMENTAL

No.	**Consumption**	**Units**	**Current**	**Conventional metering (baseline)**	**Advanced metering**
3.1	Billed metered consumption	(Kl/month)	2 331 200	2 480 000	1 680 000

3.2	Billed unmetered consumption	(Kl/month)	0	0	0
3.3	Illegal consumption	(Kl/month)	148 800	0	0
3.4	Total consumption	(Kl/month)	2 480 000	2 480 000	1 680 000
3.5	Unit consumption	(Kl/property/month)	15.5	15.5	10.5
3.6	Reduction in consumption	(Kl/month)		0	800 000
3.7	Fractional reduction in consumption	-		0.0%	32.3%
3.8	No of batteries to dispose of	(/year)			22 857

3.2.4 Economic Result

The economic results are shown in Table 14 below.

Table 15: Economic viability of WMD case study in Cape Town

4. ECONOMIC

No	Income	Units	Current	Conventional metering (baseline)	Advanced metering
4.1	Billed metered consumption	(/month)	R7 767 558.40	R8 263 360.00	R12 594 960.00
4.2	Billed unmetered consumption	(/month)	R0.00	R0.00	R0.00
4.3	Total income	(/month)	R7 767 558.40	R8 263 360.00	R12 594 960.00
4.4	Unit income	(/property/month)	R48.55	R51.65	R78.72
4.5	Increased income	(/month)		R495 801.60	R4 827 401.60
4.6	Fractional increased income			6%	62%
	Capital cost				
4.7	Water meters		R0.00	R80 000 000.00	R240 000 000.00
4.8	Installation		R0.00	R128 000 000.00	R160 000 000.00
4.9	Communication infrastructure cost		R0.00	R0.00	R0.00
4.10	Payment infrastructure cost		R0.00	R0.00	R0.00
4.11	Total capital cost		R0.00	R208 000 000.00	R400 000 000.00
4.12	Unit capital cost	(/property)	R0.00	R1 300.00	R2 500.00
	Operational cost				
4.13	Water production	(/month)	R19 840 000.00	R19 840 000.00	R13 440 000.00
4.14	Meter reading	(/month)	R1 203 200.00	R1 280 000.00	R320 000.00
4.15	Meter operation and maintenance	(/month)	R2 406 400.00	R2 560 000.00	R4 960 000.00
4.16	Billing cost	(/month)	R1 504 000.00	R1 600 000.00	R1 600 000.00
4.17	Billing system operating cost	(/month)		R0.00	R0.00

4.18	Communication system operating costs	(/month)			R0.00
4.19	Failed meter replacement cost	(/month)	R1 140 533.33	R1 213 333.33	R10 333 333.33
4.20	Battery replacement cost	(/month)			R419 047.62
4.21	Total operating cost	(/month)	R26 094 133.33	R26 493 333.33	R31 072 380.95
4.22	Unit operating cost	(/property/month)	R173.50	R165.58	R194.20
4.23	Decreased operating cost	(/month)		-R399 200.00	-R4 978 247.62
	Summary				
4.24	Operational surplus	(/month)	**-R18 326 574.93**	**-R18 229 973.33**	**-R18 477 420.95**
4.25	Increased operational surplus	(/month)		**R96 601.60**	**-R150 846.02**
4.26	Capital payment period	(months)		2 153.2	-2 651.7
4.27	Expected service life	years		18	7
4.28	Effective surplus	(/year)		-R10 396 336.4	-R58 953 009.4

The WMDs, at a capital cost of R400 million, achieve a 32.8% reduction in consumption and a 50% increase in payment rates. They therefore achieve the two primary objectives of the City of Cape Town's installation, that is debt reduction and consumption management.

This, however, means that the City must be willing to invest an additional R192 million into WMDs, which translates into an additional R2.45/kl if only capital cost and total consumption over the meter service life is considered for both scenarios. In water scarce areas, this additional cost may be preferable to bulk augmentation projects involving finding alternative water sources or importing water from neighbouring areas. Savings in production costs due to the reduced consumption can also be channelled to meeting the above additional metering costs.

It is important to note that in the evaluation framework above, a cost of R0/kl was used for FBW consumption. As such, inclusion of a government subsidy amount equivalent to the first tier tariff for this 6 kl FBW amount will change the economic results obtained since a new tariff amount of R12.62/kl, instead of R8.33/kl as in the case above, will be used. The new economic results indicate that both schemes, as in the above case, have a negative effective surplus and therefore are infeasible. However, where the conventional scheme resulted in operational savings, unlike the WMD scheme, with an increased tariff, the WMD scheme results in higher savings of R2.3 million/month compared to the conventional scheme savings of about R352 000/month.

The main objectives of the advanced scheme, and what achieving them means in terms of cost and social factor management, should therefore be reviewed before roll out of similar schemes in the future.

4. EVALUATION OF PREPAID METERS IN ILEMBE MUNICIPALITY

4.1 Model Input Parameters

The input parameters used to calculate the indicators for the evaluation factors were obtained from various sources and are discussed in this section under the headings of "global parameters", "existing system" and "proposed scheme". The input parameters are given in tables linked to the evaluation framework which is provided in **Appendix A.**

4.1.1 Global Parameters

The global parameters used in the analysis are summarised in Table 15, with the values chosen, sources of information and a brief comment. A more detailed explanation of how these model values were selected is provided in the subsequent paragraphs. Since no exact number of prepaid meters installed was provided, this case study assumes 10 000 properties to be the pilot study area.

Table 16: Global parameters for iLembe District Municipality

No.	Parameter	Value	Source	Comment
2.1	Number of properties	10 000	Pilot study source	
2.2	Water cost price	R5/kl	DWA, 2014	Based on average bulk portable tariff
2.3	Applicable water tariff	R5.40/kl	iLembe District Municipality, 2016	From iLembe District Municipality water and sewerage tariffs 2016/17. 10 kl free = R0 5 kl at R16.20/kl = R81 Thus the total cost for 15 kl is R81.00 which gives an average tariff of R5.40/kl

The ***number of propertie***s is based on the maximum number of properties that can be used for a pilot study in an area in the absence of a conclusive number of meters installed in this area.

The ***water cost price*** is based on the proposed 2013/2014 average bulk portable tariff of R4.70/Kl for Umgeni Water Board which supplies this area with water (DWA, 2014).

The ***applicable water tariff*** of R5.40/kl is based on the current iLembe District Municipality Water and Sewerage Tariffs 2016/2017 for the 2nd tier of conventional domestic consumption after FBW (iLembe District Municipality, 2016).

4.1.2 Existing System (Situation Before Metering System Upgrade)

This section describes the situation before the metering system upgrade. The values used are summarised below.

Table 17: Water Consumption before Advanced Meter Implementation

No.	Parameter	Value	Source	Comment
3.1	Billed metered consumption	9 300 properties	GIBB, 2015	Based on 7% tampering rate & thus 93% billed rate
3.1	Billed metered unit consumption	15 kl/property /month	Viljoen, 2015; iLembe District Municipality, 2015a	
3.3	Illegal or unbilled connections	700	GIBB, 2015	Based on 7% tampering rate
3.3	Illegal connections unit consumption	15 kl/property /month	N/A	Same as 3.1 above
Fraction of properties paying for water				
3.5	Billed metered consumption	31%	iLembe District Municipality, 2015b	Baseline value provided in iLembe District Municipality (2015b) report
Other parameters before advanced meter implementation				
3.8	Fraction of demand that is on-site leakage	6%	De Sousa-Alves, 2013	Retained from CoCT due to the absence of iLembe information
3.9	Ave time between meter readings (months)	1	Mthembu, 2016	Adopted since congruent with monthly billing cycles
3.10	Meter reading cost	R8/meter	Otieno et al., 2002 & Saayman, 2016	Adopted since congruent with 8.43 value provided for Umgeni Water Board
3.11	Billing cost	R10/bill	GIBB, 2015	Inclusive of administrative, printing and postage costs
3.12	Meter operation and maintenance cost	R11/meter/ month	Otieno & Mwangi, 2002	Half of the overall R22/connection/month O&M Cost
Fraction of meters failing due to				
3.13	Meter failure (/year)	5%	Wendell, 2016	Retained from CoCT due to the absence of iLembe information
3.14	Vandalism and other (/year)	2%	Wendell, 2016	Retained from CoCT due to the absence of iLembe information
3.16	Average household income (/month)	R5 000 /month	Statistics South Africa, 2012b	Based on Census 2011 municipal results for KZN
3.17	Unemployment rate	31%	Statistics South Africa, 2012a	Based on Census 2011 iLembe District results
3.18	Volatility of community (no. of protest or mass	15	Centre for Civil Society, 2016	Social Protest Observatory records 2016.

No.	Parameter	Value	Source	Comment
	action incidences per year)			

Of the 10 000 properties, 93% were assigned ***to billed metered consumption,*** based on GIBB (2015) which reported an average 7% tampering rate of conventional meters in rural and low-income areas (GIBB, 2015). Thus, 7% of the 10 000 properties were assigned to ***illegal consumption***.

In the absence of consumption information, ***billed metered unit consumption*** was based on comparison of two sources. The iLembe Municipality average monthly consumption values for billed authorised consumption over a six-year period [July 2009–May 2015] (iLembe District Municipality, 2015a) and the unit consumption value of 0.5 kl/day for the low-income category of single households surveyed in the Viljoen (2015) study of Cape Town. For iLembe municipality, the average area value given (approx. 750 000 kl/month) was divided by the total number of connections (34 632) given in the system characteristics and downscaled to also account for consumer and other industrial/institutional amounts (iLembe District Municipality, 2015a).This downscaled value fitted closer with the CoCT domestic consumption and was thus adopted with a reasonable level of confidence.

A fraction of billed metered properties paying for water of 31% was adopted from the baseline value given for the proportion of consumers paying in full versus the number of consumers billed in iLembe District Municipality's report (2015b).

The ***fraction of demand that is on-site leakage*** of 6%, based on an estimate of on-site leakage in residential areas made by the City of Cape Town (De Sousa-Alves, 2013), was adopted here due to the absence of information from iLembe Municipality in this regard.

The R8/meter value for ***meter reading cost*** for the City of Cape Town (Saayman, 2016) was maintained here since it is congruent with the R8.43 value provided as administration cost/connection/month for Umgeni Water Board which serves the iLembe municipal area (Otieno & Mwangi, 2002).

It was not possible to get a ***billing cost*** value from iLembe Municipality. However, from a feasibility study for eThekwini, billing costs were estimated as R10 per month per meter (GIBB, 2015) made up of R6 administrative cost, R1 printing cost and R3 postage cost. This estimated R10/bill was adopted as the billing cost for iLembe Municipality which is close to this area.

To estimate the typical ***meter operation and maintenance costs***, a value of R11/meter/month was taken as half of the overall sum of R22/connection/month operating and maintenance costs for Umgeni water schemes (Otieno & Mwangi, 2002).

The ***meter failure rate*** of 5% for conventional meters in the Cape Town case study (Wendell, 2016) was adopted here due to the absence of information from iLembe Municipality in this regard.

The ***failure rate due to vandalism and other reasons*** of 2% for conventional meters in the Cape Town case study was adopted here (Wendell, 2016) due to the absence of information from iLembe Municipality in this regard.

The socio-economic characteristics from the Census 2011 municipal results for KZN state an average annual household income of R61 000 for iLembe district; this was divided by 12 to get R5 083, i.e. approximately R5 000/month ***average household income*** (Statistics South Africa, 2012b).

The ***unemployment rate*** of 31% was based on Statistics South Africa (2012a) iLembe District results.

About five protests/mass action incidents have been recorded in the Centre for Civil Society Social Protest Observatory as having occurred in iLembe District Municipality, just between January and April of 2016 (Centre for Civil Society, 2016). This indicates a high ***community volatility*** of approximately 15 incidents per year.

4.1.3 Proposed Scheme for Conventional Metering (Baseline)

In the evaluation framework, the proposed scheme consists of two parallel categories, i.e. conventional and advanced metering. This is useful in evaluating the benefits of replacing the existing meters with advanced meters over conventional meters.

The parameters for the proposed conventional metering scheme are summarised in Table 17 and discussed in the rest of the section under the headings "proposed system parameters", "failure rates", "costs" and "expected consumption".

Table 18: Proposed conventional metering scheme parameters

No	Parameter	Value	Source	Comment
	Proposed system parameters			
4.1	Meter make	Variable including Elster Kent	Mthembu, 2016	Based on existing situation
4.2	Meter model	Variable including single-jet, rotating piston and others	Mthembu, 2016; van Zyl, 2011	Based on existing situation
4.3	SANS 1529-1 compliant?	True	N/A	Meets legal requirements.
4.7	Meter service life (years)	18	Van Zyl, 2011; de Sousa-Alves, 2013	From CoCT due to the absence of iLembe information
	Fraction of meters expected to fail due to			
4.9	Water meter failure (/year)	5.0%	Wendell, 2016	Same as 3.13 above
4.11	Vandalism (/year)	2.0 %	Wendell, 2016	Same as 3.14 above

No	Parameter	Value	Source	Comment
4.12	Other(/year)	N/A	N/A	Included in 4.11 above
	Costs			
4.14	Meter price	R500/meter	De Beer, 2010	Same as Cape Town value
4.15	Installation cost	R800/meter	Ngobeni, 2016	
4.17	Payment infrastructure cost	R0	N/A	Absorbed within billing cost
4.19	Meter reading cost	R8/meter	Otieno & Mwangi, 2002; Saayman, 2016	Same as 3.10 above
4.20	Meter operation & maintenance cost	R11/meter/month	N/A	Same as 3.12 above
4.21	Billing cost	R10/bill	GIBB, 2015	Same as 3.11 above
	Expected new consumption			
4.24	Billed metered consumption	10 000 properties	Viljoen, 2015; iLembe District Municipality, 2015a	Same as 3.1 above
4.24	Billed metered unit consumption	15 kl/property/month	N/A	
4.26	Illegal consumption or unbilled connections	700 properties	GIBB, 2015	
4.26	Illegal connections unit consumption	N/A	N/A	
	Fraction of properties paying for water			
4.29	Billed metered consumption	31%	iLembe District Municipality, 2015b	Same as 3.5 above
4.31	Ave time between meter readings	1 per month	Mthembu, 2016	Same as 3.9 above

(a) Proposed system parameters

- iLembe municipality indicated the Elster Kent meter as one of the various conventional ***meter makes and models*** in the district (Mthembu, 2016). However, regardless of make and model, all the newly installed conventional meters can be assumed to be ***SANS 1529-1*** compliant.
- The value for ***SANS 1529-9*** compliance is not applicable since it deals with requirements for electronic indicators that in most cases are not part of a typical conventional meter.
- A conventional ***meter service life*** of 18 years was adopted, as in the Cape Town case study, due to the similarity in conventional meters used as well as the absence of information from iLembe Municipality in this regard.

(b) Failure rates

- In assessing the water ***meter failure rate,*** a value of 5% meter failure per year as in Section 4.1.2 above was used (Wendell, 2016).
- The values of 2% ***failure per year due to vandalism and other causes*** were also adopted, as in Section 4.1.2 above (Wendell, 2016).

(c) Costs

- The typical conventional ***meter price*** used of R500/meter was adopted from the Cape case study since the conventional meters used in both municipalities are the same.
- No information on the ***installation cost*** of conventional meters in iLembe could be found. As such, an estimate of R800/meter, based on municipal staff experience in a Pretoria case study, was adopted here to account for all the materials and labour required for meter installation.
- Since the administrative portion of the ***billing cost*** is expected to cover all payment system operational costs, **no payment infrastructure costs** are expected.
- The ***meter reading, billing and meter operation and maintenance costs*** were adopted from the existing values discussed in Section 4.1.2.

(d) Expected new consumption

- All 10 000 properties were assigned to ***billed metered consumption*** based on the assumption that all illegal connections in the existing system would be discovered and rectified in the new scheme.
- As inferred above, none of the 10 000 properties were assigned to ***illegal consumption*** to account for corrective measures taken with the new scheme.
- Since it was difficult to determine whether the changes in ***unit consumption*** were attributed to leakages or improved meter accuracy, domestic consumption was assumed to remain unchanged (Mthembu, 2016).
- The ***fraction of billed metered consumption properties paying for water*** of 31% was adopted here as in the existing scheme, Section 4.1.2, since, in both cases, conventional meters are used (iLembe District Municipality, 2015b).

4.1.4 Proposed Scheme for Advanced Metering

Table 18 summarises the parameters for Utility Systems prepaid meters installed as additional features to existing meters in the iLembe municipality pilot area.

More detailed information on the parameters for this prepaid advanced metering scheme are discussed in the rest of the section under the headings “proposed system parameters”, “failure rates”, “costs” and “expected consumption”.

Table 19: Proposed advanced scheme parameters

No.	Parameter	Value	Source	Comment
Proposed system parameters				
4.1	Meter make	Prepaid drive-by meter	Mthembu, 2016	
4.2	Meter model	Variable conventional models all fitted with Utility Systems prepaid metering components	Mthembu, 2016	
4.3	SANS 1529-1 compliant?	True		Meets legal requirements
4.4	SANS 1529-9 compliant?	True		Meets legal requirements
4.5	Mean battery life (years)	10 years	Utility Systems, 2013	Adopted from manufacturer's brochure in the absence of more pertinent field information
4.6	Battery replaceable in field?	True	Mthembu, 2016	Preference for modular units
4.7	Meter service life (years)	7 years	GIBB, 2015; Pontia, 2016	
Fraction of meters expected to fail due to				
4.9	Water meter failure	5.0%	Wendell, 2016	As in Section 4.1.3 above
4.10	Electronics and other components (e.g. valve) failure	7.5%	Wendell, 2016	Adopted from Cape Town due to absence of information from iLembe municipality in this regard
4.11	Vandalism	10.0%	GIBB, 2015	
4.12	Other	N/A	N/A	Included in 4.11 above
Costs for advanced metering				
4.14	Meter price	R1 210/meter	GIBB, 2015	Summation of WMD & UIU costs
4.15	Installation cost	R1 200/meter	GIBB, 2015; Cottle & Deedat, 2002	
4.16	Communication infrastructure cost	R 10 000	GIBB, 2015; Mthembu, 2016	Based on unit price of R2 500 for each mobile data collector, and once-off installation cost of R2 500 for system
4.18	Battery replacement cost	R220/meter	Made in China.com, 2016; GIBB, 2015	Estimate from product price list
4.19	Meter reading cost	N/A	N/A	No reading required since it is a prepaid metering system
4.20	Meter operation & maintenance cost	R225/meter/month	N/A	Based on overall capital cost of each meter

No.	Parameter	Value	Source	Comment
4.21	Billing cost	N/A	N/A	No billing required for this prepaid system
Expected new consumption for advanced metering				
4.24	Billed metered consumption	9 000 properties	GIBB, 2015	90% of assumed pilot area properties
4.24	Billed metered unit consumption	15 kl/property/month	N/A	Same as existing case
4.26	Illegal consumption	1 000 properties	GIBB, 2015	Following from 4.24 above
4.26	Illegal connections unit consumption	15 kl/property/month	N/A	
	Fraction of properties paying for water			
4.29	Billed metered consumption	39%	Mathonsi, 2014	
4.31	Ave time between meter readings (months)	N/A	N/A	No billing required since this is a prepaid system

(a) Proposed system parameters

- The ***meter make and model*** chosen for this pilot scheme was the Utility Systems prepaid metering drive-by technology (Mthembu, 2016).
- Both ***SANS 1529-1 and SANS 1529-9*** compliance are applicable to advanced metering technology and therefore it is a legal requirement for the advanced meters to comply with these standards. The system and meters installed complied with these standards in all cases.
- A ***mean battery life*** of 10 years, as claimed by the manufacturer and per the warranty period provided for it, was adopted here (Mthembu, 2016).
- A modular unit which allows the ***battery to be replaceable in the field*** was the preferred option installed in this case for improved maintenance and operational cost management.
- A ***meter service life*** of 7 years for the prepaid system was adopted from Cape Town information and GIBB (2015), given a lack of any information from iLembe municipality in this regard, and also because the 15 mm WMDs in use in CoCT are from the same supplier (Pontia, 2016).

(b) Failure rates

- In the absence of information from iLembe municipality, the 5% ***meter failure rate*** obtained from CoCT was retained here. This is because this rate was close to the 3.6% per year failure rate mentioned in Singh and Xaba's (2006) Operation Gcin' Amanzi case study on prepaid meter use in Johannesburg, cited in the GIBB (2015) report.
- Similarly, the ***electronics and other components (e.g. valve) failure rate*** parameter of 7.5% from CoCT (Wendell, 2016) was retained in the absence of any information from iLembe municipality in this regard.

- Per the GIBB (2015) study in eThekwini, there is an increased probability of tampering with conventional systems with water management devices in low-cost housing areas. A 2015 value of a 43% probability of ***failure per year due to vandalism and other causes*** was given for eThekwini (GIBB, 2015). This value seems quite high and so, in the absence of information on vandalism of these devices from iLembe, an estimate of 10% ***failure per year due to vandalism and other causes*** was adopted as in the Cape Town WMD case study.

(c) Costs

- The typical advanced ***meter price*** adopted was R1 210/meter based on the sum of the USC meter and UIU unit costs obtained from the GIBB (2015) study. This study included an assessment of different suppliers' meter types and associated costs for use in eThekwini municipality (GIBB, 2015) and the above value was thus adopted in the absence of information from the municipality in this regard.
- In obtaining the ***installation cost***, a comparison was made between the GIBB (2015) value of R1 500 and Cottle & Deedat (2002)'s value of R1 200 for installation. The R1 200 value was adopted since it more closely coincides with the value that would be obtained if a similar approach as that taken in the proposed conventional metering case was used to determine the installation cost of the prepaid meters.
- For ***communication infrastructure cost***s, the different unit processes provided in the GIBB (2015) report for eThekwini suggest an approximate sum of about R35 000, which includes the unit prices for a mobile data collector and once-off installation costs provided for third-party hosts, for example Blue Label, net Vendor and Easy Pay (GIBB, 2015). However, because of the STS compliance of the USC prepaid meters, advantages in terms of making use of the existing prepaid electricity vending systems used in iLembe could be achieved (Mthembu, 2015). To take this into account, the value of R5 000, based on a unit price of R2 500 for each mobile data collector, and once-off installation costs of R2 500 for system) was considered for one mobile data collector. Purchase of at least two additional mobile data units therefore resulted in a total cost of R10 000 which was therefore adopted here.
- The ***payment infrastructure cost*** was omitted from the table since the UIU unit cost was included in the overall meter price in 4.14.
- The ***battery replacement cost*** of R220/meter used in the Cape Town case studies was retained here since no information was obtained from iLembe municipality in this regard (Made in China.com, 2016; GIBB 2015).
- The ***meter reading cost*** was considered inapplicable here since it is a prepaid metering system and so no meter readings were required for water, only sanitation which is outside the scope of this evaluation framework.
- The R225/meter/month of the Epping study in CoCT was retained here as the ***meter operation and maintenance cost*** due to the similarity of the physical and

communication infrastructure installed in both areas, and in the absence of information from iLembe municipality in this regard.

- The ***billing cost*** was considered inapplicable to this prepaid metering system.
- No ***additional communication system operating costs*** are expected since all communication costs were included in the 4.16 item and can alternatively form part of the existing iLembe vending system used.

(d) Expected consumption

- Only 90% of the 10 000 properties were assigned to ***billed metered consumption,*** to account for the 10% value assumed in 4.11 as the vandalism rate (GIBB, 2015).
- Conversely, 10% of the 10 000 properties were assigned to ***illegal consumption*** to account for said 10% tampering rate.
- The prepaid system was not expected to have any impact on ***unit consumption*** and thus it was assumed to be identical to the conventional metering system in Section 4.1.3.
- The 2013/2014 annual report (Mathonsi, 2014) indicated a 7–8% increment in bill collection resulting in an approximate 39% increment in properties paying for water compared to the previous year. This 39% was therefore adopted as the ***fraction of billed metered consumption properties paying for water*** (iLembe District Municipality, 2015b).
- The ***average time between meter readings*** per month was not applicable since this is a prepaid system and therefore requires no billing to be made.

4.2 Results

The four tables below provide the technical, social, environmental and economic results for the iLembe prepaid metering case study calculations, based on the input parameter values above.

4.2.1 Technical Result

The technical results of the evaluation are summarised in Table 19 showing compliance with SABS standards for both conventional and advanced meters. However, the prepaid meters have over three times the failure rate of the conventional meters. These high failure rates are one of the main reasons for both the municipality and community’s frustration with the prepaid scheme.

Table 20: Technical result for prepaid case study in iLembe

1. TECHNICAL

No.	Property	Conventional metering (baseline)	Advanced metering
1.1	SABS compliance	Yes	Yes
1.2	Number of meters to replace (/month)	**933**	**4 133**

4.2.2 Social Result

The social results are shown in Table 20 below. The water bill is estimated to be 3.2% of the community's household income. While this value, which is under 5%, implies that the community will be willing to pay for water, the case study report still indicates a high level of non-payment and increasing municipal debt. Although some of this debt can be attributed to the increased sewer bills explained in the case study report, the non-payment also points to the fact that technology alone cannot change water use and payment behaviour. Other social interventions like improved community engagement and awareness campaigns, rapid customer query response time and others should be worked on as well.

Table 21: Social result of the prepaid case study in iLembe

2. SOCIAL

No	Property	Value
2.1	Current rate of meters vandalised (/year)	2.0%
2.2	Unemployment rate	31.0%
2.3	Volatility of community (No. of protest or mass action incidences per year)	15
2.4	Average water bill (/month)	R162.00
2.4	Average property income (/month)	R5 000.00
2.5	Water bill as a fraction of income	3.2%

4.2.3 Environmental Result

The environmental results are shown in Table 21 below.

No reduction in consumption was observed for either metering case. In the prepaid metering case, 1 000 batteries per year will require disposal, as compared to the conventional metering case which has no battery disposal requirements.

Table 22: Environmental result of the prepaid case study in iLembe

3. ENVIRONMENTAL

No.	Consumption	Units	Current	Conventional metering (baseline)	Advanced metering
3.1	Billed metered consumption	(Kl/month)	139 500	150 000	150 000
3.2	Billed unmetered consumption	(Kl/month)	0	0	0
3.3	Illegal consumption	(Kl/month)	10 500	0	0

3. ENVIRONMENTAL

No.	Consumption	Units	Current	Conventional metering (baseline)	Advanced metering
3.4	Total consumption	(Kl/month)	150 000	150 000	150 000
3.5	Unit consumption	(Kl/property/month)	15	15	15
3.6	Reduction in consumption	(Kl/month)		0	0
3.7	Fractional reduction in consumption	-		0%	0%
3.8	No of batteries to dispose of	(/year)			1 000

4.2.4 Economic Result

The economic results are shown in Table 22 below.

Table 23: Economic viability of Prepaid Case Study in iLembe

4. ECONOMIC

No.	Income	Units	Current	Conventional metering (baseline)	Advanced metering
4.1	Billed metered consumption	(/month)	R233 523.00	R251 100.00	R315 900.00
4.2	Billed unmetered consumption	(/month)	R0.00	R0.00	R0.00
4.3	Total income	(/month)	R233 523.00	R251 100.00	R315 900.00
4.4	Unit income	(/property/ month)	R23.35	R25.11	R31.59
4.5	Increased income	(/month)		R17 577.00	R82 377.00
4.6	Fractional increased income			8%	35%
	Capital cost				
4.7	Water meters		R0.00	R5 000 000.00	R12 100 000.00
4.8	Installation		R0.00	R8 000 000.00	R12 000 000.00
4.9	Communication infrastructure cost		R0.00	R0.00	R10 000.00
4.10	Payment infrastructure cost		R0.00	R0.00	R0.00
4.11	Total capital cost		R0.00	R13 000 000.00	R24 110 000.00
4.12	Unit capital cost	(/property)	R0.00	R1 300.00	R2 411.00
	Operational cost				
4.13	Water production	(/month)	R750 000.00	R750 000.00	R750 000.00

4. ECONOMIC

No.	Income	Units	Current	Conventional metering (baseline)	Advanced metering
4.14	Meter reading	(/month)	R74 400.00	R80 000.00	R0.00
4.15	Meter operation & maintenance	(/month)	R102 300.00	R110 000.00	R2 250 000.00
4.16	Billing cost	(/month)	R93 000.00	R100 000.00	R0.00
4.17	Billing system operating cost	(/month)		R0.00	R0.00
4.18	Communication system operating costs	(/month)			R0.00
4.19	Failed meter replacement cost	(/month)	R70 525.00	R75 833.33	R451 875.00
4.20	Battery replacement cost	(/month)			R18 333.33
4.21	Total operating cost	(/month)	R1 090 225.00	R1 115 833.33	R3 470 208.33
4.22	Unit operating cost	(/property/ month)	R117.23	R111.58	R347.02
4.23	Decreased operating cost	(/month)		-R25 608.33	-R2 379 983.33
	Summary				
4.24	Operational surplus	(/month)	**-R856 702.00**	**-R864 733.33**	**-R3 154 308.33**
4.25	Increased operational surplus	(/month)		**-R8 031.33**	**-R2 297 606.33**
4.26	Capital payment period	(months)		-1618.7	-10.5
4.27	Expected service life	years		18	7
4.28	Effective surplus	(/year)		-R818 598.2	-R31 015 561.7

The economic results indicate that both schemes have a negative effective surplus and therefore are infeasible. However, the prepaid meters at a capital cost of about R24 million compared to the conventional scheme of R13 million require almost twice the investment amount making them even more unfavourable.

It is important to note that in the evaluation framework above, a cost of R0/kl was considered for the FBW consumption. As such, inclusion of a government subsidy amount equivalent to the first-tier tariff for this 6kl FBW amount will change the economic results obtained since a new tariff amount of R16.20/kl instead of R5.40/kl as in the case above will be used. The new economic results do not differ much since both schemes, as in the above case, still have a negative effective surplus and therefore are infeasible.

The main benefit of the prepaid system is that it causes a slight improvement in payment rates but not by a significant enough amount to warrant the increased operational and capital costs it imposes, with a total capital cost of R24 million compared with R13 million for conventional metering.

5. EVALUATION OF PREPAID METER INSTALLATION IN OLIEVENHOUTBOSCH, TSHWANE

5.1 Model Input Parameters

The input parameters used to calculate the indicators for the evaluation factors were obtained from various sources and are discussed in this section under the headings “global parameters”, “existing system” (i.e. the situation before new meter implementation) and “proposed scheme” (which caters for both the new conventional and new advanced metering system scenarios proposed). Appendix A contains detailed descriptions of each parameter as well as typical values that can be adopted where specific parameters required for the area under investigation are unknown.

5.1.1 Global Parameters

The global parameters used in the analysis are summarised in Table 23, with the values chosen, sources of information and a brief comment. A more detailed explanation of how these model values were selected is provided in the subsequent paragraphs. The roll out of 6 000 prepaid meters in Olievenhoutbosch to date (Ngobeni, 2016) was considered as the project scope for this evaluation.

Table 24: Global parameters

No	Parameter	Value	Source	Comment
2.1	Number of properties	6 000	Ngobeni, 2016	
2.2	Water cost price	R8.00 /kl	De Sousa-Alves, 2013; City of Tshwane, 2015	
2.3	Applicable water tariff	R6.75 /kl	City of Tshwane, 2016	City of Tshwane water and sanitation tariffs: 12 kl free = R0 6 kl at R16.23/kl = R97.38 2 kl at R18.78/kl = R37.56 Thus, the total cost for 20 kl is R134.94 which gives an average tariff of R6.75/kl
2.4	Billed unmetered tariff (R/month)	N/A	City of Tshwane, 2015	This denomination does not currently exist under the city tariff structure

- The ***number of properties*** is based on the total number of prepaid meters in Tshwane as per October 2016 (Ngobeni, 2016).
- For the ***water cost price***, since the R8.00/kl value used in the Cape Town case studies is quite close to the City of Tshwane July 2015–June 2016 bulk water supply cost of R7.49/kl (City of Tshwane, 2015), the previous approximation of R8.00/kl was retained here.

- The applicable ***water tariff*** of R6.75/kl is based on a weighted average of 1st and 2nd FBW tariff considerations and the 3rd and 4th water and sanitation tier tariffs, effective from 1st July 2016 to 30th June 2017, for Scale B: Single dwelling households, for both conventional and prepaid metering (City of Tshwane, 2016).
- All unauthorised consumption, under the City of Tshwane 2015 tariff structure, refers to illegal connections and thus no ***billed unmetered tariff*** or denomination was considered applicable to this case study (City of Tshwane, 2015).

5.1.2 Existing System (Situation Before Metering System Upgrade)

This section describes the situation before the metering system upgrade. The values used are summarised in Table 24.

Table 25: Water consumption before advanced meter implementation

No	Parameter	Value	Source	Comment
3.1	Billed metered consumption	5 040 properties	City of Tshwane, 2010	
3.1	Billed metered unit consumption	20 kl/property /month	City of Tshwane, 2009	Domestic consumption estimates
3.2	Billed unmetered consumption	N/A	N/A	
3.2	Billed unmetered unit consumption	N/A	N/A	
3.3	Illegal or unbilled connections	960 properties	City of Tshwane, 2010	Based on remaining 6% of overall 6 000 properties
3.3	Illegal connections unit consumption	20 kl/property /month	City of Tshwane, 2009	Same consumption estimates as 3.1 above
Fraction of properties paying for water				
3.5	Billed metered consumption	69%	Peters, 2011	Based on non-payment stats
3.6	Billed unmetered consumption	N/A	N/A	
Other parameters before advanced meter implementation				
3.7	Fraction of demand that is on-site leakage	10%	Van Zyl et al., 2007; Lugoma et al., 2012	Average of on-site leakage in l/stand/day extrapolated over a month
3.8	Ave time between meter readings (months)	1	Ngobeni, 2016	Adopted since congruent with monthly billing cycles
3.9	Meter reading cost	R8/meter	Saayman, 2016	
3.10	Billing cost	R10/bill	GIBB, 2015	Inclusive of administrative, printing and postage costs

No	Parameter	Value	Source	Comment
3.11	Meter operation & maintenance cost	R16/meter/month	N/A	Estimated as a ratio of overall capital cost
Fraction of meters failing due to				
3.12	Meter failure (/year)	5%	Wendell, 2016	
3.13	Vandalism and other (/year)	2%	Wendell, 2016	
3.14	Average household income (/month)	R15 200/month	Parliament, 2012	Based on Census 2011 City of Tshwane Results
3.15	Unemployment rate	24%	Parliament, 2012	Based on Census 2011 City of Tshwane Results
3.17	Volatility of community (No. of protest or mass action incidences per year)	75	Centre for Civil Society, 2016	Social Protest Observatory records, 2016

- The 5 040 value for ***billed metered consumption*** properties was obtained by applying a factor of 84% to the overall 6 000 properties installed with prepaid meters as per the City of Tshwane IDP 2010 target of 84% meter reading/billing efficiency per month (City of Tshwane, 2010).
- In the absence of ***billed metered unit consumption*** data for Olievenhoutbosch, an estimate had to be made. City of Tshwane (2009) assumes an approximate consumption of 20kl/month for a typical subsidised household in the Gauteng area, and this estimate was therefore adopted here.
- Since all 6 000 properties were assumed to be metered, the values for ***billed unmetered properties*** and their unit consumption were not applicable for this case study.
- The 960 value for ***illegal or unbilled connections*** was obtained by applying the remaining fraction of 6% to the overall 6 000 properties on the assumption that this uncaptured fraction represents these types of connections in Tshwane.
- A similar ***illegal connections unit consumption*** of 20 kl/property/month as in the billed metered unit consumption case was adopted in the absence of more conclusive information from City of Tshwane.
- In the absence of information from City of Tshwane in this regard, a ***fraction of billed metered properties paying for water*** of 69% was adopted as a representative value. This was based on the Stats SA 2005 percentage total of 31% of consumers with water debts for various reasons as plotted in the text (Peters, 2011).
- The ***fraction of billed unmetered properties paying for water*** was considered inapplicable since consumption was considered to fall either under the billed or illegal consumption category.

- The ***fraction of demand that is on-site leakage*** of 10% was taken as an average approximation from two studies in which investigation of on-site leakage forms a part. A 2.5% value was extrapolated from the average of 5–28l/day per stand on-site leakage determined in the consumption levels study for selected South African cities (van Zyl et al., 2007). In a study on the extent of on-site leaks in Johannesburg, which neighbours Tshwane, established suburbs were determined to have approximately 25% on-site leakage, translating to about 17kl/month (Lugoma et al., 2012). Since this case study deals with a low-income area, an approximation between the two values above was taken to be 10%.
- The R8/meter value for ***meter reading cost*** was obtained from the City of Cape Town (Saayman, 2016) and maintained in this case study in the absence of any information from Tshwane in this regard.
- It was not possible to get the ***billing cost*** from City of Tshwane. The eThekwini study estimated value of R10/bill was thus adopted here, as it was in the Cape Town case (GIBB, 2015).
- To estimate the typical ***meter operation and maintenance costs*** a ratio of 15% of the overall capital cost of a conventional meter per annum was used due to the absence of more conclusive information on this. An estimate of about R199.8 per annum, and thus R16.65/month, was obtained, which value was rounded off to approximately R16/meter/month, as in the other case studies.
- The ***meter failure rate*** of 5% for conventional meters obtained from the Cape Town case study (Wendell, 2016) was retained here in the absence of information from City of Tshwane in this regard.
- As above, the ***failure rate due to vandalism and other reasons*** of 2% for conventional meters from the Cape Town case study (Wendell, 2016) was also retained here in the absence of information from City of Tshwane in this regard.
- A parliamentary report on the socio-economic characteristics of the City of Tshwane states that the ***average household income*** is R182 822 per annum which translates to approximately R15 200/month, as per the Census 2011 (Parliament, 2012). This figure was adopted here.
- An ***unemployment rate of 24%,*** based on the Census 2011 City of Tshwane Results (Parliament, 2012), was adopted.
- Over 25 protest/mass action incidents were recorded in the Centre for Civil Society Social Protest Observatory as having occurred in different parts of Tshwane/Pretoria just between January and April of 2016 (Centre for Civil Society, 2016). This indicates a high ***community volatility*** of approximately 75 incidents per year.

5.1.3 Proposed Scheme for Conventional Metering (Baseline)

In the evaluation framework, the proposed scheme consists of two parallel categories, i.e. conventional and advanced metering. This is useful in evaluating the benefits of replacing the existing meters with advanced meters over conventional meters.

The parameters for the proposed conventional metering scheme are summarised in Table 25 below and discussed in the rest of the section under the headings of "proposed system parameters", "failure rates", "costs" and "expected consumption".

Table 26: Conventional meter scheme parameters

No.	Parameter	Value	Source	Comment
Proposed system parameters				
4.1	Meter make	Variable, including Elster Kent, Utility Systems, etc.		
4.2	Meter model	Variable, including rotary piston, single jet and multi-jet meters		
4.3	SANS 1529-1 compliant?	True	N/A	Meets legal requirements
4.7	Meter service life (years)	18	Van Zyl, 2011	
Fraction of meters expected to fail due to				
4.9	Water meter failure (/year)	5%	Wendell, 2016	As in Section 5.1.2 above
4.11	Vandalism (/year)	2%	Wendell, 2016	As in Section 5.1.2 above
4.12	Other(/year)	N/A	N/A	Included in 4.11 above
4.13	Total failure rate (/year)	7%	N/A	Sum of all the above failure rates, 4.9 to 4.12
Costs				
4.14	Meter price	R532/meter	Ngobeni, 2016	
4.15	Installation cost	R800/meter	Ngobeni, 2016	
4.17	Payment infrastructure cost	R0	N/A	Absorbed within billing cost
4.19	Meter reading cost	R8/meter	Saayman, 2016	
4.20	Meter operation & maintenance cost	R16 meter/month	N/A	Based on overall capital cost of the meter
4.21	Billing cost	R10/bill	GIBB, 2015	Inclusive of administrative, printing and postage costs
Expected new consumption				
4.24	Billed metered consumption	6 000 properties	Ngobeni, 2016	
4.24	Billed metered unit Consumption	20 kl/property/month	City of Tshwane, 2009	No change assumed

No.	Parameter	Value	Source	Comment
4.26	Illegal consumption or unbilled connections	N/A	N/A	Illegal connections are assumed to have been identified and metered
4.26	Illegal connections unit consumption	N/A	N/A	Based on above
Fraction of properties paying for water				
4.29	Billed metered consumption	69%	Peters, 2011	Same as Section 5.1.2
4.31	Ave time between meter readings	1 per month	Ngobeni, 2016	Congruent with monthly billing cycle

(a) Proposed system parameters

- CoT has different makes of conventional meters including Elster Kent and Utility Systems, amongst others.
- The value for ***SANS 1529-9*** compliance was omitted from Table 3 since it deals with requirements for electronic indicators that in most cases are not applicable to typical conventional meters.
- A conventional ***meter service life*** of 18 years, as used in the CoCT case study, was retained here in the absence of information from City of Tshwane in this regard.

(b) Failure rates

- For water ***meter failure rate***, a value of 5% meter failure per year, as in Section 5.1.2 above, was used (Wendell, 2016).
- The value of 2% ***failure per year due to vandalism and other causes*** was adopted as in Section 5.1.2 above.

(c) Costs

- The typical conventional ***meter price*** used was approximately R532/meter, obtained from City of Tshwane (Ngobeni, 2016).
- The typical ***installation cost*** of the conventional meters used was R800/meter, obtained from City of Tshwane (Ngobeni, 2016).
- Since the administrative portion of the ***billing cost*** is expected to cover all payment system operational costs, no payment infrastructure costs are expected.
- The ***meter reading, billing and meter operation and maintenance costs*** were adopted from the existing values discussed in Section 5.1.2 above.

(d) Expected consumption

- All 6 000 properties were included in the category of ***billed metered consumption*** in this proposed metering case since illegal connections were assumed to have been identified and rectified accordingly.
- Since the proposed meter type here is the same as the existing conventional one, ***consumption*** was assumed to remain unchanged, as in Section 5.1.2 above.

- A ***fraction of billed metered consumption properties paying for water*** of 69%, as in Section 5.1.2 above, was maintained since the same meters as in the existing case are used.

5.1.4 Proposed Scheme for Advanced Metering

The parameters for the prepaid metering scheme in Olievenhoutbosch are summarised in Table 26 and discussed in the rest of the section under the headings "proposed system parameters", "failure rates", "costs" and "expected consumption".

Table 27: Proposed Advanced Metering Scheme Parameters

No.	Parameter	Value	Source	Comment
Proposed system parameters				
4.1	Meter make	Prepaid Meters	Ngobeni, 2016	
4.2	Meter model	Elster Kent	Ngobeni, 2016	
4.3	SANS 1529-1 compliant?	True	N/A	Meets legal requirements
4.4	SANS 1529-9 compliant?	True	N/A	Meets legal requirements
4.5	Mean battery life (years)	7 years	Pontia, 2016; Elster Kent, 2014	Adopted from field experience
4.6	Battery replaceable in field?	True	Ngobeni, 2016	
4.7	Meter service life (years)	7 years	Pontia, 2016 & Elster Kent, 2014	
Fraction of meters expected to fail due to				
4.9	Water meter failure	10%	Extrapolated from Ngobeni, 2016	
4.10	Electronics and other components (e.g. valve) failure	10%	Extrapolated from Ngobeni, 2016	
4.11	Vandalism	10%	Extrapolated from Ngobeni, 2016	
4.12	Other	5%	Extrapolated from Ngobeni, 2016	
4.13	Total failure rate (/year)	35%	N/A	Sum of all the above failure rates 4.9 to 4.12
Costs for advanced metering				
4.14	Meter price	R3 200 /meter	Ngobeni, 2016	
4.15	Installation cost	R800 /meter	Ngobeni, 2016	
4.16	Communication infrastructure cost	N/A	N/A	
4.17	Payment Infrastructure cost	R38 000	GIBB, 2015	
4.18	Battery replacement cost	R220 /meter	Made in China.com, 2016 & GIBB, 2015	
4.19	Meter reading cost	N/A	N/A	

No.	Parameter	Value	Source	Comment
4.20	Meter operation & maintenance cost	R525 /meter/month	N/A	Based on overall capital cost of meter
4.21	Billing cost	N/A		
Expected new consumption for advanced metering				
4.24	Billed metered consumption	6 000	Ngobeni, 2016	
4.24	Billed metered unit consumption	15 kl/property/month	Extrapolated from Ngobeni, 2016	
4.26	Illegal consumption	N/A	N/A	All assumed to have been identified and removed
4.26	Illegal connections unit consumption	N/A	N/A	See above
Fraction of properties paying for water				
4.29	Billed metered consumption	95%	Maromo, 2016	
4.31	Ave time between meter readings (months)	N/A	N/A	

(a) Proposed system parameters

- Prepaid meters are the advanced ***meter make*** considered in this case study (Ngobeni, 2016).
- The ***meter model*** used in Olievenhoutbosch was Elster Kent (Ngobeni, 2016).
- Both ***SANS 1529-1*** and ***SANS 1529-9*** compliance are applicable to prepaid meters and the meters installed complied with these legal standards in all cases.
- The ***mean battery life*** of 7 years obtained from City of Cape Town (Pontia, 2016) was maintained here since it coincided with the Elster Kent prepaid hardware component's service life (Elster Kent, 2014).
- A modular unit which allows the ***battery to be replaceable in the field*** was input as the typical characteristic of the prepaid system proposed since this was the preferred option at the time of tendering.
- A ***meter service life*** of 7 years for advanced metering systems was adopted from the same hardware components mean battery life above and the corresponding City of Cape Town experience (Pontia, 2016; Elster Kent, 2014).

(b) Failure rates

- A 30–40% overall ***meter failure*** per year due to various component failures was the City of Tshwane's experience with these meters (Ngobeni, 2016). An average total of 35% failure was therefore adopted for this case study, and distributed into 10% allotments to account for each of the three major causes of failure alluded to in this evaluation framework, and 5% for failures due to other causes. Consequently, a 10% meter failure rate was adopted for parameter 4.9 of the table.

- The ***electronics and other components (e.g. valve) failure*** rate parameter, as well as the ***vandalism rate,*** were both adopted as 10%, as in the extrapolation explanation above (Ngobeni, 2016).
- The remaining 5% of the 35% ***total failure rate*** per year was adopted as the failure per year due to ***other causes*** (Ngobeni, 2016).

(c) Costs

- The typical prepaid ***meter price*** used was approximately R3 200/meter, as provided by City of Tshwane (Ngobeni, 2016).
- A similar ***installation cost*** to that of conventional meters was adopted here per City of Tshwane information provided, i.e. R800/meter (Ngobeni, 2016).
- For ***communication infrastructure costs***, since these meters are not remotely read, the value for this has been omitted.
- Due to an absence of information from City of Tshwane on this, the ***payment infrastructure cost*** of R38 000 was estimated by adding the Elster Kent vending software cost of R24 960 and the hand-held vending station cost of R13 465 provided in the GIBB (2015) feasibility study of different advanced meters that could be used in eThekwini. This sum was thus approximated to account for the overall cost of the vending station used for water credit purchases in Olievenhoutbosch (GIBB, 2015).
- The ***battery replacement cost*** for this prepaid system was based on comparison of two source values, explained in the Epping case study, and adopted here in the absence of information from City of Tshwane in this regard.
- The ***meter reading cost*** was not applicable for these meters since payment is made up front.
- Similar to the conventional case, to estimate the ***typical advanced meter operation and maintenance costs***, a ratio of 15% of the overall capital cost of the advanced meter and infrastructure per annum was used. An estimate of about R6 300 per annum and thus R525/meter/month was obtained and adopted in the absence of more conclusive information from City of Tshwane.
- The ***billing cost*** was not applicable here since the system under consideration here is prepaid.
- No additional ***communication system operating costs*** are expected in this system and this value was consequently omitted from the table.

(d) Expected consumption

- All 6 000 properties, as in Section 5.1.3 above, were assumed to be under ***billed metered consumption*** as part of the new prepaid project implementation.
- City of Tshwane observed an overall reduction in consumption after installation of the prepaid meters (Ngobeni, 2016). However, since no specific information on the actual reduced consumption per household have been made, the value of

15 kl/property/month was adopted to represent the **reduced billed metered unit consumption** in this area.

- All illegal connections, and consequently all ***illegal consumption,*** are assumed to have been identified and removed as part of the new prepaid meter installation process, and were thus omitted from the table.
- A 95% fraction of ***billed metered consumption properties paying for water*** was based on the Tshwane chief financial officer's comment on the percentage of Tshwane residents who pay their bills and adopted in the absence of any information from City of Tshwane in this regard (Maromo, 2016).

5.2 Results

The four tables below provide the technical, social, environmental and economic results for the Olievenhoutbosch prepaid metering case study calculations, based on the input parameter values above.

5.2.1 Technical Result

The technical results of the evaluation are summarised in Table 27, showing compliance with SABS standards for both conventional and advanced meters. However, the prepaid meters have over five times the failure rate of the conventional meters.

Table 28: Technical result for prepaid case study in Olievenhoutbosch

1. TECHNICAL

No.	Property	Conventional metering (baseline)	Advanced metering
1.1	SABS compliance	Yes	Yes
1.2	Number of meters to replace (/month)	**35**	**175**

5.2.2 Social Result

The social results are shown in Table 28 below. The water bill is estimated to be 1.6% of the community's household income. This value, which is under 5%, implies that the community will be willing to pay for water and this was confirmed by the wide social acceptance and even popular demand for these prepaid meters, as mentioned in the case study report.

Table 29: Social result of the prepaid case study in Olievenhoutbosch

2. SOCIAL

No.	Property	Value
2.1	Current rate of meters vandalised (/year)	2.0%
2.2	Unemployment rate	24.0%
2.3	Volatility of community (No. of protest or mass action incidences per year)	25
2.4	Average water bill (/month)	R236.25

2.4	Average property income (/month)	R15 200.00
2.5	Water bill as a fraction of income	1.6%

5.2.3 Environmental Result

The environmental results are shown in Table 29 below.

A 25% reduction in consumption was observed for the prepaid metering case with 857 batteries requiring disposal per year.

Table 30: Environmental result of the prepaid case study in Olievenhoutbosch

3. ENVIRONMENTAL

No.	Consumption	Units	Current	Conventional metering (baseline)	Advanced metering
3.1	Billed metered consumption	(kl/month)	100 800	120 000	90 000
3.2	Billed unmetered consumption	(kl/month)	0	0	0
3.3	Illegal consumption	(kl/month)	19 200	0	0
3.4	Total consumption	(kl/month)	120 000	120 000	90 000
3.5	Unit consumption	(kl/property/month)	20	20	15
3.6	Reduction in consumption	(kl/month)		0	30 000
3.7	Fractional reduction in consumption	-		0%	25%
3.8	No. of batteries to dispose of	(/year)			857

5.2.4 Economic Result

The economic results are shown in Table 30 below.

Table 31: Economic viability of prepaid case study in Olievenhoutbosch

4. ECONOMIC

No.	Income	Units	Current	Conventional metering (baseline)	Advanced metering
4.1	Billed metered consumption	(/month)	R469 476.00	R558 900.00	R577 125.00
4.2	Billed unmetered consumption	(/month)	R0.00	R0.00	R0.00
4.3	Total income	(/month)	R469 476.00	R558 900.00	R577 125.00
4.4	Unit income	(/property/month)	R78.25	R93.15	R96.19

4.5	Increased income	(/month)		R89 424.00	R107 649.00
4.6	Fractional increased income			19%	23%
	Capital cost				
4.7	Water meters		R0.00	R3 192 000.00	R19 200 000.00
4.8	Installation		R0.00	R4 800 000.00	R4 800 000.00
4.9	Communication infrastructure cost		R0.00	R0.00	R0.00
4.10	Payment infrastructure cost		R0.00	R0.00	R38 000.00
4.11	Total capital cost		R0.00	R7 992 000.00	R24 038 000.00
4.12	Unit capital cost	(/property)	R0.00	R1 332.00	R4 006.33
	Operational cost				
4.13	Water production	(/month)	R960 000.00	R960 000.00	R720 000.00
4.14	Meter reading	(/month)	R40 320.00	R48 000.00	R0.00
4.15	Meter operation & maintenance	(/month)	R80 640.00	R96 000.00	R3 150 000.00
4.16	Billing cost	(/month)	R50 400.00	R60 000.00	R0.00
4.17	Billing system operating cost	(/month)		R0.00	R0.00
4.18	Communication system operating costs	(/month)			R0.00
4.19	Failed meter replacement cost	(/month)	R39 160.80	R46 620.00	R700 000.00
4.20	Battery replacement cost	(/month)			R15 714.29
4.21	Total operating cost	(/month)	R1 170 520.80	R1 210 620.00	R4 585 714.29
4.22	Unit operating cost	(/property/month)	R232.25	R201.77	R764.29
4.23	Decreased operating cost	(/month)		-R40 099.20	-R3 415 193.49
	Summary				
4.24	Operational surplus	(/month)	**-R701 044.80**	**-R651 720.00**	**-R4 008 589.29**
4.25	Increased operational surplus	(/month)		**R49 324.80**	**-R3 307 544.49**
4.26	Capital payment period	(months)		162.0	-7.3
4.27	Expected service life	years		18	7
4.28	Effective surplus	(/year)		R147 897.6	-R43 124 533.8

The prepaid meters, at a capital cost of about R24 million, achieve a 25% reduction in consumption and a 26% increase in payment rates. They therefore achieve one of the objectives of the municipality which is to increase payment for water services, as well as assist in consumption management; a benefit particularly useful in water scarce areas.

This, however, means that the City must be willing to invest an additional R16 million into prepaid meters, which translates into an additional R6.35/kl, if only capital cost and total consumption over the meter service life is considered for both scenarios. In water scarce areas, this additional cost may be preferable to bulk augmentation projects involving finding alternative water sources or importing water from neighbouring areas. Savings in production costs due to the reduced consumption can also be channelled to meeting the above additional metering costs.

The framework also indicates that while the advanced metering scheme is infeasible with a negative effective surplus, the conventional scheme is not. In fact, while the new conventional metering scheme results in a R49 324.80/month reduction in the operational deficit of the existing scheme; this is not the case for the prepaid metering scheme. Even with its slightly increased income, the higher operating expenditure of this prepaid scheme cannot be offset resulting in a R3 307 544.49/month increment in the operational deficit of the existing scheme.

It is important to note that in the evaluation framework above, a cost of R0/kl was considered for FBW consumption. As such, inclusion of a government subsidy amount equivalent to the first tier tariff for this 6kl FBW amount will change the economic results obtained since a new tariff amount of R16.49/kl, instead of R6.75/kl, as in the case above will be used. The new economic results do not differ much from the first scenario with the prepaid metering scheme still infeasible and the conventional case a better option.

The main benefit of the prepaid system is that user consumption can be better managed, and in areas where water supply is under severe stress this benefit may override the economic benefits of conventional metering. However, this comes at a significantly higher financial risk associated with a total capital cost of R24 million compared with R8 million for conventional metering.

6. EVALUATION OF EPPING AMR CASE STUDY IN CAPE TOWN

6.1 Model Input Parameters

The input parameters used to calculate the indicators for these factors were obtained from various sources and are discussed in this section under the headings of "global parameters", "existing system" (i.e. the situation before new meter implementation) and "proposed scheme" (which caters for both the new conventional and new advanced metering systems proposed). The input parameters are given in tables linked to the evaluation framework, which is provided in **Appendix A**.

6.1.1 Global Parameters

The global parameters used in the analysis are summarised in Table 31, with the values chosen, sources of information and a brief comment. A more detailed explanation of how these model values were selected is provided in the subsequent paragraphs. The study was a pilot with only 465 properties.

Table 32: Global Parameters

No.	Parameter	Value	Source	Comment
2.1	Number of properties	465	Wendell, 2016	
2.2	Water cost price	R8/kl	De Sousa-Alves, 2013	
2.3	Applicable water tariff	R17.10/kl	City of Cape Town, 2015	From City of Cape Town water and sanitation tariffs

- The ***number of properties*** is based on results of the meter audit in Epping done at the end of AMR project implementation (De Beer, 2010).
- The ***water cost price*** is the water production cost, and includes only raw water and purification costs. It was adopted as R8.00/kl, as a fraction of the water reticulation cost provided in the De Sousa-Alves (2013) Cape Town report.
- The ***applicable water tariff*** of R17.10/kl is based on the water and sanitation tariffs 2015-2016-CoCT for the industrial consumer category (City of Cape Town, 2015).

6.1.2 Existing System (Situation Before Metering System Upgrade)

This section describes the situation before the metering system upgrade.

Table 33: Water consumption before advanced meter implementation

No	Parameter	Value	Source	Comment
3.1	Billed metered consumption	465 properties	Wendell, 2016; De Beer, 2010	100% of the properties in the pilot study area
3.1	Billed metered unit consumption	80 kl/property /month	Van Zyl et al., 2007; City of Cape Town, 2016	Industrial consumption estimates
3.3	Illegal or unbilled connections	N/A	N/A	
3.3	Illegal connections unit consumption	80 kl/property /month	N/A	
	Fraction of properties paying for water			
3.5	Billed metered consumption	100%	Sivatho & De Sousa-Alves, 2016	
Other parameters before advanced meter implementation				
3.8	Fraction of demand that is on-site leakage	5%	De Sousa-Alves, 2013	
3.9	Ave time between meter readings (months)	1	Saayman, 2016	Adopted since congruent with monthly billing cycles
3.10	Meter reading cost	R8/meter	Saayman, 2016	
3.11	Billing cost	R10/bill	GIBB, 2015	Inclusive of administrative, printing and postage costs
3.12	Meter operation & maintenance cost	R16/meter/ month	N/A	Estimated as a ratio overall capital cost
Fraction of meters failing due to				
3.13	Meter failure (/year)	5%	Wendell, 2016	
3.14	Vandalism and other (/year)	2%	Wendell, 2016	

- It was clear from the implementation report (De Beer, 2010) that ***billed metered consumption*** was considered for all 465 properties in the pilot study area.
- In the absence of guidelines on estimation of industrial consumption, from the Red Book, as well as no consumption data for this consumer category from CoCT, an estimate had to be made. The average bi***lled metered unit consumption*** of 80kl/property/month is based on an AADD (average annual daily demand) of 3 kl/day allotted to industrial area stands of 3 000 m^2 (van Zyl et al., 2007). This 3 kl value was applied over 26 days to obtain the monthly consumption value above. The approximation of a 3 000 m^2 stand area value for Epping resulted from a review of typical plot sizes in different industrial areas in Cape Town (City of Cape Town, 2016, and SA Commercial Prop News, 2014).
- A ***fraction of billed metered properties paying for water*** of 100% was adopted from an overview of metering, billing and free basic services by Sivatho & De Sousa-Alves (2016).

- The ***fraction of demand that is on-site leakage*** was based on an estimate of on-site leakage in industrial areas made by the City of Cape Town (De Sousa-Alves, 2013).
- The R8/meter value for ***meter reading cost*** was obtained from the City of Cape Town (Saayman, 2016).
- It was not possible to get the ***billing cost*** from City of Cape Town. However, from a feasibility study for eThekwini, billing costs were estimated as R10 per month per meter (GIBB, 2015) made up of R6 administrative cost, R1 printing cost and R3 postage cost. This estimated R10/bill was thus adopted as the billing cost for Cape Town.
- To estimate the typical ***meter operation and maintenance costs***, a ratio of 15% of the overall capital cost of the conventional meter per annum was used, due to the absence of more conclusive information on this. An estimate of about R195 per annum and thus R16.25/month was obtained, which value was rounded off to approximately R16/meter/month.
- The ***meter failure rate*** of 5% for conventional meters in Cape Town was obtained from the City of Cape Town (Wendell, 2016).
- The ***failure rate due to vandalism and other reasons*** of 2% for conventional meters in Cape Town was also obtained from the City of Cape Town (Wendell, 2016).

6.1.3 Proposed Scheme for Conventional Metering (Baseline)

In the evaluation framework, the proposed scheme consists of two parallel categories, i.e. conventional and advanced metering. This is useful in schemes where all existing meters are replaced, for instance when old conventional meters are replaced with new meters and the benefits of replacing the existing meters with advanced meters over conventional meters should be evaluated.

However, in the case of Epping, the existing system was not in a bad condition and thus not all the conventional meters were replaced. The advanced metering component was mostly added to the existing conventional meters. In this contract, the low compatibility necessitated replacement of 80–90% of the meters (Saayman, 2016). It was assumed that the meters that were replaced would have required replacement, even if the advanced metering was not implemented.

To allow the lower replacement costs of only 90% of the meters in the model, the meter price (4.14) was reduced accordingly.

The parameters for the modified conventional metering scheme are summarised below and are discussed in the rest of the section under the headings of “proposed system parameters”, “failure rates”, “costs” and “expected consumption”.

Table 34: Modified conventional metering scheme parameters

No	Parameter	Value	Source	Comment
Proposed system parameters				
4.1	Meter make	Variable, including Elster Kent, Actaris, Sensus	De Beer, 2010	Based on existing situation
4.2	Meter model	Variable, including Woltmann and multi-jet meters	De Beer, 2010; van Zyl, 2011	Based on existing situation
4.3	SANS 1529-1 compliant?	True	N/A	Meets legal requirements
4.7	Meter service life (years)	18	Van Zyl, 2011; De Sousa-Alves, 2013	
Fraction of meters expected to fail due to				
4.9	Water meter failure (/year)	5%	Wendell, 2016	
4.11	Vandalism (/year)	2%	Wendell, 2016	
4.12	Other(/year)	N/A	N/A	Included in 4.11 above
Costs				
4.14	Meter price	R413.98/meter	Saayman, 2016; De Beer, 2016; WRP Consulting Engineers, 2009	Meter cost, excluding the AMR compatible units, was proportionally reduced according to the fraction of meters that were replaced (385 meters replaced out of 465 x R500 per meter)
4.15	Installation cost	R663.37/meter	Ngobeni, 2016	Installation cost as in 4.14 above was proportionally reduced according to the fraction of meters that were replaced (385 meters replaced out of 465 x R800 per meter)
4.17	Payment infrastructure cost	R0	N/A	Absorbed within billing cost
4.19	Meter reading cost	R8/meter	Saayman, 2016	
4.20	Meter operation & maintenance cost	R16/meter/month	N/A	Based on initial capital cost of the meter
4.21	Billing cost	R10/bill	GIBB, 2015	Inclusive of administrative, printing and postage costs
Expected new consumption				
4.24	Billed metered consumption	465 properties	Wendell, 2016	

No	Parameter	Value	Source	Comment
4.24	Billed metered unit consumption	80 kl/property/month	N/A	Increased to account for improved meter accuracy
4.26	Illegal consumption or unbilled connections	N/A	N/A	
4.26	Illegal connections unit consumption	80 kl/property/month	N/A	
Fraction of properties paying for water				
4.29	Billed metered consumption	100%	Sivatho & De Sousa-Alves, 2016	Same as Section 6.1.2
4.31	Ave time between meter readings	1 per month	Saayman, 2016	Congruent with monthly billing cycle

(a) Proposed system parameters

- The ***meter make and model*** varied to maintain compatibility with the different existing system fittings and junctions which required replacement (De Beer, 2010). However, regardless of make and model, all the newly installed conventional meters were ***SANS 1529-1 compliant***.
- The value for ***SANS 1529-9*** compliance was omitted since it deals with requirements for electronic indicators that in most cases are not part of a typical conventional meter.
- A conventional ***meter service life*** of 18 years was adopted as herein explained; Cape Town has ±12.5% meters above the age of 20 years (De Sousa-Alves, 2013). However, due to variation in meter types and consequently their performance periods, smaller meters are able to last between 12 and 20 years, and larger meters (≥75 mm) have typically lower service lives of 5 and 10 years (van Zyl, 2011). Since smaller meters are typically used, an average meter service life value of 18 years was adopted. This value also accounts for a study which showed that on average 5% of meters are replaced per year in South Africa, implying a field life of 20 years per meter.

(b) Failure rates

- In assessing the water ***meter failure rate,*** a value of 5% meter failure per year, as in Section 6.1.2 above, was used (Wendell, 2016).
- The values of 2% ***failure per year due to vandalism and other causes*** were adopted as in Section 6.1.2 above (Wendell, 2016).

(c) Costs

- The conventional ***meter price*** used was R500/meter, based on comparison of two sources herein explained; a range of prices from R180–R700 per meter depending on the make, size and material of the meter (De Beer, 2016) and the replacement cost of R500/meter used by WRP Consulting Engineers (2009). The R500/meter value was adopted as an average of the two. This unit price, as explained in the table above, was reduced to R413.98 to account for the 83% fraction of meters replaced.
- No information on the ***installation cost*** of conventional meters in Epping could be found. As such, an estimate of R800, based on municipal staff experience in the Tshwane case study, was adopted here to account for all the materials and labour required for meter installation. Since meter prices and their associated installation costs vary with the meter size, material and make, it was considered prudent to take an approach of a typical value no less than that of the meter installed. As with the meter price above, this unit cost was also reduced by the fraction of meters replaced to R662.37.
- Since the administrative portion of the ***billing cost*** is expected to cover all payment system operational costs, no payment infrastructure costs are expected.
- The ***meter reading, billing and meter operation and maintenance costs*** were adopted from the existing values discussed in Section 6.1.2.

(d) Expected consumption

- All 465 properties were assigned to ***billed metered consumption,*** as stated for the existing system in Section 6.1.2.
- Since only a few meters were replaced and these would have no impact on the consumers, the ***consumption*** was assumed to remain unchanged.
- A fraction of ***billed metered consumption properties paying for water*** of 100%, as in Section 6.1.2 above, was maintained.

6.1.4 Proposed Scheme for Advanced Metering

Table 35 summarises the parameters for the RealSens AMR system that was installed on the existing and replaced meters in Epping.

The meter price parameter includes both the AMR add-on to the meters and the cost of the meters that were replaced. To allow the lower replacement costs of only a few meters in the model, the meter price (4.14) component of the advanced metering system was reduced as was the case for the conventional meters above.

The parameters for the modified advanced metering scheme are summarised in Table 34 and are discussed in the rest of the section under the headings “proposed system parameters”, “failure rates”, “costs” and “expected consumption”.

Table 35: Proposed Advanced Metering Scheme Parameters

No.	Parameter	Value	Source	Comment
Proposed System Parameters				
4.1	Meter make	Advanced Meter Reading	De Beer, 2010	Requirement of the awarded pilot project tender
4.2	Meter model	Variable conventional models, all fitted with RealSens AMR System	De Beer, 2010	Inferred from implementation process
4.3	SANS 1529-1 compliant?	True	De Beer, 2010	Meets legal requirements
4.4	SANS 1529-9 compliant?	True	De Beer, 2010	Meets legal requirements
4.5	Mean battery life (years)	7 years	Pontia, 2016	Adopted from field experience
4.6	Battery replaceable in field?	True	Not available	Preference for modular units assumed
4.7	Meter service life (years)	5 years	Wendell, 2016	
Fraction of meters expected to fail due to				
4.9	Water meter failure	5%	Wendell, 2016	As in Section 6.1.3 above
4.10	Electronics and other components (e.g. valve) failure	7.5%	Wendell, 2016	From implementation and subsequent O&M experience
4.11	Vandalism	2%	Wendell, 2016	From implementation and subsequent O&M experience
4.12	Other	4.2%	Wendell, 2016	From implementation and subsequent O&M experience
	Costs for advanced metering			
4.14	Meter price	R1 241.94/meter	GIBB, 2015	Meter cost excluding the AMR compatible units was proportionally reduced according to the fraction of meters that were replaced (385 meters replaced out of 465 x R 1500 per meter)
4.15	Installation cost	R1 241.94/meter	GIBB, 2015	Based on reduced meter price above
4.16	Communication infrastructure cost	R15 000	GIBB 2015	Based on field estimates

No.	Parameter	Value	Source	Comment
4.18	Battery replacement cost	R220/meter	Made in China.com, 2016; GIBB, 2015	Estimate from product price list
4.19	Meter reading cost	R120/meter	Saayman, 2016	
4.20	Meter operation & maintenance cost	R225/meter/month	N/A	Based on capital cost of meter
4.21	Billing cost	R10/bill	GIBB, 2015	
Expected new consumption for advanced metering				
4.24	Billed metered consumption	465	N/A	All properties in pilot study area
4.24	Billed metered unit consumption	80 kl/property/month	N/A	
4.26	Illegal consumption	N/A	N/A	
4.26	Illegal connections unit consumption	80 kl/property/month	N/A	
Fraction of properties paying for water				
4.29	Billed metered consumption	100%	N/A	
4.31	Ave time between meter readings (months)	1	N/A	Congruent with monthly billing cycle

(a) Proposed system parameters

- A ***RealSens Advanced Meter Reading*** technology was the requirement for the pilot scheme in Epping (De Beer, 2010).
- Both ***SANS 1529-1 and SANS 1529-9*** compliance are applicable to advanced metering technology and therefore it is a legal requirement for the advanced meters to comply with these standards. The system and meters installed complied with these standards in all cases.
- The ***mean battery life*** claimed by manufacturers of AMR communication systems is 15 years for ultra-low-power radio systems, but this varies with the frequency that readings are taken (De Beer, 2010). However, 7 years was the value for advanced meters obtained from City of Cape Town (Pontia, 2016) and it is this conservative value that was adopted here.
- A modular unit which allows the ***battery to be replaceable in the field*** was input as the typical characteristic of the AMR system proposed, since this was considered to be the preferred option for maintenance and operational cost management.
- A ***meter service life*** of 5 years for the AMR system was obtained from the City of Cape Town (Wendell, 2016) based on their current installations as well as historical records of faulty meters.

(b) Failure rates

- A 5% ***meter failure rate*** was obtained from CoCT, based on O&M experience of the pilot area (Wendell, 2016).
- The ***electronics and other components*** (e.g. valve) ***failure rate*** parameter was 7.5%. This was based on the CoCT radio failure rates reported for the AMR system in Epping, due to various reasons (Wendell, 2016).
- The ***failure rate due to vandalism*** was also based on the AMR pilot project experience shared by CoCT. The failure rate due to vandalism was approximately 2% of the total meters installed (Wendell, 2016).
- The ***other failure rate*** approximation of 4.2% was also obtained from the City of Cape Town (Wendell, 2016).

(c) Costs

- The typical advanced ***meter price*** adopted was R1 500 based on an average of the Utility Systems and Lesira Teq advanced meter unit costs provided in a study for eThekwini (GIBB, 2015). This unit price, as explained in the table above, was reduced to R1 241.94 to account for the 83% fraction of meters replaced.
- A similar approach as that taken in the proposed conventional metering case was used to determine the ***installation cost*** of AMR and compared with the GIBB (2015) report value for installation of prepaid meters. Since these two values coincided, the R1 500/meter installation cost was adopted here with a reasonable degree of certainty. However, as with the meter price above, this unit cost was also reduced by the fraction of meters replaced to R1 241.94.
- For ***communication infrastructure costs***, a table with estimates of AMR meter configuration was reviewed with similar focus on the more competitive Utility Systems and Lesira Teq costs (GIBB, 2015). The mobile data collector unit costs were excluded since the AMR system used in Epping was a remote reading system at the time of implementation. An average of R14 130, rounded off to R15 000, was therefore adopted here in the absence of further information.
- The ***payment infrastructure cost*** was omitted from the table since the AMR system used for this case study was a post payment system similar to that of conventional meters, thus requiring no vending infrastructure.
- The ***battery replacement costs*** for this AMR system were obtained by comparison of an advanced meter battery product price list (sourced from Made in China.com, 2016) and the GIBB (2015) value of R197 for Elster Kent battery replacement costs. The average price of R220/meter was adopted on the assumption that the amount for associated labour/installation costs would be included in the meter operation and maintenance costs.
- The R120/meter value for advanced ***meter reading cost*** was obtained from CoCT (Saayman, 2016).

- As with the conventional case, to estimate the typical ***advanced meter operation and maintenance costs***, a ratio of 15% of the overall capital cost of the advanced meter per annum was used in the absence of more conclusive information. An estimate of about R2 700 per annum, and thus R225/meter/month, was obtained.
- The ***billing cost*** of R10/bill as adopted from GIBB (2015) in Section 6.1.2, has been maintained for this metering system since conventional billing was retained.
- No additional ***communication system operating costs*** are expected in this AMR system because no sms or mobile applications typically used in prepaid systems are applicable in the conventional billing system that was used here. All communication costs have thus already been included in the 4.16 value given before.

(d) Expected consumption

- The AMR system was not expected to have any impact on consumption and billing, and thus these were assumed to be identical to the conventional meter system above.
- The same 100% fraction ***of billed metered consumption properties paying for water*** as in Section 6.1.3 above was maintained, as the conventional billing system was still applied in this system.
- The same ***average time between meter readings per month*** of 1, as in Section 6.1.3, was maintained. This is because even as the AMR technology is capable of taking daily or even hourly meter readings (De Beer, 2010), the Epping case largely was meant to pilot and test the benefit of these functionalities. The conventional meter reading and billing cycle therefore remained, as in the past, in spite of this potential.

6.2 Results

The four tables below provide the technical, social, environmental and economic results for the Epping case study calculations, based on the input parameter values above.

6.2.1 Technical Result

The technical results of the evaluation, as summarised in the table below, show compliance with SABS standards for both conventional and advanced meters. However, the advanced meters had about twice the failure rate of the conventional meters, and the multiple components required to make them work imposed heavy logistical requirements on the project.

Table 36: Technical result for AMR Case Study in Cape Town

1. TECHNICAL

No.	Property	Conventional metering (baseline)	Advanced metering
1.1	SABS compliance	Yes	Yes
1.2	Number of meters to replace (/month)	**3**	**7**

6.2.2 Social Result

The social results are shown in Table 36 below. The social feasibility aspect was not critical for this case study since the focus was on industrial and not domestic consumption. However, social recommendations to do with time scheduling to minimise project interruption of industrial activities, and liaison with all relevant electricity or street lighting authorities amongst others, are included in the case study report.

Table 37: Social result of the AMR case study in Cape Town

2. SOCIAL

No.	Property	Value
2.1	Current rate of meters vandalised (/year)	2%
2.2	Unemployment rate	-
2.3	Volatility of community (No. of protest or mass action incidences per year)	-
2.4	Average water bill (/month)	R2 736.00
2.4	Average property income (/month)	-
2.5	Water bill as a fraction of income	N/A

6.2.3 Environmental Result

The environmental results are shown in Table 37 below.

No reduction in consumption was observed for either metering case. In the AMR case, 66 batteries require disposal per year, and this, as well as the fact that some AMR components need a permanent power source to run, makes this AMR scheme even less environmentally friendly.

Table 38: Environmental result of the AMR case study in Cape Town

3. ENVIRONMENTAL

No.	Consumption	Units	Current	Conventional metering (baseline)	Advanced metering
3.1	Billed metered consumption	(kl/month)	37 200	37 200	37 200
3.2	Billed unmetered consumption	(kl/month)	0	0	0

3.3	Illegal consumption	(kl/month)	0	0	0
3.4	Total consumption	(kl/month)	37 200	37 200	37 200
3.5	Unit consumption	(kl/property/month)	80	80	80
3.6	Reduction in consumption	(kl/month)		0	0
3.7	Fractional reduction in consumption	-		0%	0%
3.8	No. of batteries to dispose of	(/year)			66

6.2.4 Economic Result

The economic results are shown in Table 37 below.

Table 39: Economic viability of AMR case study in Cape Town

4. ECONOMIC

No.	Income	Units	Current	Conventional metering (baseline)	Advanced metering
4.1	Billed metered consumption	(/month)	R636 120.00	R636 120.00	R636 120.00
4.2	Billed unmetered consumption	(/month)	R0.00	R0.00	R0.00
4.3	Total income	(/month)	R636 120.00	R636 120.00	R636 120.00
4.4	Unit income	(/property/month)	R1 368.00	R1 368.00	R1 368.00
4.5	Increased income	(/month)		R0.00	R0.00
4.6	Fractional increased income			0%	0%
	Capital cost				
4.7	Water meters		R0.00	R192 500.70	R577 502.10
4.8	Installation		R0.00	R308 002.05	R577 502.10
4.9	Communication infrastructure cost		R0.00	R0.00	R15 000.00
4.10	Payment infrastructure cost		R0.00	R0.00	R0.00
4.11	Total capital cost		R0.00	R500 502.75	R1 170 004.20
4.12	Unit capital cost	(/property)	R0.00	R1 076.35	R2 516.14
	Operational cost				
4.13	Water production	(/month)	R297 600.00	R297 600.00	R297 600.00

4.14	Meter reading	(/month)	R3 720.00	R3 720.00	R55 800.00
4.15	Meter operation & maintenance	(/month)	R7 440.00	R7 440.00	R104 625.00
4.16	Billing cost	(/month)	R4 650.00	R4 650.00	R4 650.00
4.17	Billing system operating cost	(/month)		R0.00	R0.00
4.18	Communication system operating costs	(/month)			R0.00
4.19	Failed meter replacement cost	(/month)	R2 919.60	R2 919.60	R17 998.82
4.20	Battery replacement cost	(/month)			R1 217.86
4.21	Total operating cost	(/month)	R316 329.60	R316 329.60	R481 891.67
4.22	Unit operating cost	(/property/month)	R680.28	R680.28	R1 036.33
4.23	Decreased operating cost	(/month)		R0.00	-R165 562.07
	Summary				
4.24	Operational surplus	(/month)	**R319 790.40**	**R319 790.40**	**R154 228.33**
4.25	Increased operational surplus	(/month)		**R0.00**	**-R165 562.07**
4.26	Capital payment period	(months)		#DIV/0!	-7.1
4.27	Expected service life	years		18	5
4.28	Effective surplus	(/year)		#DIV/0!	-R2 220 745.7

When viewed from the scope of the evaluation framework, all the metering scheme scenarios run on a surplus. However, while the above model input parameters and calculations reveal that investment in a new conventional metering scheme doesn't cause any change in the operational surplus of the existing scheme, investment in the AMR scheme causes a R165 562.07/month reduction in the operational surplus of the existing scheme. This is because the utility has an increased expenditure cost with the new AMR scheme and yet there is no increase in the total income obtained from it compared to the existing or conventional case. As such, the increased operational costs leave the utility with a lower operational surplus than before.

No capital payback period can thus be calculated for the new conventional metering case. This is not the case for the AMR scheme which has a negative capital payment period and eventual effective surplus that renders this scheme economically unfeasible.

Thus for this case study, it is clear that a conventional metering system is a better choice than the AMR in all respects and comes at a significantly lower financial risk, with a total capital cost of R500 500 compared with R1 170 000 for AMR.

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