GUIDELINES FOR THE EVALUATION AND SELECTION OF ADVANCED WATER METERING SYSTEMS

JE van Zyl, L Ngabirano, M Malunga, M Mwangi

WATER RESEARCH COMMISSION

TT 765/18

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Report to the
WATER RESEARCH COMMISSION

by

Department of Civil Engineering
University of Cape Town

WRC Report No TT 765/18

October 2018

Obtainable from:
Water Research Commission
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GEZINA, 0031

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The publication of this report emanates from a project entitled *State-of-the-Art in Advanced Metering Technology and Application* (WRC Project No. K5/2370).

ISBN 978-0-6392-0046-0

Printed in the Republic of South Africa

EXECUTIVE SUMMARY

INTRODUCTION

The development of advanced metering systems resulted 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*** is defined as systems using 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*** is defined as systems using water meters with additional components and functionality over and above those used by 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.

Advanced metering has the potential to provide substantial benefits if appropriately applied. However, compared with conventional metering 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.

ADVANCED METERING

Advanced metering systems may have a large range of components that may be categorised as meter-based components, communication sub-systems and management sub-systems. Some examples of these advanced metering products and their suppliers in South Africa are detailed in Appendix A of this report.

Driving forces for considering advanced water metering include water scarcity, aging infrastructure, non-revenue water, efficient consumption, payment for services, operational budgets and the water-energy nexus.

SELECTING AN ADVANCED METERING SYSTEM

Advanced metering systems should be selected taking the full meter life cycle shown in Figure 1 into account. This report provides guidance and a tool to assist with the evaluation process as summarised below.

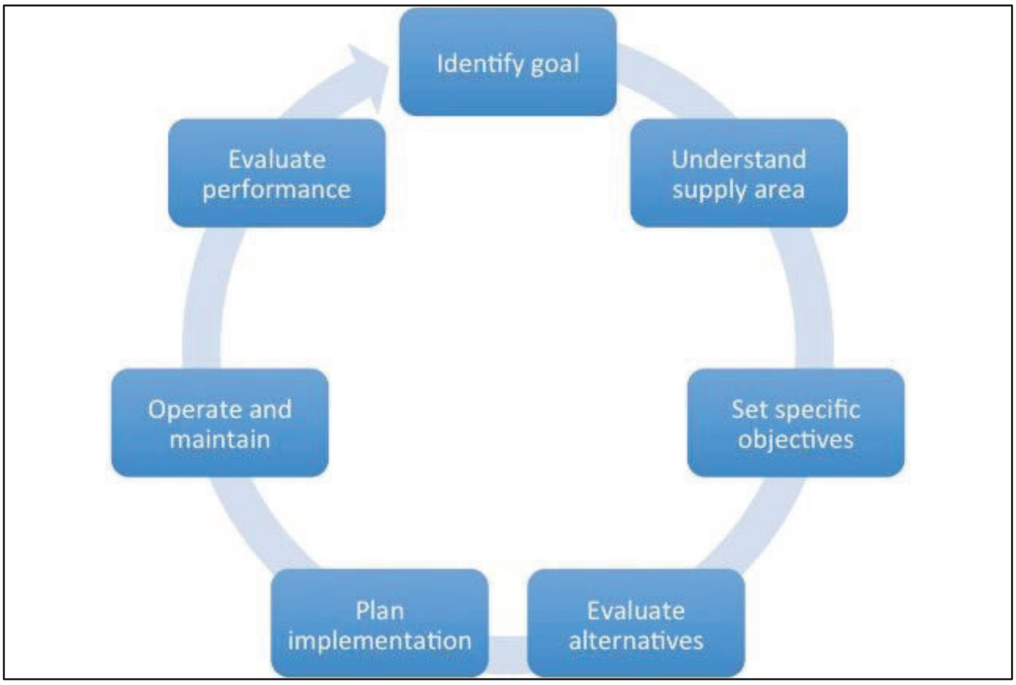

Figure 1: Advanced metering life cycle

Identify the Goal to be Achieved

Advanced metering should never be considered as a goal in itself, but rather as part of the solution to a particular problem or goal to be achieved. Goals may include increasing revenue from water sales, managing consumer debt, water demand management, consumer choice, extending the formal network or reduced operational costs.

Understand the Supply Area

It is essential to understand the supply area where advanced metering is considered in order to evaluate the feasibility of the proposed scheme. An evaluation framework is provided and described in Appendix B. Chapter 2 of Appendix B provides tables with recommended information to obtain. Handling of free basic water and the community's attitude to water services and payment are critical factors that need to be understood. Social problems, such as resistance to paying for services, can't be addressed with a technological solution such as advanced metering.

Set Specific Project Objectives

It is necessary to set specific objectives to be achieved for an advanced metering solution to be implemented. The evaluation framework in Appendix B assists the designer with setting objectives in four areas: technical, social, environmental and economic.

Evaluate All Alternatives

All possible alternative solutions for achieving the project objectives should be considered, including solutions that do not use advanced metering. The evaluation framework in Appendix B provides a tool to evaluate the viability of advanced metering projects, particularly in the environmental and economic areas. The evaluation framework includes an evaluation of the alternative of conventional water meters.

Plan Implementation of the Best Solution

Once all alternatives have been evaluated and a decision made on the best solution, it is necessary to plan the implementation of this solution. That includes the requirement for adequate qualified staff, financial planning and putting the required tender documents in place. It is recommended that a pilot study is first implemented before any large-scale roll-out of advanced metering.

Operate and Maintain

The longest phase of any infrastructure project is the operation and maintenance phase. It is important that advanced meters are operated and maintained in accordance with manufacturer specifications.

Evaluate the Project Performance

Once the advanced metering project has been operational for some time (say a year), it is recommended that the evaluation process is repeated to evaluate how realistic the assumptions made were and learn from mistakes made.

EXPERIENCES WITH ADVANCED METERING IN SOUTH AFRICA

A brief of a few case studies in South Africa and the lessons learned from these case studies are summarised in Chapter 4. These case studies were evaluated by use of the evaluation framework detailed in Appendix B.

Most case studies showed that conventional meters outperformed advanced metering systems in the critical area of economic feasibility, even if the conventional meters had significantly lower payment rates.

A sensitivity analysis for a typical low-income area showed that advanced metering systems carry a particularly high risk of economic infeasibility in areas with high existing payment rates or low consumption levels; as well in cases where low payment rates or low consumption (relying mainly on free basic water supply) occur after installation of advanced metering. Finally, high failure rates of advanced meters also present a high risk to the success of a scheme.

While some benefits were gained in the case studies, these are small compared to the large number of challenges experienced. The benefits and challenges, as well as lessons learned, are summarised in Chapter 4.

EVALUATION FRAMEWORK

This report evaluate contains an evaluation framework description in Appendix B for selecting and determining the viability of advanced metering projects, particularly in the environmental and economic terms. The associated spreadsheet tool can be downloaded at http/www.wrc.org.za/software/AdvancedMetering

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SUPPLIED SEPARATELY: EVALUATION FRAMEWORK SPREADSHEET MODELS – Can be downloaded at **http://www.wrc.org.za/software/AdvancedMetering**

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ABBREVIATIONS

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)
WAN	Wide Area Network
WBKMS	Web-based Knowledge Management system
WCDMA	Wideband code-division multiple-access
WMN	Wireless Mesh Network
WRC	Water Research Commission of South Africa

1. INTRODUCTION

1.1 Background

The water meter industry has seen substantial developments in the last two decades, with many new capabilities added to water meters. These *advanced water meters* (also called intelligent, smart or prepaid meters) have additional capabilities, such as the ability to communicate with the municipality or user, monitor consumption patterns, manage free basic water or sound a leakage alarm.

Internationally, advanced water metering is part of a much larger movement towards smart networks and intelligent infrastructure. The smart infrastructure systems of the future will have large numbers of sensors that continuously monitor the behaviour of these systems, share information through a cloud-based management data systems and implement controls to improve system operations. These networks will allow systems to optimize the reliability, security and efficiency of water and other services.

In South Africa and in other developing countries, advanced water metering (in the form of prepaid meters or water management devices) has been developing along a parallel path, driven by the need to provide services to previously unserved communities and deal with the problems caused by rapid urbanisation. These systems are mostly implemented at a local level to address particular problems and thus integration with other systems are often not considered.

Advanced metering has the potential to provide substantial benefits if appropriately applied. However, compared with conventional metering 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 investigate the feasibility of advanced water metering in South Africa and develop tools and guidelines for the appropriate application of these devices.

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

1.2 Defining Advanced Metering

Water meters have been used in South Africa for several decades. In fact, it is a legal requirement in South Africa that every supply point in a distribution system must be metered.

The development of advanced metering systems resulted 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*** is defined as systems using 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*** is defined as systems using water meters with additional components and functionality over and above those used by 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 pre-paid water meters and the later generation of meters developed from pre-paid meters.
- ***Smart water meters*** are advanced meters that cannot control the flow delivered to the consumer, but include advanced technology to communicate the meter reading to the municipality and/or consumer.

1.3 Layout of this Document

Every municipality is unique in its needs and constraints, and therefore it is impossible to write a "one-size fit all" guideline for selecting advanced water meters. The purpose of this guideline is to provide information and tools to support the decision making process when selecting and implementing advanced metering systems.

The document is structured as follows:

- CHAPTER 2: An overview of the basics of conventional and advanced water metering. This chapter discusses the types of advanced metering systems and their components.
- CHAPTER 3: A method for selecting an appropriate advanced metering or alternative system is described based on considering the full meter life cycle.
- CHAPTER 4: An overview of the driving forces, functionality benefits and challenges of advanced metering as well as Experiences with advanced metering in South Africa based on several case studies are presented. Benefits, challenges and lessons learned are summarised.

- APPENDIX A: An overview of some of the advanced metering products available in South Africa is provided to give readers an idea of the range of products available on the market.
- APPENDIX B: 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.

1.4 Additional Resources

This document aims to provide relevant guidelines and tools for the implementation of advanced metering systems as a stand-alone document. 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 deals with advanced water metering in low and high income communities respectively 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. ADVANCED WATER METERING BASICS

2.1 Introduction

As discussed in the previous chapter, advanced water metering is defined as using meters with additional components and functionality over and above those used by conventional water meters.

In this chapter conventional water meters are first briefly introduced. The components that are commonly used in advanced meters are then discussed. Many different types of advanced meters can be produced based on the specific components included on the meter.

2.2 Conventional Water Meters

In conventional water metering uses water meters that only display readings on the devices themselves, and have no additional functionality. They are read by physically visiting the meters. Conventional water meters are widely used in water supply systems for consumer billing and water management.

In consumer metering, conventional meters are read periodically (typically monthly) and the consumer is sent a bill based on their consumption. Water is supplied on a credit basis to the consumer, who pays for the water consumed after receiving a municipal bill. However, consumers have to pay a deposit when applying for a water connection, and this deposit is used to cover the municipality against any unpaid consumption.

Conventional consumer meters require the municipality to read the meters on a regular basis, send out water bills and collect outstanding debts when consumers fail to pay. In cases where consumers don’t pay for water, a municipality may shut off their water supply.

All conventional water meters contain four basic components: a sensor, transducer, counter and indicator (vanZyl, 2011) as shown in Figure 2.

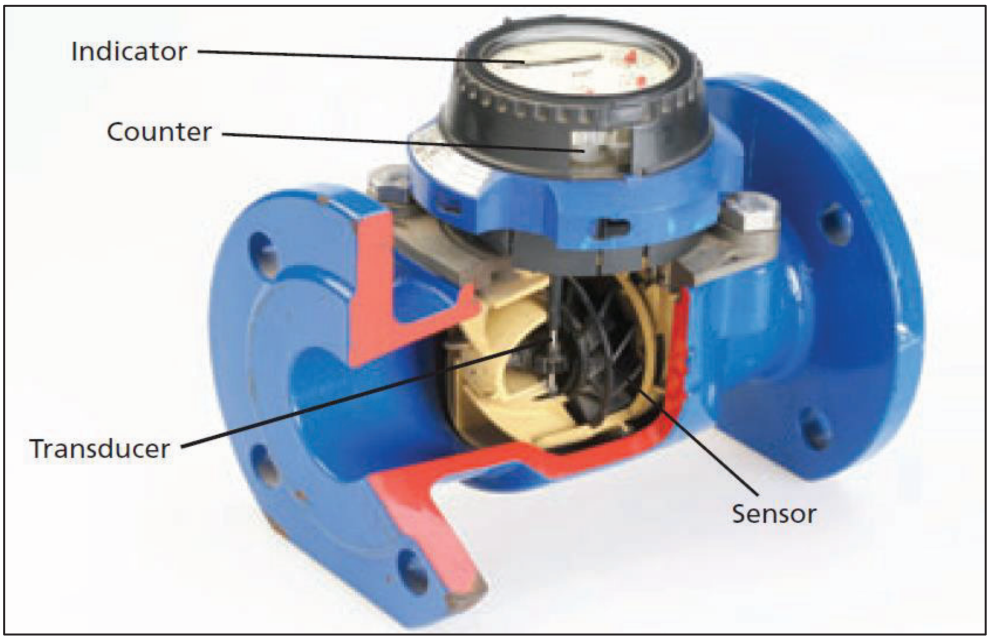

Figure 2: Section of a meter showing its components (adopted from Van Zyl, 2011)

The sensor picks up the flow passing through the meter and is used to classify meters, for instance as positive displacement, multijet, Woltmann or electromagnetic meters. The transducer transmits the signal detected by the sensor to the counter, which accumulates the volume of water that has passed through the meter. Finally, the indicator conveys the meter reading to a reader.

By law all water meters used for consumer billing purposes have to comply with the requirements of SANS 1529: *Water Meters for Cold Potable Water*. Currently this code has three parts that are relevant to conventional water meters:

- Part 1: Metrological characteristics of mechanical water meters of nominal bore not exceeding 100 mm.
- Part 3: Physical dimensions.
- Part 4: Mechanical meters of nominal bore exceeding 100 mm but not exceeding 800 mm.

Advanced meters and meters with electronic indicators should also comply with SANS 1529 Part 9: *Requirements for electronic indicators used with mechanical water meters, electronic water meters and electronic pre-payment water measuring systems.*

Some of the important requirements of SANS 1529 require the following:

- Housings for meters installed outdoor should be durable. Plastic meters must be protected against sunlight and metal housings against corrosion.

- A meter designed to operate horizontally only or vertically only must be marked to indicate the required orientation.
- By default, meters must be designed for a working pressure of 1 600 kPa. If a meter is designed for a different working pressure, this must be indicated on the meter.
- Meters should be able to withstand revere flow without any damage to the normal operational parameters.
- The maximum permissible relative errors of new meters are 5% in the lower zone, which is between the minimum (q_{min} or Q_1) and transitional flow (q_t or Q_2) rates, and 2% in the upper zone, which is between the transitional and overload (q_s or Q_4) flow rates.
- For meters in the field the maximum permissible errors are 8% in the lower zone and 3.5% in the higher zone.
- Meters must measure volume in cubic meters and multiples and fractions of cubic metres should be clearly distinguished.
- Class A meters are not permissible for consumer billing.

Conventional water meter technology is mature and good quality meters can be expected to operate satisfactorily for ten to twenty years. However, each meter model should be evaluated on its merits since meters may be designed for shorter service lives or use inferior components.

Conventional water meters have a number of drawbacks. Meter reading is susceptible to human error and corrupt practices of meter readers, such as under-reporting of meter readings or signs of meter tampering. Access to the meters can be a problem leading to municipalities relying on unreliable estimates of consumption. Conventional meter reading requires billing, which is expensive and hard to achieve in informal areas. Consumers not paying for water requires the manpower and funding for disconnections and debt management, which in turn may increase meter tampering and illegal connections.

2.3 Components and Sub-systems

All advanced water meters require a conventional meter as their first component. The conventional meter may be a stand-alone meter that is connected to the other components of the advanced meter, or it may be integrated into the advanced meter itself.

Different types of advanced metering are available based on the target application and technology used in the system. Before the different types of advanced metering are discussed, this section discusses the different components and sub-systems that may be used in advanced metering.

It is convenient to classify the components and sub-systems used in advanced water metering into the following three categories:

- Meter-based components
- Communication sub-systems
- Management sub-systems

Figure 3: The diagram below depicts the three classes of components schematically. The components of each sub-system are described accordingly.

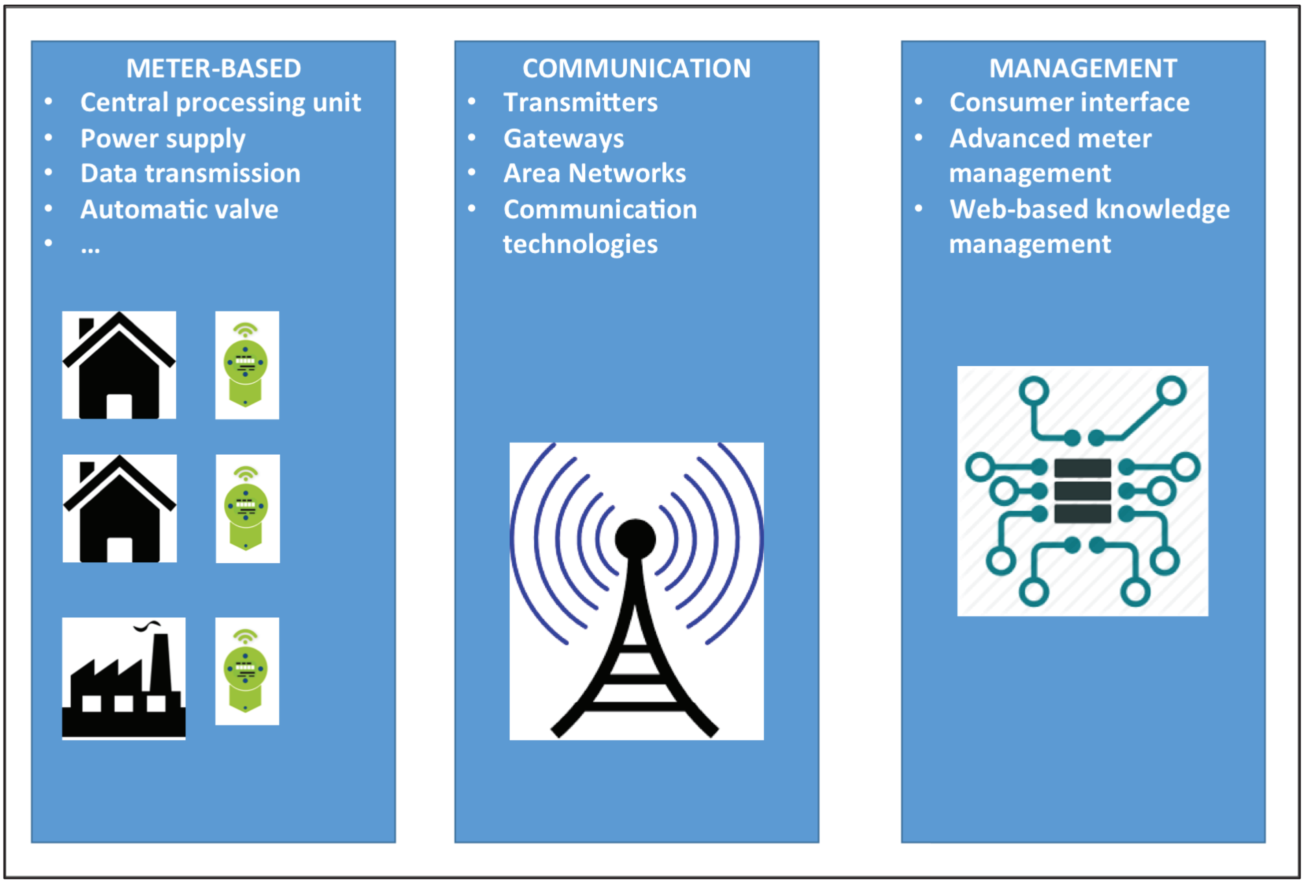

Figure 3: Components and Sub-systems of an Advanced Metering System

2.4 Meter-based Components

2.4.1 Signal Pick-up

The reading of a conventional water meter needs to be converted into a signal that the advanced meter can record. In most cases this is done through a pick-up unit that reacts to the movements of the meter mechanism.

The mechanisms of most mechanical meters are provided with a small magnet or mirror that turns with the counter. A pick-up unit attached to the meter is activated every time the magnet or mirror passes it, resulting in a pulse that is sent to the central processing unit to record.

Every pulse is associated with a specific volume (for instance 10 litres), which means that the volume of water passing through the meter can be calculated.

The signal pick-up units are not perfect and may miss some signals or even count false signals. Thus it is important that physical meter readings are taken on advanced meters in at least annual intervals to ensure the accuracy of these systems.

2.4.2 Central Processing Unit

Advanced meters normally require a central processing unit, which is a small computer that is used to manage all the processes occurring on the meter. These include the processing of consumption signals, calculation of the cost of the water consumed, shutting or opening a valve and transmitting the meter reading or an alarm.

2.4.3 Memory

Memory is required for the central processing unit to hold the operating system, software and data such as water tariffs. It also allows the meter to log the consumption data for detailed analysis of a user's consumption patterns. The data may be collected on a regular basis or as required for analysis. Certain analyses, such as leak detection, may be conducted on the meter and an alarm raised if detected.

2.4.4 Power Supply

Various advanced metering components require power to operate, including the central processing unit, sensors, data transmission and automatic valve. The most common power source is a battery since an electrical connection is normally not available at the water meter.

Batteries have limited service lives that are reduced by frequent use of power by different meter components. Suppliers often quote battery service lives that are based on ideal operational conditions and minimum use. In addition, only a typical or maximum battery life is given, while in practice batteries will have a range of service lives with some failing soon after installation and others lasting much longer.

Batteries are a significant disadvantage of advanced meters, since replacing them require significant resources and costs. Municipalities typically manage very large numbers of meters, meaning that battery replacement will have to be a continuous function. There is also the additional problem of safely disposing the old batteries.

It should be noted that some meters allow the battery to be replaced in the field, while others will required the meter to be replaced when the battery is flat.

A loss of power supply through a flat battery means that the advanced meter cannot fulfil any of its functions. The valve may be stuck in the closed position, disconnecting the consumer even if they have sufficient credit loaded on the meter. If the valve is stuck in the open position, the consumer is supplied with free water with no incentive to report the failure.

2.4.5 Data transmission

Data may be received by or sent from an advanced water meter if relevant electronic components are installed. This process is normally referred to as AMR (Automatic Meter Reading) or AMI (Advanced Metering Infrastructure).

AMR is an automated way to collect meter reading data, without any data sent back to the meter. The simplest form of AMR is a hand-held meter reader that can collect data from the water meter through a temporary RF (Radio Frequency) link when the reader walks or drives past the meter (Electa et al.,2008).

AMI, on the other hand, allows real-time or frequent transmission of measurements over a communication network to a central collection point allowing on-demand interrogation of meter readings. AMI allows for two-way communication between the meter and the data management system.

The electronic data stream from the register can contain the meter's current reading as well as additional information such as cumulative water consumption, peak demand, and alarm flags (Blom et al., 2010).

Figure 4 illustrates an AMI system: data is collected and stored in data loggers (memory). The information is then transmitted through from a transmitter on the meter (e.g. RF or Wi-Fi) to the nearest transmitter mast. The mast broadcasts the signal to the receivers in the utility's Ethernet (a family of computer networking technologies for a LAN), from where it is transferred to the main server or central computer.

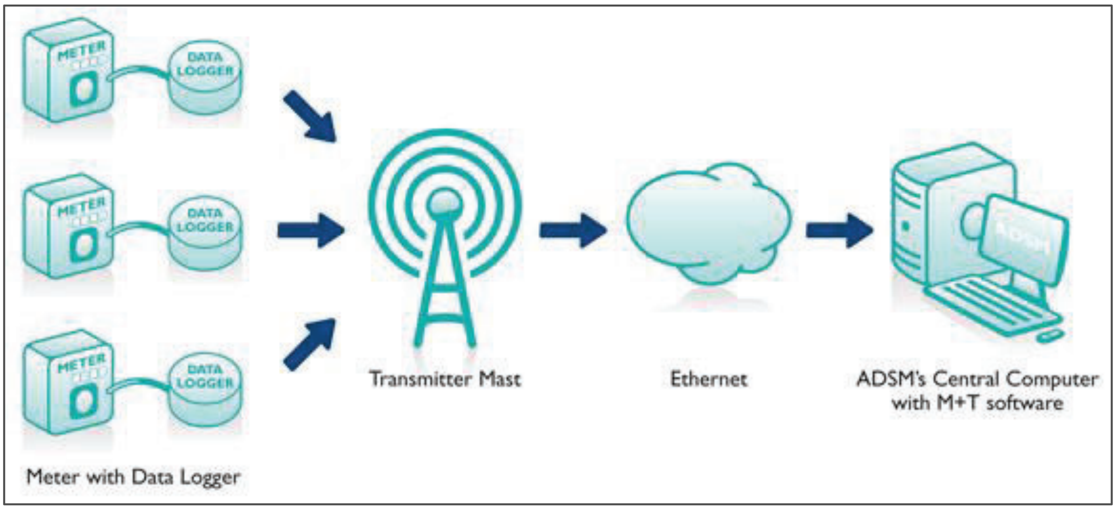

Figure 4: Meter reading through AMI/Automatic Meter Infrastructure (adopted from Mburu, 2017)

2.4.6 Automatic Valve

The water management device class of advanced water meters use an automatic valve to shut off or restrict the flow to a consumer. These valves typically rely on the water pressure in the system to open or close and is one of the most problematic components on a water management device. Valves are often required to open and close at regular intervals (for instance daily when the free basic allowance is depleted) and should use minimum battery power to do this, which is very difficult to achieve.

2.4.7 Token System

In some cases a token system is employed where the user transfer credit to the token at a vendor and then holds the token against the meter to transfer the credit. Water metering information may also be transferred through the token to the vendor and then the municipal management system (Malete, 2010). Figure 5 shows a typical water management device (or prepaid water meter) that uses a token system for credit and data transfer.

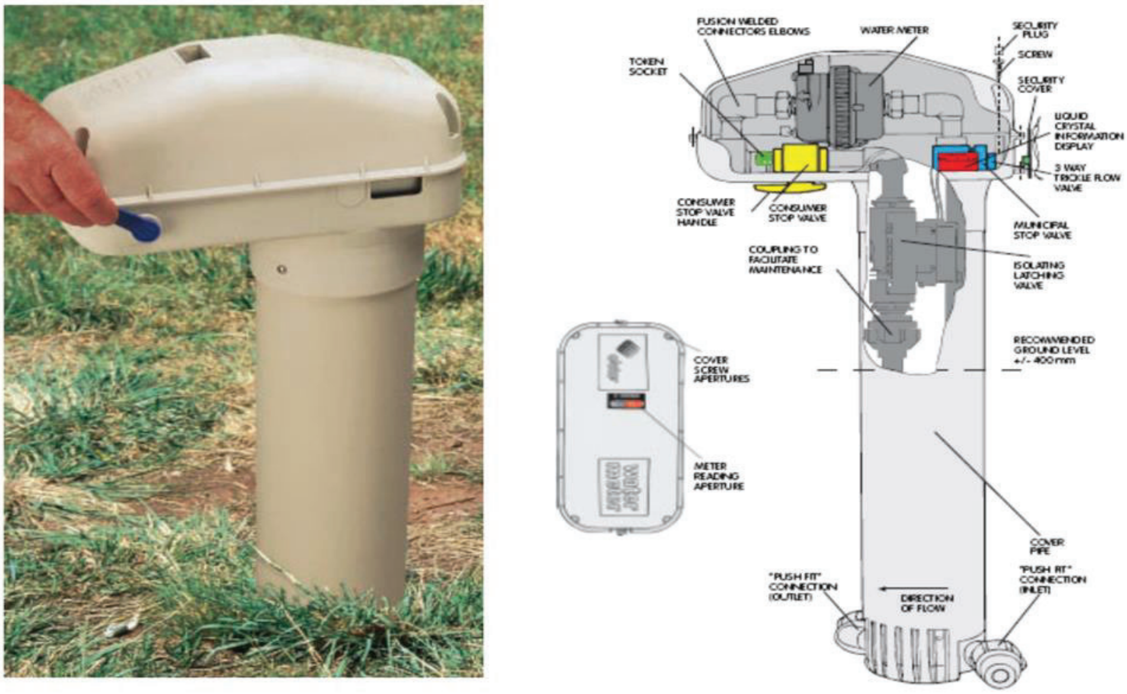

Figure 5: A Water Management Device recharged using a token system (courtesy of Elster Kent)

2.4.8 Other Components

Advanced water meters can be provided with several other components, such as pressure or water quality sensors, that can expand the capabilities of these meters.

2.5 Communication Sub-systems

The communication sub-systems of advanced water metering transmit a signal from the water meter to a central point where the data is processed, and may also allow for instructions to be sent back to the meter.

These abilities allow for improved level of functionality and interaction between the different bodies involved in the supply chain (Haney et al. 2009). Communication infrastructure is therefore a critical component of advanced metering technology (Lipošüak & Boškoviü 2013).

This section provides an overview of the main components of a communication sub-system (transmitters, gateways and area networks) before discussing the different communication technologies that may be used.

2.5.1 Transmitters

A transmitter is the most basic component of the advanced water metering communication system is normally part of the meter (see Section 2.4.5). Transmitters send water meter data to a remote location, typically in the form of radio waves. For smart metering applications, the typical range of a transmitter using wireless radio is about one kilometre (Blom et al., 2010).

2.5.2 Gateways

A gateway is a device that receives signals from one or more data transmitting devices and relays the information to another location (Blom et al., 2010). Gateways act as large loggers and can store multiple data points and transmit them in packets to the receiving station. This process of data storage and transmission decreases the need to for each meter to relay data over large distances (Blom et al., 2010). AMI and data loggers typically use radio transmitters to send information to a gateway, which then relays all end-use data via GSM networking (Blom et al., 2010).

2.5.3 Area Networks

Advanced meter systems require supporting communication infrastructure to enable information to be communicated or transmitted. Possible networks types include the following:

- Home Area Network (HAN)
- Local Area Network (LAN)
- Wide Area Network (WAN)

Figure 6 portrays a simplified view of how the various area networks may link parts of an advanced metering system together. Data is collected locally from the advanced meters and transmitted via a LAN to a data collector. The data collector can then opt to process the data or transmit it unprocessed. The data is then transmitted via a WAN to the utility's central data collection point. At this stage, data can be processed and used for business applications. An

AMI system allows for a two-way communication process and signals can be sent directly to meters, customer premises or distribution devices.

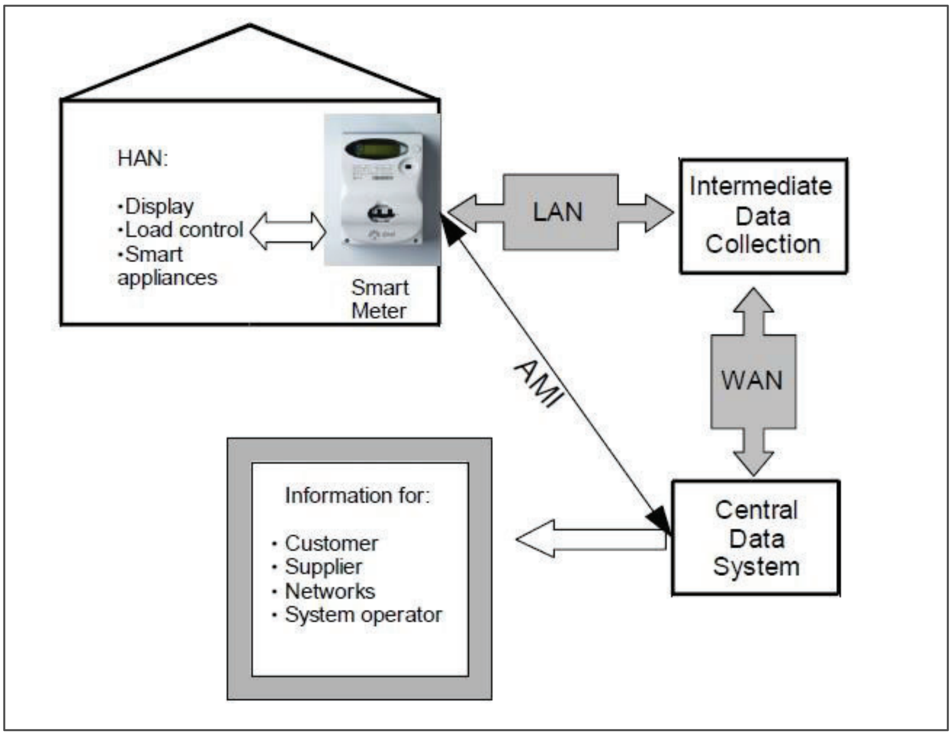

Figure 6: Schematic Illustrating Advanced Water Metering supported by Area Networks (adapted from Haney et al., 2009)

In an AMI system the advanced water meter can act as a platform for co-ordinating with other devices in the home (display devices), with the customer through the HAN and with the rest of the electricity system through the LAN and WAN. **Figure 7** illustrates a form of AMI and how area networks are used to provide communication support.

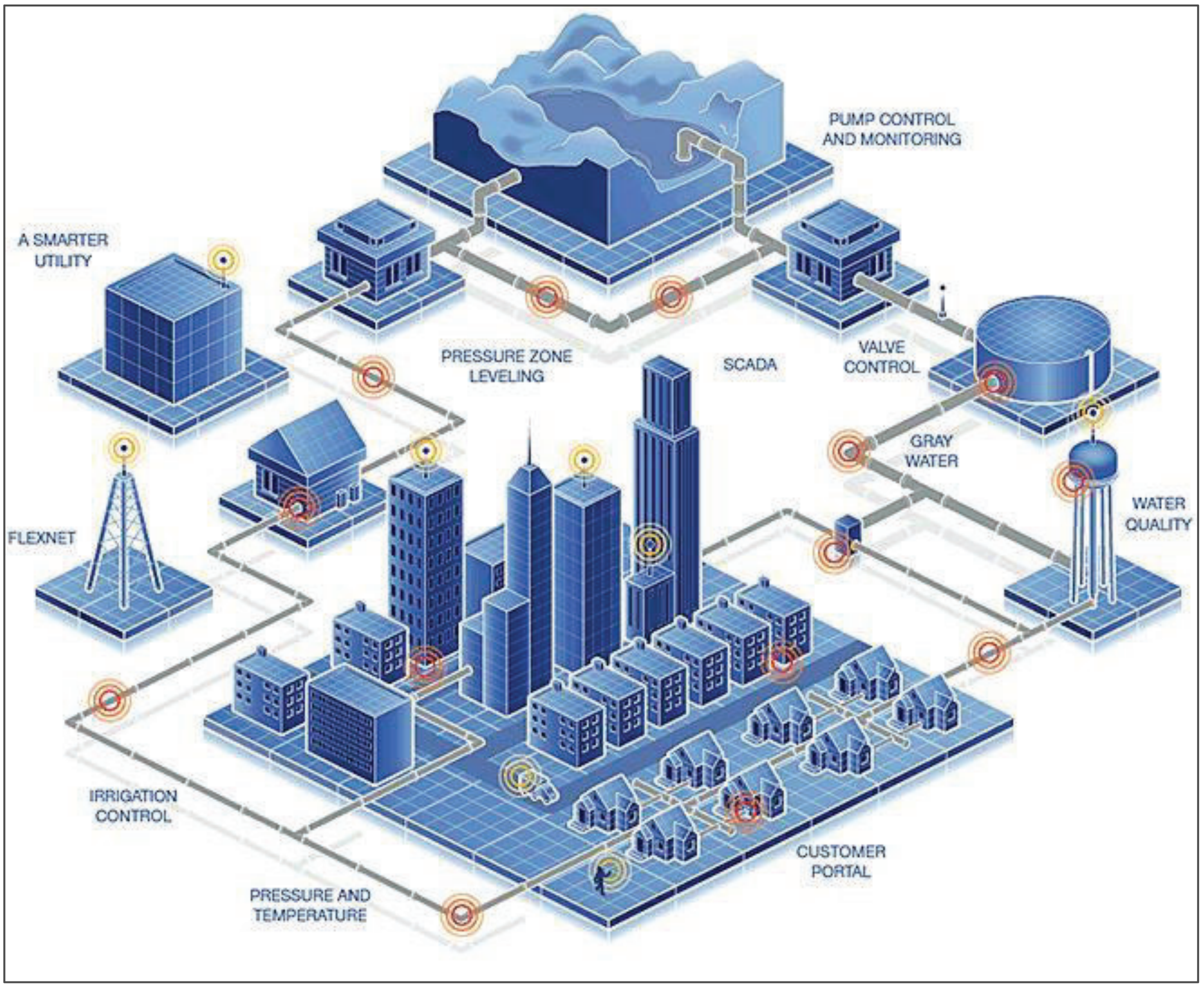

Figure 7: Illustration of an AMI System in a community and the required support from Area Networks (HAN; LAN; WANO) (Adapted from Sensus)

2.5.4 Communication Technologies

In order for communication to take place within an advanced metering system specific communication technology is required. This is the means by which information or data is transmitted and transferred. Various technologies are used for advanced meters, including the following:

- ZigBee
- Wireless mesh
- Radio frequency mesh
- Radio frequency point-to-multipoint networks
- Power line communication
- Cellular networks

(a) ZigBee Networks

ZigBee is a wireless communication language that can be used to create personal area networks and connect everyday devices with small, low-power digital radios. It has a relatively low power usage, data rate, complexity, and cost of deployment. The technology is intended to be simpler and less costly than other personal area network technology such as Bluetooth or Wi-Fi. It is typically used for low data rate applications that need a long battery life.

Its low power demand limits the possible transmission distance to 100 m, depending on the power output but ZigBee devices can transmit data over longer distances by passing data through a mesh network of intermediate devises to reach more distant ones.

ZigBee and ZigBee Smart Energy Profile (SEP) are considered to be one of the most suitable communication standards for a smart grid residential network domain by the U.S. National Institute for Standards and Technology (NIST).

The communication between smart meters and other intelligent home appliances, as well as home displays, is important. ZigBee integrated smart meters can communicate with the ZigBee integrated devices and control them. ZigBee SEP gives the service utility the ability to send messages to the home owners. Home owners in turn have access to information of their real-time energy consumption. **Figure 8** demonstrates the structure of a typical ZigBee network.

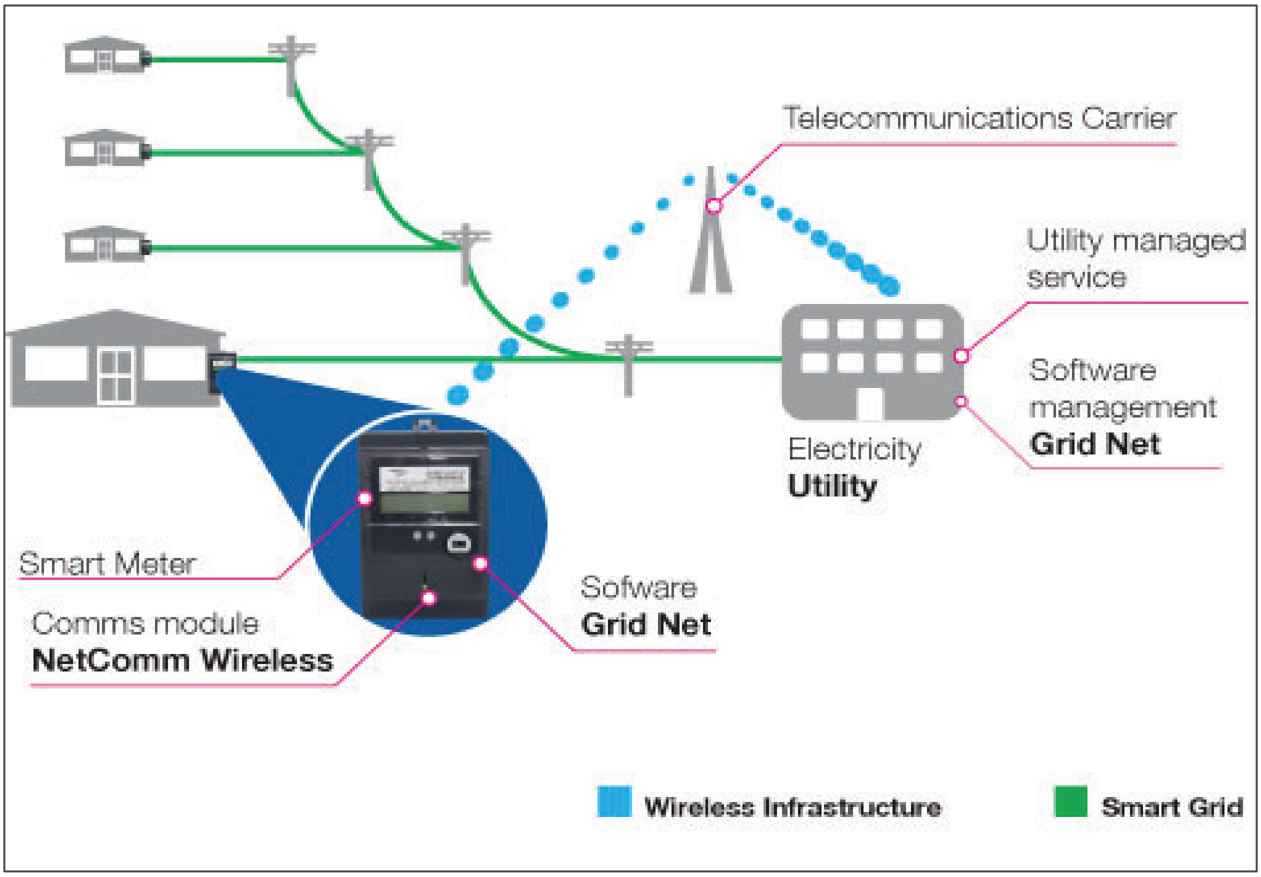

Figure 8: Structure of a ZigBee Communication Network (adopted from Mburu, 2017)

The advantages of using ZigBee communication technology can be summarised as:

- Robust system
- Low bandwidth requirements
- Low cost of deployment
- Easy network implementation
- Good load control and reduction can be achieved
- Aid with demand response and real-time system monitoring and pricing

The disadvantages of ZigBee networks are as follows:

- Low processing capabilities
- Small memory size
- Small delay requirements
- May experience interference from other appliances

(b) Wireless Mesh Communication

A wireless mesh network (WMN) is a communication network comprising radio nodes that are structured in mesh format. It consists of mesh routers and mesh clients and gateways. A mesh router has minimal mobility and act as the backbone of the network (Akyildiz et al., 2005).

Wireless mesh networks can wirelessly connect entire cities using relatively inexpensive, existing technology. Traditional networks relied on a small number of wired access points or wireless hotspots to connect users. However, in a wireless mesh network, the network connection is widespread among numerous of wireless mesh routers that can communicate with each other to share the network connection across a large area (Akyildiz et al., 2005). Wireless mesh networks have self-healing capabilities as the network allows communication signals to find another router if one router drops out of the network (Güngör et al., 2011)

In order for a wireless mesh network to function, each smart meter device is equipped with a radio module. This module enables information to be transferred to a nearby mesh router, which in turn can route the metering data through to other nearby routers. Each router acts as a signal repeater until the collected data reaches the electric network access point. Then, collected data is transferred to the utility via a communication network. Figure 9 illustrates the structure of a wireless mesh network. These networks can also be integrated with other networks such as cellular through the bridging capabilities of mesh routers. (Güngör et al., 2011)

The advantages of using WMN include the following:

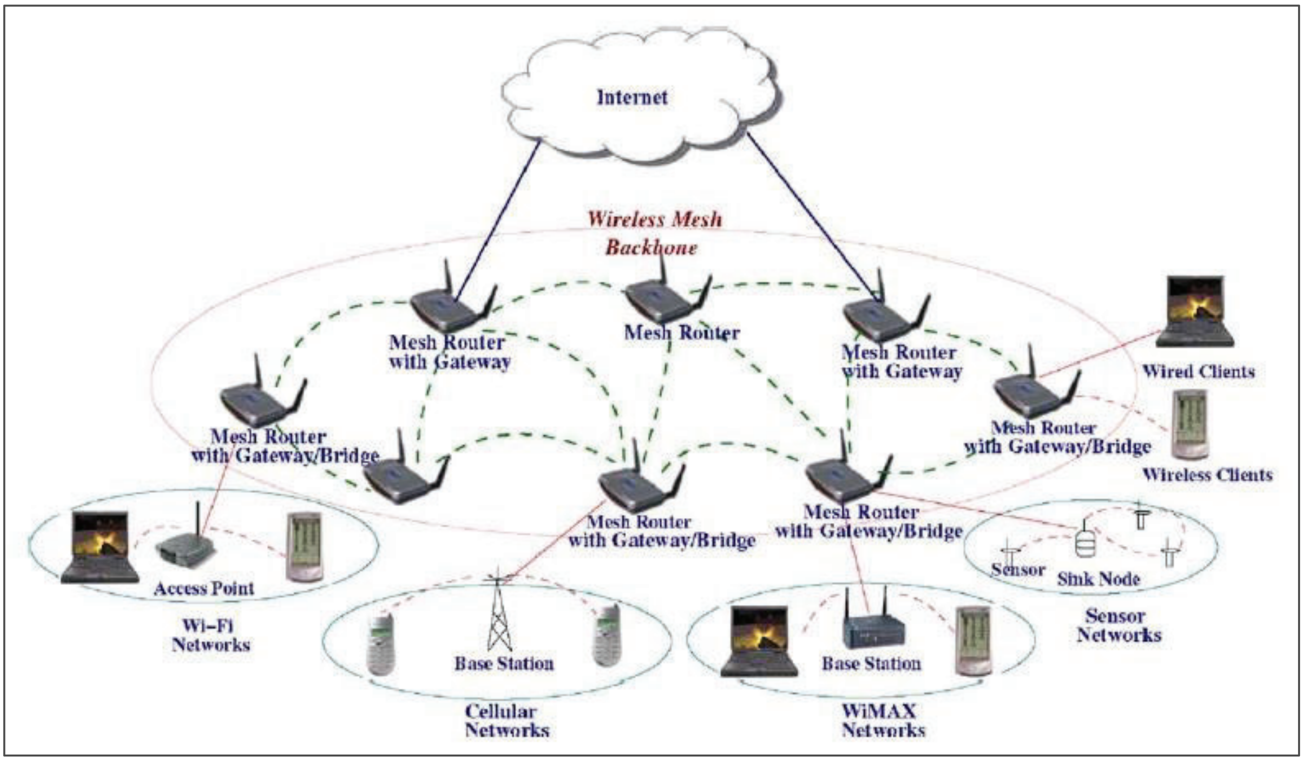

Figure 9: Structure of a Wireless Mesh Network (adapted from Akyildiz et al., 2005)

- Cost effective solution as wireless mesh networks operates on existing infrastructure and has dynamic self-organization and self-healing capabilities.
- Improved the network performance due to the self-organizing capabilities.
- Load is automatically balanced within the network.
- Widespread network coverage.

The disadvantages of WMN can be summarised as follows:

- Fading and interference can easily occur.
- Lack of complete coverage due to high meter density in urban areas.
- A third party company is required to manage the network.
- Strict measures need to be taken to ensure data security.

(c) Radio Frequency (RF) Mesh Networks

Radio Frequency Mesh Networks are similar to the Wireless Mesh Networks. The smart meters act as the routers of the network and can communicate with each other in a LAN system. The signals are then transmitted to a collector through a mesh router. The collector transmits the data using various WAN methods to the utility central location.

The advantages of using a RF mesh technology are as follows:

- Low implementation costs
- Acceptable latency (signal delay through transmission).
- Large bandwidth

The disadvantages of RF mesh technology include the following:

- Terrain may prove challenging in rural areas as line of sight is required.
- Cannot cover large distances
- A third party company is required to manage the network (EEIC and AEIC Committee Members 2011)

(d) Radio Frequency Point-to-Multipoint Networks

In a RF point-to-multipoint network, smart meters communicated directly to a collector, usually a tower. The tower collector transmits the data using various methods to the utility central location for processing.

The advantages of a RF point-to-multipoint are as follows:

- There is little or no latency
- Direct communication with each endpoint
- Large bandwidth for better throughput
- Can cover longer distances.

The disadvantages of RF point to multipoint networks are that terrain may prove challenging in rural areas (EEIC and AEIC Committee Members 2011)

(e) Power Line Communications

Power Line Communication (PLC) is technology carrying data as well as transmitting electric power on power lines (Kim et al., 2011). Since power lines have being widely established, there is no need to install separate communication lines.

By utilising the power lines, PLC can easily be installed and connected to various other networks via a backbone network (i.e. the main network that is connected to several local networks (LANs) (TechTerms, 2014)). Furthermore, devices could easily be connected into the system by simply plugging into an electrical outlet port.

PLC is highly suitable for advanced electricity meters due to them being part of the electrical grid. For advanced water meters, PLC can only work if these meters powered by the electrical grid, which will require the water meter to be installed indoors. This may be costly to achieve, but if done will have the additional benefit of removing the need for battery replacements.

Figure 10 illustrates the operation of a PLC communication system (Park et al., 2002). The meters are connected to a PLC modem through a data port (Park et al., 2002). The modems are then connected to a concentrator modem, which acts as a bridge between the PLC and a data networks.

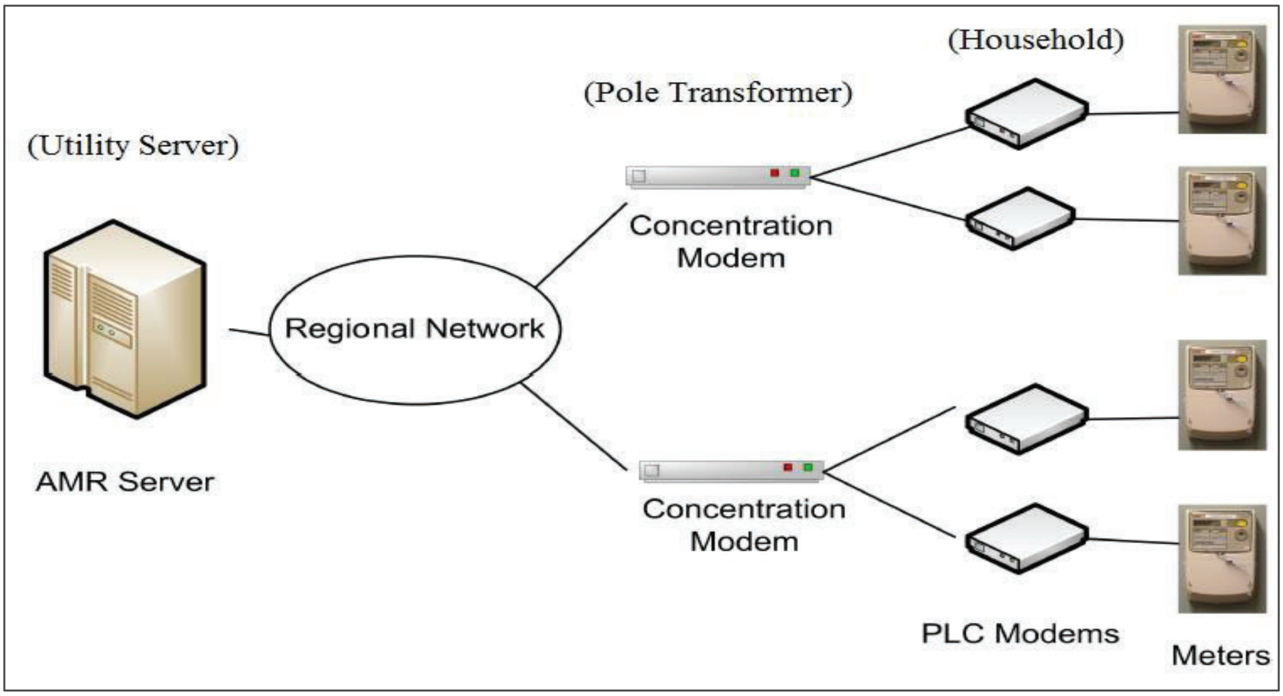

Figure 10: Configuration of AMR system using PLC (adapted from Park et al., 2002)

Another example of how PLC is used to transmit measurements is shown in **Figure 11** (Choi et al., 2008). The system involves various devices and different communication technologies where water meters first transmit their measurements over wireless links to a device called Home Concentration Unit (HCU), which is to be installed in every household. A number of HCUs, from different households, send the measurements to a device called Data Concentration Unit (DCU). This device sends the metering data in Device Language Message Specification (DLMS) format through a PLC modem to the utility company. Data traffic direction is only from the meters to the utility.

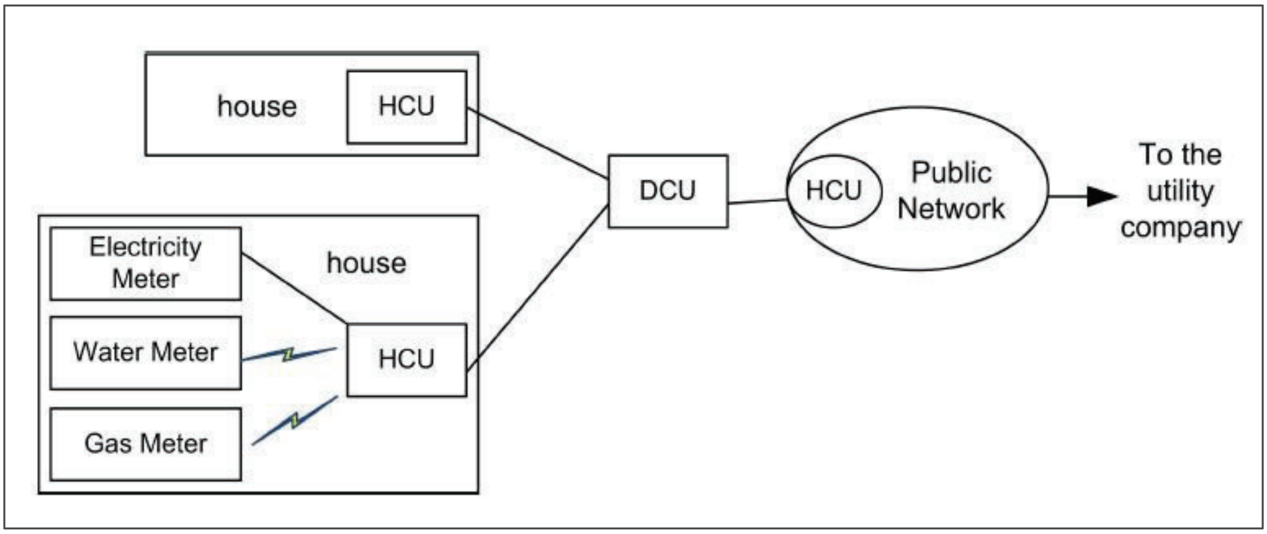

Figure 11: An example of a PLC system (Choi et al., 2002)

The advantages of PLC technology include the following (EEIC and AEIC Committee Members 2011):

- Data transmission is secure.
- Leveraging the use of existing electrical utility infrastructure.
- Improved cost effectiveness for rural lines.
- Capability to work over long distances.

The disadvantages of PLC technology are as follows (EEIC and AEIC Committee Members 2011):

- Longer data transmission time (more latency).
- Less bandwidth and throughput.
- Limited interface with distribution automation devices.
- Higher cost in urban and suburban locations.

(f) Cellular Network Communication

Cellular Network is another alternative means of communication between water meters, utilities and consumers. Similar to PLC, cellular networks consist of existing communication infrastructure. This means that the utilities do not have to dispense with the cost of installing these infrastructure, as well as initial operations and implementation costs.

Cellular network solutions also enable smart metering deployments spreading to a wide area environment (Güngör et al., 2011). Cellular communication technology such as 2G, 2.5G, 3G, WiMAX, and LTE, are available to utilities for smart metering deployments.

When a typical data transfer interval of 15 minutes between the meter and the utility is used, a huge amount of data is transmitted and a high speed connection is required to transfer the data to the utility (Güngör et al., 2011).

For example, in UK the T-Mobile Global System for Mobile communications (GSM) network is for the deployment of Echelon's Networked Energy Services (NES) system. An embedded T-Mobile SIM within a cellular radio module is integrated into the advanced meters to enable the required communication. Since T-Mobile's GSM network will handle all the communication requirements for the smart metering network, there is no need for further investment into a new dedicated communications network by utilities.

The schematic diagram in **Figure 12** depicts an example of cellular network used in a smart metering system.

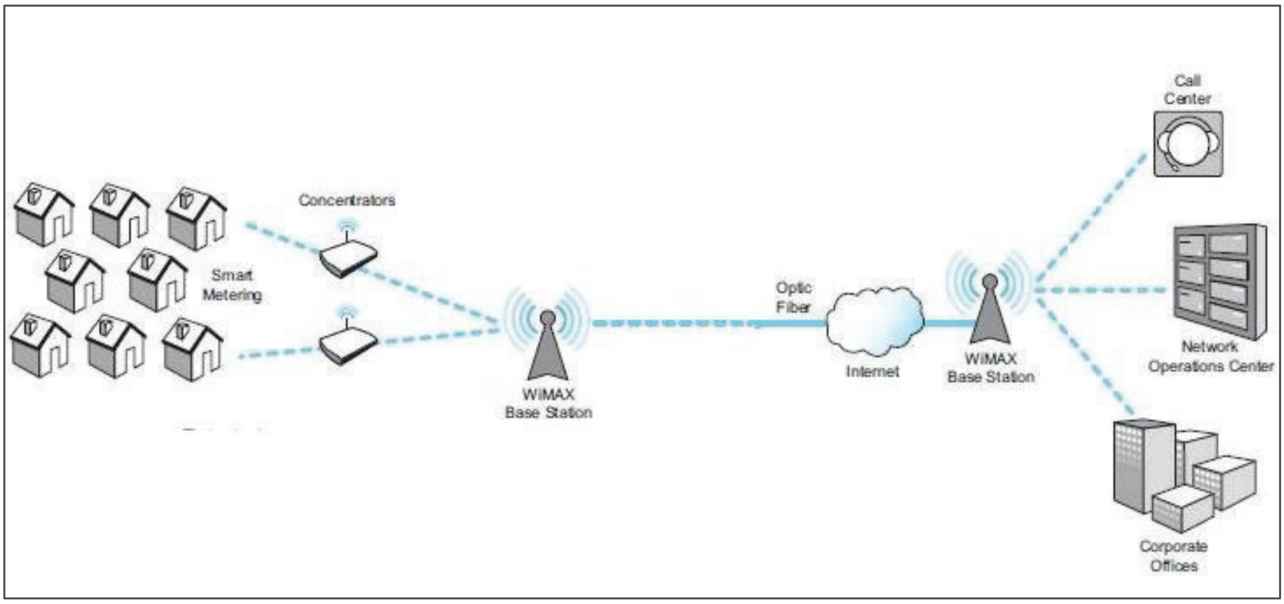

Figure 12: An example of smart metering via cellular connections (adopted from Mburu, 2017)

Cellular networking has a lot of advantages as a communication means for smart metering and they are as follows:

- Cost effective as there are no extra costs on constructing the necessary infrastructure.
- Widespread coverage due to all the infrastructure and signal masts in place.
- Secure data transmissions due to the strong security controls in place.
- Easily adaptable to any communication infrastructure and network.
- Low maintenance costs
- Fast installation features (Güngör et al., 2011)

Cellular networks also have various drawbacks. These include the following:

- Network congestion as cellular networks share with customer markets.
- Network performance can decrease in emergency situations.
- Hindrance can be caused by abnormal conditions, e.g. wind storm. (Güngör et al., 2011)

2.6 Management Sub-systems

Management sub-systems include all systems that receive and process metering data. These include display devices in consumer homes and municipal meter data management systems.

2.6.1 Consumer Interfaces

A consumer interface is a device installed in a consumer's home that allows them to receive and display water meter data, including parameters such as the current consumption rate, consumption for the month, water bills, leakage alarms. These devices raise consumer awareness of their water use and provide timely warnings of problems such as on-site leakage. They can be used as part of a larger water demand management strategy.

2.6.2 Advanced Meter Management

Advanced Meter Management (AMM) is an extension of AMI with the ability to manage meters remotely. This structure is similar to an AMI as it's a two-way communication process between the meter and the rest of the network. However, unlike AMI, water meters can be remotely managed as commands or messages can be sent and uploaded to the meters as well as data to be downloaded from the meter. The remote management of the meter includes the capability for remote connection or disconnection and remote changes in contracted power or price schemes (Electa et al.,2008).

2.6.3 Web-Based Knowledge Management System

Web-based Knowledge Management system is the system of metering in which water consumption data, wireless communication networks and information are integrated to provide real-time information on how, when and where water is being consumed for the consumer and the utility (Stewart et al., 2010); it is also used to provide summary and detailed data for the system.

Primary functionalities of the WBKMS are the following (Stewart et al., 2010):

- Collecting real-time water consumption data.
- Transferring and storing the data into a knowledge repository.
- Data processing and analysis.
- Producing reports that can be accessed online by a broad range of users like consumers, water utilities, government organisations, developers.

WBKMS allows for individual consumers to log into their user-defined water consumption web page to view their daily, weekly and monthly consumption tables as well as charts on water use patterns for categories of water end-use (Stewart et al., 2010) and cumulative water billing can be updated daily or even hourly, and online alarms will be generated to indicate potential causes for excessive water use like internal leaks. This may help consumers to take proactive water saving actions.

This system also enables water utilities to intervene as soon as an exception alarm is raised for end uses such as major water leaks (Stewart et al., 2010). The analytical reports generated by the system also help utilities to identify the water consumption patterns of different types of consumers. With knowledge of correlation of water consumption to types of consumers, will allow water authorities to develop targeted education campaigns relating to conservation and water use, and an opportunity to develop different tariff systems to influence consumption behaviour (Stewart et al., 2010).

One future system that has been suggested aims to establish the correlation between water consumption data and types of water consumption, requiring the advanced water meter to generate high resolution data (Stewart et al., 2010). This type of system will allow detailed analysis of consumption patterns at end-use level, enabling the distinction of hydraulic flow into discrete water end-use events such as shower, toilet and garden irrigation.

It should be noted that the value of water consumption information derived from a smart metering system is dependent on the water meter's resolution and the data logging frequency. Current generation large scale smart metering implementations utilise affordable standard resolution water meters (i.e. 1 pulse per litre) logging at typically hourly intervals. **Figure 13** provides a schematic illustration of the structure of a WBKMS.

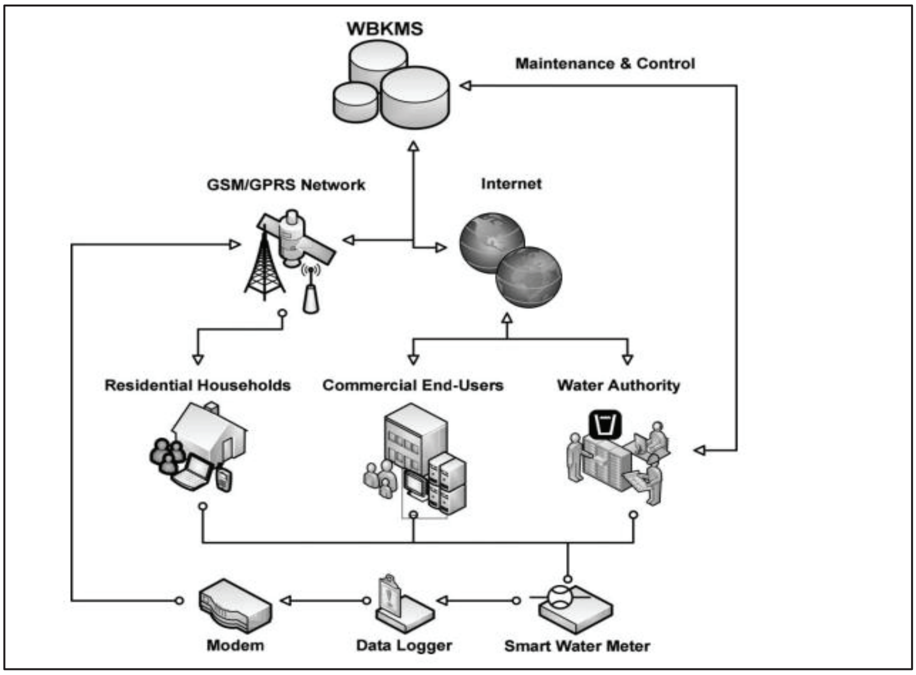

Figure 13: Web-Based Knowledge Management System (Stewart et al., 2010)

WBKMS makes it possible to correlate stored demographic data with water consumption patterns, thus enabling deeper understanding of different categories of water users. This type of information will allow water authorities to develop targeted education campaigns relating to conservation and water use, and an opportunity to develop different tariff systems to influence consumption behaviour.

3. SELECTING AN ADVANCED METERING SYSTEM

3.1 Overview

Like all water meters, advanced meters have a limited service life and have to be replaced at regular intervals. Thus the full life cycle of advanced meters should be considered when a decision is made to implement them.

It should be stressed that while advanced meters have unique and potentially beneficial properties, they are significantly more expensive to implement, operate and maintain compared to conventional meters. Thus advanced meters should not be implemented without careful consideration and appropriate preparations in place for the increased operational requirements.

The life cycle of advanced metering projects is shown in **Figure 14** and discussed in the rest of this chapter.

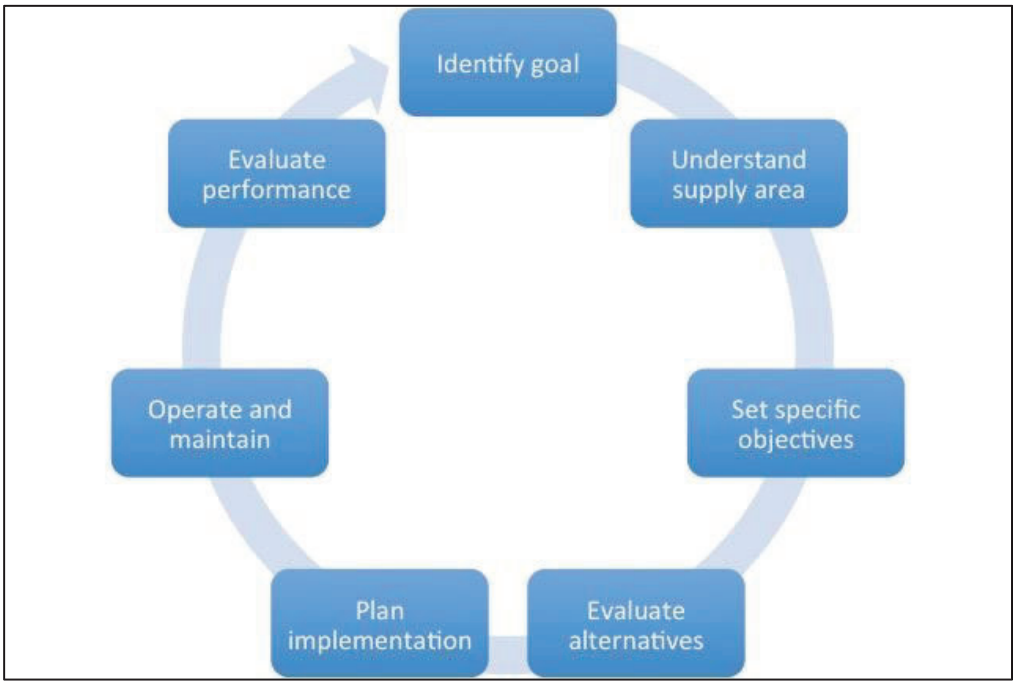

Figure 14: Advanced metering life cycle

3.2 Identify the Goal to be Achieved

Advanced metering should never be considered as a goal in itself, but rather as part of the solution to a particular problem or goal to be achieved. Thus the starting point of any new project should always be "How do we best achieve this goal?" and never "How can we apply advanced water meters?"

Advanced metering may be used as part of the strategy to achieve a number of goals or address problems experienced by water service providers, including the following:

- ***Increasing revenue from water sales.*** Advanced meters such as prepaid meters can be used to increase water payment rates since the water supply is automatically shut off when the user's credit runs out. Thus the consumer has an incentive to purchase credit in advance as not to experience the inconvenience of being disconnected by the meter.
- ***Managing outstanding consumer debt.*** In areas where consumers have large outstanding water debts that are unlikely to be recovered, advanced metering may be used as part of a system to get consumers to start paying for water used. For instance, outstanding debt may be recovered and/or scrapped over a number of months when the consumer purchases credit for their prepaid water meter.
- ***Water demand management.*** Advanced meters can be an important tool in reducing water consumption by allowing the municipality to quickly identify irregular consumption patterns, identifying on-site leakage and creating consumer awareness of their water consumption.
- ***Consumer choice.*** Advanced meters may be provided to consumers as an add-on service allowing them greater choice in how to manage their own water consumption. For instance, consumers renting out their properties may prefer a prepaid meter to prevent tenants from getting behind with water payments, and environmentally conscious consumers may be willing to pay for an advanced meter keeping track of their consumption and warning them of on-site leakage.
- ***Extending the formal network.*** In areas where consumers cannot be reached through a conventional metering system, for instance in informal settlements, advanced metering can allow water to be supplied and billed without the need for a formal stand number or address.
- ***Reduced operational costs.*** In certain cases advanced meters can assist municipalities to reduce operational costs by doing automatic water meter reading and using online water metering information to improve operational efficiencies. However, this goal is highly unlikely to be achieved in a developing country like South Africa where labour for meter reading is relatively cheap and sophisticated data management systems are not common. Even in high income countries it is hard to make a case for reducing operational costs by implementing advanced metering. The increased operational and maintenance costs of the advanced meters and systems will likely exceed any savings made in operational expenses.

3.3 Understand the Supply Area

Once a goal is identified, it is critical that a study is conducted to understand the supply area and its particular challenges. Each supply area is unique and it is essential that reliable information is gathered to be used in the development and analysis of the proposed system.

A recommended list of points to gather information on is provided in the user guide to the evaluation framework that forms part of this report. The list is provided in the following tables in Chapter 2 of Appendix A:

- Table 2-1: System parameters
- Table 2-2: Global parameters
- Table 2-6: Current consumption parameters
- Table 2-7: Current payment levels
- Table 2-8: Other Parameters

A number of the points included in the tables above are listed below as they are of particular importance for the viability of any advanced metering system:

- ***Free Basic Water*** is provided free to all consumers in South Africa. While the cost for providing free basic water should be recovered from cross-subsidisation or a Government subsidy, this is not always achievable. Advanced metering systems are expensive to implement, operate and maintain, and this might not be a good solution to manage consumers that rely on the free basic water allowance and can't afford to pay for additional water.
- ***Attitude of the community water services and paying for them.*** No infrastructure project can succeed if it isn't accepted by the community it is implemented in, and thus it is critical that the history, attitude and internal dynamics of the community are understood. For example, if a community resists the idea of paying for water, it is impossible to force them to pay for water using a technology like advanced metering. It is not possible to solve a social problem with a technical solution and it will be necessary to first create an awareness of the need to pay for services and a willingness to do so before any new system is implemented. It is recommended that the community is consulted at an early stage when any new water service project is considered.

3.4 Set Specific Project Objectives

Once the overall goal of the system is identified and the supply area understood, it is necessary to set specific goals that will indicate whether a proposed system will achieve the goal given the limitations of the supply area.

It is recommended that the objectives are set in four areas as supported by the evaluation framework in Appendix A. These are:

- ***Technical objectives.*** The technical objectives of the proposed scheme should include the minimum legal requirements (e.g. SABS compliance of water meters), but may have additional detail. Many of the technical requirements may already be specified in the municipality's own standards and guideline documents. Technical requirements may include meter types (e.g. positive displacement or multijet), communication standards (e.g. STS compliance), payment system specifications and others. Some technical requirements may be minimum requirements, while others indicate a preference that can be relaxed if necessary.
- ***Social objectives.*** The main social objective should be that the community accepts the proposed scheme and this may help define more detailed objectives such as changing community attitudes to payment for services or water metering.
- ***Environmental objectives.*** Various environmental objectives may be considered, but with advanced metering a key objective is the reduction of water consumption, which is key to preserving the limited water resources, particularly in water scarce countries like South Africa.
- ***Economic objectives.*** Economic objectives are generally considered the most critical for infrastructure projects. It is normally required that the overall benefits should exceed the costs of the project. The evaluation framework in Appendix A uses two measures for economic evaluation, namely the capital repayment period and the effective surplus.

It is important to recognise that different objectives may affect each other. For instance an improved environmental performance when water consumption is reduced will invariably reduce the income from water sales and thus affect economic viability of the scheme.

A second important point is that, while it is desirable to have a project that meets objectives in all four areas, this may not be possible. In some cases it may be acceptable for a project not to be feasible in one area because the objectives in another more important area are met. For instance, in an area under severe water stress a solution that reduces water consumption may be selected even though it is not economically feasible. In such a situation, the increased financial loss or reduced surplus can be seen as the cost of reducing consumption.

3.5 Evaluate All Alternatives

All possible alternative solutions for achieving the project objectives should be considered, including solutions that do not use advanced metering.

For instance, flow limiters provide a simple and cheap mechanism to provide consumers with free basic water. If these systems are combined with on-site storage tanks, a good level of service can be provided in a cost-effective and reliable way.

The evaluation framework in Appendix A provides a tool to evaluate the viability of advanced metering projects, particularly in the environmental and economic areas. The evaluation framework includes an evaluation of the alternative of conventional water meters.

Since conventional meters are much cheaper to implement and operate than advanced meters, these may outperform advanced meters even if they don't result in the same improvements to payment levels compared with advanced meters.

It is recommended that a sensitivity analysis is conducted once an evaluation framework model has been developed for a particular application. This entails what-if scenario testing to investigate the impact on the viability of a project if, for instance, the payment level objectives aren't met.

A number of case studies have been evaluated using the evaluation framework, and these are documented in Chapter 5 and Appendix B. It is recommended that these case studies are used when learning to use the evaluation framework and to compare any new project with the closest case study.

3.6 Plan Implementation of the Best Solution

Once all alternatives have been evaluated and a decision made on the best solution, it is necessary to plan the implementation of this solution. That includes the requirement for adequate qualified staff to oversee the system implementation and deal with the problems that should be expected during this phase, financial planning and putting the required tender documents in place. It is important to specify performance targets for the advanced meter provider, including guarantees of claims made regarding failure rates and battery life and support for the implementation process and staff training.

Advanced metering projects are expensive and carry high risks of failure. Thus it is a good idea to first implement these meters as a small pilot study. Once the pilot study is operating successfully, a second scheme can be implemented doubling the size of the previous study. This process of doubling the previous scheme can continue until the full area has been covered.

3.7 Operate and Maintain

The longest phase of any infrastructure project is the operation and maintenance phase. It is important that advanced meters are operated and maintained in accordance with manufacturer specifications.

3.8 Evaluate the Project Performance

Once the advanced metering project has been operational for some time (say a year), it is recommended that the evaluation process is repeated to evaluate how realistic the assumptions made were and learn from mistakes made.

4. APPLICATION OF ADVANCED METERING

4.1 Introduction

This chapter provides an overview of the driving forces, applications, benefits and challenges of advanced water metering. The information was obtained from several literature sources as well as the summarised case studies presented at the end of this chapter.

4.2 Driving Forces

Investments and development in advanced water meters and 'smart' networks are being driven in part by the increased availability, reliability, and functionality of ever newly available technology. However, there are a number of driving factors that lead to advanced metering implementation in the water supply sector.

It is important to understand these driving factors, because the final selection and implementation of the advanced metering system for a specific scenario, depends on the driving factors that supports the application of advanced metering. Driving factors include:

- ***Water scarcity.*** The rise in demand for water could exceed the existing water sources especially with the pressures felt from climate change, historic over-use and population and economic growth. As such there is a need for more efficient use of the water available (Woods & Strother, 2013). (Fróes et al., 2012) state that there is a need for natural resources to be better managed and the means by which they propose to do this is by better monitoring the water consumption and relay the information through the use of smart meters
- ***Aging infrastructure.*** As numerous water supply infrastructure have being for long periods of time, new infrastructure is needed as an upgrade to the aging infrastructure. This provides an opportunity to introduce intelligent infrastructure that will allow service provision to improve while resources are managed more efficiently.
- ***Non-revenue water.*** Non-revenue water consist of water losses (leakage, water meter under-registration, illegal connections, etc.) and unbilled consumption (e.g. water used for public bathrooms, parks and firefighting. The World Bank estimates that the cost of global NRW is at $14 billion per year (Woods & Strother, 2013). More detailed information on water consumption allows municipalities to better estimate water losses and unbilled consumption.
- ***Efficient water consumption.*** In Australia, (Britton et al., 2013) experiments were conducted to investigate effectiveness of communication interventions to the repair of household leaks and the attributed water savings resulting from these repairs. It was found that smart water meters had a significant impact in reducing the leaks as water wasted on leakage reduced by about 89%.

- ***Payment for services.*** Advanced metering technology such as prepaid water meters is often used to improve rates of payment for water.
- ***Utility operations budgets.*** Manually reading meters requires labour, and in countries where labour is expensive, cost savings when replacing meter readers with advanced metering is an important consideration.
- ***The Water-Energy nexus.*** The last decade has seen increased awareness of the inter-relationship between water and energy: water is used in all the phases of energy production and energy is required to extract and deliver potable water. Managing both resources in such a way that both are used optimally and efficiently is an important challenge (U.S. Department of Energy, 2014). Water utilities are looking to use advanced meters to help reduce energy costs, and contribute to broader energy efficiency and greenhouse gas reduction targets being set by cities, governments, and international bodies (Woods & Strother, 2013).
- ***Impact of urbanization.*** Urbanization of the world's developing nations is having an impact on the global landscape. Between 2010 and 2050, almost 3 billion additional people will require urban drinking water and wastewater services. An investment in basic water infrastructure is the primary requirement to meet these needs; however, smart water networks can also play a role.

4.3 Functionality of Advanced Water Meters

The components of advanced metering systems may be combined in different ways to provide a range of functions. The functions that may be provided by advanced metering systems include the following:

- ***Automatic meter reading.*** If advanced meters are provided with a transmitter, meter readings may be collected automatically by walking or driving past the meter, or by sending readings to a central location. This has the potential to improve reading efficiency and do more accurate water balances through readings taken at the same time.
- ***Storing consumption data*** records for billing and analysis purposes, and archiving this data.
- ***Analysing consumption data*** on the meter to identify anomalies that may indicate a problem such as a defective meter or on-site leakage.
- ***Raising alarms*** for potential problems or illegal activity such as on-site leakage, wasteful consumption, vandalism or meter tampering.
- ***Managing free basic water supply*** by dispensing the free basic water allowance in daily volumes to help consumers stay within their monthly allowance.

- ***Sending information and instructions to individual water meters***. This allows the municipality to remotely update meter firmware, settings and water tariff structures, and send instructions such as closing a valve or logging specific data.
- ***Collecting additional data.*** If additional sensors are added to an advanced water meter, e.g. for pressure or water quality, the same infrastructure can be used to monitor the distribution system performance.

4.4 Benefits of advanced metering

Smart water metering is largely driven by unique benefits that the technology has over the old conventional water metering, including the following:

- Ability to provide a formal water connection to consumers that cannot be served through the formal supply system, such as consumers in informal settlements.
- Increased revenue
- Reduced meter reading costs
- Reduced need to access meters in hard-to-get locations.
- Early detection of problems such as on-site leakage, meter problems or wasteful consumption.
- More efficient water use by raising consumer awareness of their consumption patterns and on-site leakage.
- It can empower consumers to manage their own consumption and avoid excessive water bills by automatically limiting or shutting off the water supply.
- Allows the municipality to incentivise off-peak consumption by implementing a water tariff that varies through the day.
- Generates large quantities of data on the distribution system and consumer behaviour that may be analysed and used to improve the efficiency of service provision.
- Better service provision by being able to access meter readings on demand to assist in answering consumer queries.

4.5 Drawbacks and Challenges

Advanced meters have important drawbacks and challenges to overcome when compared with conventional meters, including the following:

- Higher cost of meters and installation.
- Higher cost of operation and maintenance.
- Greater failure rates.

- The need for more and better trained municipal support staff.
- Difficulty in dealing with free basic water and block tariff structure.
- Data security and the risk of third parties accessing private data or cyber-attacks on the distribution system.
- Limited battery life resulting in the need to replace batteries or meters in the field.
- Community acceptance not always easy to achieve.
- A larger financial risk due to the high cost of implementing the system.
- Consumer frustration and resistance when water is shut off at inconvenient times, particularly if this is due to a fault on the meter.

The sections below provide an overview of a number of advanced metering case studies in South Africa and the lessons learned from these. More details on the case studies on which this section is built can be found in Report 2.

4.6 Case Studies

Several case studies were investigated using the evaluation framework described in Appendix A. Summaries of these case studies are provided in this chapter. More detail of the studies can be found in Report 2. The following case studies are included:

- Prepaid metering in a typical low income area, including a sensitivity analysis.
- Water management devices in Cape Town, which are implemented on a voluntary basis to indigent homes to assist them with managing their consumption.
- Prepaid meters installed in the iLembe District Municipality of Kwazulu-Natal.
- Prepaid meters installed in the Olievenhoutbosch area of Tshwane.
- Automatic meter reading in Epping industrial area of Cape Town, installed as part of a pilot study into the feasibility of automatic water meter reading.

4.6.1 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 1000 connections and used in this model to investigate 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.

The system assumed that free basic water 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 (R2000/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 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:

- 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.

4.6.2 Water management devices in Cape Town

According to the Draft Water By-law (City of Cape Town, 2009), a "water management device is a device that controls the quantity of water flowing through a water meter over a certain time period".

In 2006 the City of Cape Town (CoCT) started the roll out of water management devices in different parts of Cape Town including Samora Machel, Fisantekraal, Phillipi, Hanover Park, Mfuleni. The primary reason implementing water management devices was to reduce debt and save water by helping consumers manage their usage (Saayman, 2016).

Water management devices from different manufacturers, including Aqualoc and Utility Systems, have been used in Cape Town and to date approximately 160 000 devices have been installed (Saayman, 2016).

The main benefits from the WMDs was reduced consumption, which saved water sources and deferment of water supply augmentation projects, and also improved consumer budgeting and consequently reduced water debts (Saayman, 2016).

Significant technical, economic and social challenges issues were experienced in use of these meters resulting in a number of social protests against the meters throughout Cape Town. Some of these challenges include billing inconsistencies and inefficient debt cancellation and indigence policies, high levels of vandalism, health risks due to unexpected supply interruptions and social mistrust and tensions due to the self-disconnection nature of these meters in areas with high numbers of indigent residents (Plato, 2009; Wilson et al., 2012; Phaliso et al., 2010 & Nkomo, 2012).

Economic evaluation of these systems revealed a negative effective surplus for both the WMD and conventional meters of R10 million/year and R59 million/year respectively. The capital payment period for both systems were excessive (> 170 years) confirming that neither option was economically viable.

It is clear that the City of Cape Town considers the reduced consumption and improved in debt management using WMD sufficient benefit to warrant the economic loss suffered. The current policy on meter replacement done in different parts of Cape Town requires that conventional meters are replaced with WMDs based on different activation protocols (Saayman, 2016). However, some areas like Khayelitsha and Dunoon still have significant political and community resistance to these devices and thus the City continues to struggle to have WMDs fully rolled out in these areas (Saayman, 2016).

4.6.3 Prepaid meters installed in iLembe

ILembe District Municipality is located in KwaZulu-Natal along the North Coast (65 km north of Durban) where it covers an area of 1 455 km^2 comprising of four local municipalities (The Water Dialogues, 2008). The four local municipalities of Maphumulo, Ndwedwe, Mandeni and Kwadukuza are 80%, 80%, 60% and 20% rural respectively (Mthembu, 2016). The 2011 census results indicate a population of 607 000 in iLembe with a 0.8%/a population growth rate (Statistics South Africa, 2012).

In October 2013, the Ilembe District Municipality embarked on the roll out of prepaid meters in an effort to combat debt accruement and increase the municipal revenue collection from water sales (iLembe District Municipality, 2015). Utility Systems (USC) was the supplier chosen to implement this project with a metering system comprising of four main components: a water management device, a user interface unit (UIU), vending infrastructure and data collection hardware and software.

A few benefits, such as identification of existing vandalised and faulty meters within the area during the meter audit and replacement phases, short term job creation for municipal youth and updating and reconciliation of the city's meter database were realised (iLembe District Municipality, 2013). However, a multitude of challenges were experienced, including higher failure rates, higher maintenance costs, delays in sanitation billing and increased tampering and vandalism of the meters (Mthembu, 2016).

Therefore, in spite of the municipality's initial optimism in the benefits that prepaid meters would provide, the quantity of problems experienced rendered municipality in need of even more intensive operation and maintenance teams and activities than was the case with conventional meters.

Economic evaluation of the prepaid system revealed that, even though both prepaid and conventional meters would result in deficits, the deficit for prepaid case is 37 times greater (at R31 million/a) than that of the conventional metering system. The prepaid system is therefore a much riskier investment and it is no wonder that that these economic challenges combined with an unwillingness to pay for water services and consequent tampering and/or bypassing of the prepaid meters has impeded further roll out of these meters (Mthembu, 2016).

The municipality now hopes for a competitor on the advanced meter market who will offer a more durable product or require USC to improve their product (Mthembu, 2016).

4.6.4 Prepaid meters installed in the Olievenhoutbosch

Olievenhoutbosch is a township located in the Southern Region of City of Tshwane with an area of about 11.39 km^2 and a population of approximately 71 000 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).

In 2003, Olievenhoutbosch Extensions 36 & 37 were the main recipients of a prepaid metering pilot project with a total of about 6 000 prepaid meters installed to date (Ngobeni, 2016) and it is in these areas that the prepaid meter implementations remain focused to the present day (Ngobeni, 2016). The prepaid meters were installed to assist in debt management and to minimize billing inefficiencies caused in the conventional meter reading process (City of Tshwane, 2012 & Ngobeni, 2016).

The Elster Kent prepaid metering system was chosen for this project. It is a proprietary token-based vending system comprising of a domestic water dispenser, above-ground meter box, tokens, prepaid meter display, accompanying hardware and a software cash flow management systems (Elster Kent, 2014). Some of the benefits of this system included wide scale community acceptance of the system largely because lower fixed rates were charged to consumers on prepaid meters, reduced consumption and reduction in the resources required for meter reading and billing (Ngobeni, 2016).

However, as in the other case study areas, some challenges were also experienced in the prepaid meters maintenance and operation processes. These included higher failure rates that sometimes caused large water losses when meters failed in the open position, unsatisfied consumers due to the inconvenience of using a proprietary vending system with few vending stations and restricted working hours; and only a few skilled municipal staff to maintain and repair these new systems (Ngobeni, 2016).

Economic evaluation of this prepaid AMR system revealed that the prepaid metering scheme had deficit of R43 million/year even if 95% of users are assumed to pay for their consumption. Conversely, replacing all the meters with conventional meters would have resulted in a small surplus if only 68% of users paid for their consumption.

In spite of this and the other challenges with the advanced meters, they remain the preferred option for the consumers in Olievenhoutbosch on whose requests the prepaid meters installations continued in the area (Ngobeni, 2016). This willingness may be largely due to the fact that there has been no increase in water tariffs for consumers on the prepaid system since their first roll-out in 2003, rendering them significantly cheaper than conventional meters with annually adjusted tariffs (Ngobeni, 2016).

As such, currently planned increases of R2 to R3/kl may result in protests from the community (Ngobeni, 2016). New specifications are being developed that require STS-compliance to diversify the available vending options and thus improve the future efficiency in use of these prepaid meters (Ngobeni, 2016).

4.6.5 Automatic meter reading in Epping industrial area

Epping industrial area is one of the major industrial areas in Cape Town with products ranging from fabricated metal work, machines and equipment, wood and other chemical and plastic products (City of Cape Town, 2016). In February 2008, it and two other residential areas of Sunset Beach and N2 Gateway were chosen for a pilot project to implement advanced metering reading (AMR) in Cape Town (De Beer, 2010). The project objective was to test the economic and technical efficacy of using AMR technology to measure water consumption and manage demand, while improving customer service (De Beer, 2010).

A joint venture of Hydrometrix Technologies and Cape Digital Solutions was chosen to implement this pilot and consequently they installed a RealSens AMR system which was based on a two-way, license-free, 868 MHz radio frequency communication system (De Beer, 2010). This system transmits meter reading data via a GSM (GPRS) network to a remote system server where data is inserted automatically into a MySQL database (De Beer, 2010).

A number of benefits were experienced as a result of this pilot study, including the identification of bypassed, faulty and vandalized meters, timely detection of meter tampering, leaks, faulty meters, the ability to carry out on-demand meter readings, consumption monitoring and updating the city's meter database to improve billing efficiency and customer service query handling (De Beer, 2010).

However, throughout both the project implementation, as well as later operation and maintenance processes, a significant number of challenges were experienced. These included incompatibility of existing meters and delays in procurement of new AMR compatible meters, higher failure rates due to multiple components, difficulty in accessing old installations due to poor maintenance and operation practises and need for institutional capacity development as well as labour re-assignment for the prior meter readers. This pilot therefore aided the city better understand the methodology of implementation and the social, environmental, technical and institutional changes required to manage this metering technology.

Economic evaluation of this AMR system showed that the system is not economically feasible and resulted in an effective deficit R2.2 million/year.

Based on this result it is not surprising that the AMR technology is not used anymore and the City has returned to conventional meter reading. The current CoCT approach is to use AMR meters only for industrial and high income consumer areas where it makes economic sense (Saayman, 2016).

4.7 Benefits Gained

A number of benefits were gained by municipalities implementing advanced metering systems. The main benefits reported are as follows:

- An ***update and reconciliation of the municipal water meter database*** with associated improvements in billing efficiency and revenue collection.

- ***Reduction in nonrevenue water*** due to the timely detection of tampering, leaks and improperly functioning water meters.
- ***Reduced consumption*** due to the monitoring and restriction of flow by advanced water meters. Reduced consumption supports water demand management efforts and can help defer water infrastructure augmentation projects.
- During the meter audit and replacement phases, ***bypassed, vandalised, over-sized, old and faulty meters*** were identified and repaired or replaced.
- Prepaid metering ***reduced the resources*** required for meter reading and billing of water supplied.
- ***Short term job creation*** for municipal youth as field workers during meter audits were also availed.
- With AMR technology, ***on-demand meter readings*** and consumption monitoring could be done, thus reducing meter reading costs and easing water balance calculations.
- Where lower fixed rates were charged for consumers on advanced meters, ***community acceptance*** of the system largely resulted in minimal vandalism of infrastructure compared to the conventional meters.

It may be concluded from this list and the case studies that the benefits gained were generally not substantial, could have been gained in other ways and were only experienced in certain cases.

4.8 Challenges Experienced

The case studies showed that, while advanced meters can have benefits, a large number of challenges were also experienced. In this section the challenges that were experienced are discussed under the headings of technical, social and economic challenges.

4.8.1 Technical challenges

This section summarises the main technical challenges experienced in advanced metering projects in South Africa.

High meter failure rates*.* Advanced water meters have multiple components susceptible to failure. As such, it was found that the failure rates of advanced meters were significantly higher than those of the conventional meters, which required higher replacement rates and repair interventions.

Slow response times. A significant lag in the response to some of the advanced meter complaints made by residents is highlighted in a number of studies. This is due to the increased technical failure rates without additional municipal resources to deal with these.

***Valves failing in the open position*.** Automatic shut-off valves malfunctioning and failing in the open position leads to increased non-revenue water.

On-site leakage. In areas with old or poor quality plumbing fittings, a major cause of problems was that on-site losses resulted in premature cut-offs without the full allotment being used by consumers.

***Leak and tamper detection**.* When water meter readers are not visiting meters to take readings, their help in identifying leaks, tampering, vandalism and meter bypassing is also lost, leading to higher non-revenue water.

Consumption monitoring. For prepaid meters where tokens are used to purchase water, it is difficult to monitor individual consumption patterns and thus the accuracy in demand monitoring and water balancing is reduced.

Health & safety risks: A lack of reliable emergency water supplies in cases of on-site fires or medical incidents where meters shut off the water supply due to the available credit running out.

Incompatibility issues. Where the AMR technology was installed, high levels of incompatibility with existing meters were found, resulting in these meters having to be replaced.

***Data transmission problems**.* Drive-by and remote data collection were found to present significant challenges with failed readings, for instance due to cars or other objects obstructing the signal, interference with the radio frequency signals by electrical devices. Meter chambers with metal lids and buildings with excessive metal cladding and/or steel reinforcing were also found to negatively affect the transmission of radio frequency waves.

***Field Installation Complications**.* In the course of some meter replacements, problems like incompatible meter flange types, incompatible meter box lengths with procured meter sizes and defective shut off valves caused delays in the project implementation.

***Accessibility of meter sites**.* In instances where meters had been installed in customer driveways, break up and reinstatement of these pave-ways was required as part of the meter upgrade process. In spite of prior notification of the project, consumers in some cases resisted or refused to grant the contractor access to their properties where meters were located inside them. Other issues like limited working times prescribed by industrial consumers in order to minimise disruption to their operations lengthened the overall project completion time of some metering projects (De Beer, 2010).

4.8.2 Social challenges

This section summarises the main social challenges experienced in advanced metering projects in South Africa.

***Community Perceptions**.* Significant community biases and disparities in implementation of the different metering strategies in different communities may negatively affect community attitudes towards advanced metering technologies. Implementing advanced meters in volatile areas present several risks of failure when a community rejects the project.

Poor Stakeholder Engagement. In some cases insufficient consumer education and stakeholder engagement on planned advanced metering implementations results in resistance, for instance due to confusion on the alignment of the metering technology with Free Basic Water supply (the water dialogues, 2008). In some instances, perceptions were created of water being more expensive due to the installation of advanced meters when higher rates actually resulted from improved meter accuracy.

***Community protests due to high failure rates**.* Frustration of customers with multiple failures of advanced water meters and the consequent interruptions to their supply have in many instances led to vandalism of the meters and sometimes even demands of getting the earlier conventional meters back (Mthembu, 2016). These incidents are further exacerbated by minimal consultation prior to implementation and insufficient discussion between municipalities and consumers on the way forward after the advanced meter installations (Wilson et al., 2012).

Increased Social Tensions. The water restrictions and self-disconnections imposed by advanced meters, both in their proper functioning and malfunctions, have implications for the social environment of consumers. For instance, in case 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 causes embarrassment and strains relations between community members (Phaliso et al., 2010 & Nkomo, 2012).

***Consumer inconvenience**.* Proprietary vending advanced meter options often resulted in the need for consumers to interrupt their schedules to purchase water during the business hours or do without water in cases where it runs out after these times (Ngobeni, 2016).

***Billing Inconsistencies**.* Disparities in billing frequency, high bills for some and none for others are examples of these disparities that occur in municipalities and these not only amplify the worry of residents but also create more mistrust and reluctance to accept advanced meter installations in their homes.

***Health Risks**.* Water supply interruptions caused by malfunctioning advanced meters and slow response times in addressing them have been found to result in consumers adopting water saving strategies that may carry health risks. These include sharing bath water, recycling dish washing water, going to the toilet in outside bushes to avoid flushing (Pereira, 2009 & Kumwenda, 2006). The water-borne diseases and other health complications that may arise from such practices place additional burdens on the municipal health sector.

***Labour Concerns**.* A major labour concern some utilities have to consider is perceptions around job security of meter readers when remote reading or prepaid systems are implemented (De Beer, 2010 & Saayman, 2016).

Litigation. In some instances, the legality of the self-disconnection nature of some advanced meters has been contested in court, requiring municipalities to deal with delays and costs resulting from litigation. Even the legality of the billing records from remote readers may be challenged and need to be verified by regular manual readings.

Dealing with indigent consumers. In instances where indigence grants apply to advanced meter installations, the complex nature of the indigent policy implementation as well as the low level of awareness of residents about these policies sometimes serve to further entrench negative attitudes in the public towards advanced meters.

Consumption Monitoring. In instances where consumers are unable to easily monitor their consumption with advanced meters, increased suspicion and levels of distrust of these devices and the utilities which installed them has resulted (Nkomo, 2012).

Privacy Concerns. Some consumers disagreed with the advanced meters due to the notion of privacy invasion through the continual meter monitoring aspect of AMR systems (De Beer, 2010).

4.8.3 Economic Challenges

Increased Capital Costs. The capital costs of advanced meters are substantially higher than those of conventional meters, imposing an additional cost burden on the municipality (Ngobeni, 2016).

Reduced income from water sales. When advanced water meters are installed they often assist or force consumers to reduce their consumption. Poor consumers may aim to stay within their FBW allowance or even seek alternative water sources (Pereira, 2009). Reduced water sales impact on a municipality's ability to recuperate the increased investment costs of the advanced meters through water and sanitation charges, and affects the financial viability of these projects.

Increased maintenance costs. Due to the increased complexity of advanced meters, more and better trained staff and greater resources are required to maintain the meters, increasing the operation and maintenance costs required at the municipal level (Ngobeni, 2016).

Increased non-revenue water. As mentioned in the technical challenges above, prepaid meter device failure in the open position results in large volumes of water being supplied to the consumer regardless of credit availability (Ngobeni, 2016). As such, significant revenue is lost from this unregistered water (Ngobeni, 2016).

Water Tariff implementation: - Implementation of a rising block tariff to prepaid meters was found to be problematic. This is due to the fact that raising block tariffs operate on monthly consumption, while credit for prepaid meters may be purchased for any period of time.

Affordability: - In areas where water costs make up a significant fraction of household income, payment for water outside of the FBW becomes problematic for many people regardless of the type of meters used. This may lead to increases in meter tampering and illegal connections and high non-payment levels.

Negative effects on home industries. Informal home industries may be affected by water restrictions or costs imposed by advanced meters, limiting the economic resilience of communities.

4.9 Lessons Learned

Community Involvement*:* - Consumer education and awareness is required to improve community attitudes towards advanced meters. Several shortfalls in clarifying the billing, indigence policy and debt rebate or cancellation's application to the advanced meter implementations still exist and to prevent the consequent worry and rejection of these meters in various communities, extensive awareness campaigns should be in place before these devices are rolled out (Wilson et al., 2008).

Stakeholder Engagement*:* - Many of the studies done on WMDs imply that the acceptance to pay for services does exist in many of these areas (Rodina et al., 2016). This implies that a need to extensively engage with local leaders and community members to identify and mitigate social burdens on the especially vulnerable in these areas is necessary to build a sense of ownership for these devices in the community.

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.

Disaster Preparedness*:* - The ability to immediately respond to fire and other medical emergencies is critical to saving of 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 in different areas.

Institutional Capacity*:* - Some advanced meters due to their self-disconnection function place significantly higher demands on the maintenance and operation capacity of the municipality. As such, 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.

Plumbing and Retrofitting*:* - As mentioned in the technical challenges section above, the 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.

***Maintenance and Operations:* -** 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 consumptions (De Beer, 2010)

Compatibility Issues*:* - Incompatibility was one of the major causes of the increased logistical requirements during AMR project implementation. 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).

***Financial Analysis:* -** 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.

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).

Labour Reallocation*:* - Municipalities, particularly those with highly unionised staffing components should ensure that re-assignment or training programmes are in place to avoid job losses to meter readers when remote meter reading systems are in place.

Vending Infrastructure: - Large scale roll out of proprietary based systems is not feasible for some areas since the risk of being locked or tied to a system that may not work is high and the reinvestment into all new advanced system infrastructure not viable. These proprietary systems should therefore only been 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).

Legal Considerations*:* - The legality of using some advanced meter records for example AMR records for billing purposes is restricted to six months after which duration 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.

Notification of Upcoming Works*:* - An advanced metering project, like any other city infrastructure implementation, has numerous affected parties whose usual operations will be impacted by the works to be done. As such, notifications of the upcoming works as well as their planned timeline are critical to minimise the interruptions to scheduled activities as well as customer complaints during contract implementation (De Beer, 2010).

Energy Use and Battery Disposal: - Significant battery replacement needs have been observed for advanced metering technologies. The environmental impact of this battery disposal if advanced meter roll outs are done 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 in during the advanced meter planning phases.

Water Savings: - Due to some advanced meter's ability 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 otherwise lost within the network as well as reduce power requirements during the production stage of these lower volumes (De Beer, 2010).

Multipronged Method*:* - A multi-faceted approach from education of adults and children, water saving device usage and employment of local labour to assist in some of the conservation measures (clearing alien vegetation) should be done concurrently with the advanced meter implementation (Turton et al., 1999).This approach serves to both permeate information on several levels as well as instil a sense of ownership that makes the advanced metering project sustainable.

5. REFERENCES

Akyildiz, I.F., Wang, X., Wang, W. (2005) Wireless mesh networks: a survey, *Computer Networks*, **47** (4)

Blom, A., Cox, P. & Raczka, K. (2010) *Developing a Policy Position on Smart Water Metering.*

Britton, T.C., Stewart, R A. & O'Halloran, K.R. (2013) Smart metering: Enabler for rapid and effective post meter leakage identification and water loss management. *Journal of Cleaner Production*, 54, pp.166-176. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652613003272 [Accessed March 19, 2014].

Choi, M., Ju, S. & Lim, Y. (2008) Design of integrated meter reading system based on power-line communication. *2008 IEEE International Symposium on Power Line Communications and Its Applications*, pp.280-284. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper. htm?arnumber=4510439.

City of Cape Town (2009) Draft Water By-law, 2009.

City of Cape Town, Economic Development Department (2016) Industrial survey

City of Tshwane (2010) City of Tshwane Integrated Development Plan; 3rd Revision for 2009/2010.

City of Tshwane (2012) Motion 24: Investigation into the Possibility of Installation of Main Supply Domestic Pre-Paid Water Meters on Voluntary Basis.

De Beer, I. (2010) AMR Pilot Project: Tender 30S 2007/2008 (Hydrometrix Technologies/Cape Digital Solutions JV) For the City of Cape Town

EEIC and AEIC Committee Members (2011) *Smart Meters and Smart Meter Systems : A Metering Industry Perspective*.

Electa, K.U.L.E. et al. (2008) An evaluation of two-way communication means for advanced metering in Flanders (Belgium).

Elster Kent. (2014) The Elster Kent/Telbit Pre-Paid Domestic Metering System.

Fróes Lima, C.A. & Portillo Navas, J.R. (2012) Smart metering and systems to support a conscious use of water and electricity. *Energy*, 45(1), pp.528-540. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360544212001284 [Accessed March 19, 2014].

Güngör, V.C. et al. (2011) Smart Grid Technologies : Communication Technologies and Standards. , 7(4), pp.529-539.

Haney, A.B., Jamasb, T. & Pollitt, G. (2009) Smart Metering and Electricity Demand : Technology, Economics and International Experience.

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.

ILembe District Municipality (2013) IDM Introduces the New Prepaid Metering System in Mandeni

ILembe District Municipality (2015) Update on WC/WDM Program – Performance in 2014/15 Financial Year and 2015/16 Financial Year Outlook: iLembe District Municipality

Kim, S. et al. (2011) A Secure Smart-Metering Protocol Over Power-Line Communication. *IEEE Transactions on Power Delivery*, 26(4), pp.2370-2379. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5951817.

Lipošüak, Z., Boškoviü, M. (2013) Survey of Smart Metering Communication Technologies. (July), pp.1391-1400.

Malete, L. (2010) Interact Media Defined. *Water meters...what you need to know.*

Malunga, M. (2017) Advanced Water Metering and its Application in Low Income Communities, Masters dissertation, University of Cape Town.

Mburu, M. (2017) Advanced Water Metering and its Application in High Income Communities, Masters dissertation, University of Cape Town.

McDonald, A.D. (2002) Cost Recovery and the Crisis of Service Delivery in South Africa.

Mthembu, N. (2016) Co-operation with the iLembe District Municipality. [Personal Communication, 26th September]. Stanger, iLembe District. (Unpublished)

Ngabirano, L. (2017) Advanced Water Metering Case Studies in South Africa, Masters dissertation, University of Cape Town.

Nkomo, S. WESTERN CAPE. (2012) New water meters a curse, blessing. Retrieved June 8, 2016, from http://www.iol.co.za/news/south-africa/western-cape/new-water-meters-a-curse-blessing-1401045

Ngobeni, P. (2016) Co-operation with Pretoria Municipality. [Personal Communication, 25th October]. Pretoria. (Unpublished)

Park, B.S., Hyun, D.H. & Cho, S.K. (2002) Implementation of AMR system using power line communication. *IEEE/PES Transmission and Distribution Conference and Exhibition*, 1, pp.18-21. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1178253.

Pereira, T. (2009) Household Impacts of Water Management Devices – Summary of Initial Research. 26 November 2009 EMG Water and climate change seminar Presentation.

Phaliso, S. & Naidoo, Y. (2010) West Cape News. Cape Town water meters leave poor high and dry. Retrieved June 8, 2016, from http://westcapenews.com/?p=1729

Plato, D. (2009) Cape Town tells ANC to stop spreading misinformation. Retrieved July 11, 2016, from http://www.politicsweb.co.za/news-and-analysis/cape-town-tells-anc-to-stop-spreading-misinformati

Rodina, L. & Harris, L.M. (2016) Water Services, Lived Citizenship, and Notions of the State in Marginalised Urban Spaces: The Case of Khayelitsha, South Africa. Water Alternatives 9(2): 336-355

Saayman, B. (2016) Co-operation with the City of Cape Town. [Personal Communication, 7th June]. Cape Town. (Unpublished)

Sensus (2012) Taking Measure of Advanced Water Metering Technologies. *White Paper.*

Statistics South Africa (December 2012) Cape Town Profile. Compiled by Strategic Development Information and GIS Department, City of Cape Town 2011 using 2011 Census data supplied by Statistics South Africa.

Stewart, R.A., Willis, R., Giurco, D., Panuwatwanich, K. & Capati, G. (2010) Web-based knowledge management system. *Australian Planner*

TechTerms (2014) Backbone Network. p.2014. Available at: http://www.techterms.com/definition/backbone

The water dialogues (2008) iLembe Case Study Full Report.

Turton, A.R. (1999) Water Demand Management (WDM): A Case Study from South Africa. MEWREW Occasional Paper No. 4. Presented to the Water Issues Study Group, School of Oriental and African Studies (SOAS) on January 18, 1999

U.S. Department of Energy (2014) *The Water-Energy Nexus: Challenges and Opportunity*

Van Zyl, J.E. (2011) *Introduction to Integrated Water Meter Management*, ISBN 978-1-4312-0117-4, Report TT 490/11, Water Research Commission, Pretoria.

Van Zyl, J.E. (2014) *Introduction to Operation and Maintenance of Water Distribution Systems*, ISBN 978-1-4312-0556-1, Report TT 600/14, Water Research Commission, Pretoria.

Wilson, J. & Pereira, T. (2012) Water Demand Management's Shadow Side; Tackling Inequality and Scarcity of Water Provision in Cape Town.

Woods, E. & Strother, N. (2013) Executive Summary : Smart Water Networks Smart Water Meters, Communications Infrastructure, Network Monitoring and Automation Technologies, and Data Management and Analytics : Market Analysis and Forecasts.

APPENDIX A

OVERVIEW OF PRODUCTS AND SUPPLIERS

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

CONTENTS

LIST OF FIGURES

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ABBREVIATIONS

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)
WAN	Wide Area Network
WBKMS	Web-based Knowledge Management system
WCDMA	Wideband code-division multiple-access
WMN	Wireless Mesh Network
WRC	Water Research Commission of South Africa

1. OVERVIEW OF PRODUCTS AND SUPPLIERS

1.1 Introduction

This appendix attempts to group the different advanced meter products in South Africa. It also provides a brief of the main suppliers in the advanced metering industry in South Africa.

As stated in Chapter 1 above, advanced meters are typically coined as conventional meters with additional functionality. These additional functions can be obtained through add-on components to the conventional meters or as already inbuilt facilities within the meter. The conventional meters which are mechanical in nature usually require additional components typically for signal transmission, memory storage and data transmission more clearly explained in Section 2.4 of the Main Report 1. The other conventional meters typically electronic in nature have most of the above inbuilt and thus need fewer components to carry out their multitude of advanced metering functions. These additional components will typically be only communication systems which different components are described in Section 2.5 of the Main Report 1.

Since all advanced meters will typically fall into the above two groups, for the purposes of this report the products available will be categorized according to the primary functions or attributes for which they are installed. In South Africa, four main functions or systems can therefore be considered;

a) Prepaid metering systems
b) Water (demand) management systems
c) Advanced Meter Reading (AMR) Systems
d) Advanced Metering Infrastructure (AMI) Systems

This document is structured in the following way;

Chapter 2: - This describes what a WMD typically is and provides a brief of a few WMD products available in South Africa

Chapter 3: - This describes a typical prepaid water metering system and provides a brief of some prepaid metering products available in South Africa

Chapter 4: - This describes what an AMR system typically is and gives a few examples of the AMR products available in South Africa

Chapter 5: - In this chapter, typical characteristics of AMI systems are provided as well as a few examples of the AMI products available in South Africa

Chapter 6: - A brief of the overall communication and support infrastructure of advanced meters is provided here with some generic examples of these infrastructure products for different suppliers in South Africa.

Chapter 7: - An overview of the different advanced meter suppliers in South Africa and their relevant contact details are provided here.

2. WATER (DEMAND) MANAGEMENT SYSTEMS

These advanced meters are similar to prepaid metering systems because they too require a control valve. However, unlike the prepaid metering system, the valves used here are not necessarily linked to the credits purchased and can therefore be used for other functions. These include varying the amount of flow going through meters in case of drought restrictions or for consumer non-payment in post-paid water management systems. Vending is therefore not critical here as in the prepayment option above and the activation protocol for these devices is typically at the discretion of the utility using them.

Some of these products from suppliers in South Africa include the following;

2.1 Utility Systems Water Management Device

The Water Management Device (WMD) shown in Figure 15 below is an electronic control valve that is capable of controlling the flow of water to a consumer point (Utility Systems Corporation, 2016). This device is linked to a pulse output water meter to function as a tool for water demand management in residential properties and small commercial properties. This device enables 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 STS prepayment water metering

This device also forms a primary component in the Utility Systems prepaid metering system.

Figure 15: Utility Systems Management Device (adapted from Utility Systems Corporation, 2011)

Linking this device to a pulse output meter thereby provides the ability to limit a consumer to a Free Basic Water allocation or a voluntary finite (or negotiated) quantity of water. This is mostly applicable and important in low-income communities where consumers may never be able to afford to pay for water, but have the right to be provided with at least a basic level of service.

Inclusion of this device enables a water metering system to provide meter readings by radio signal or the global system for mobile communications (GSM) to a drive by or walk by collector, or through a fixed network(Utility Systems Corporation, 2016).

Another important claim the manufacturer makes about the WMD is that it can overcome some of the common challenges faced by conventional billing systems such as making water metering easy with illiterate consumers who cannot interpret bills and making water metering possible in areas where posting of bills is difficult due to consumers not having addresses. Lastly, these devices are claimed to lead to reduced revenue collection cycles (Utility Systems Corporation, 2011).

According to the Utility Systems Corporation, these WMDs are SANS certified and STS approved. Furthermore, the manufacturer claims the devices have the following technical specifications (Utility Systems Corporation, 2011):

- compatibility with pulse output water meters
- use of infrared or radio communications
- ability to dispense between 10 to 5000 litres per hour
- can be mounted either horizontally or vertically
- a 10 year battery life.

2.2 Lesira Teq Water Management Devices

A number of Water Management devices are available from Lesira Teq. More detailed product specifications are provided on order. However, the Figures 16 and 17 below depict some of these products.

Figure 16: Different Lesira Teq WMD Products, with AMR abilities

Figure 17: Additional Lesira Teq WMD Products

3. PREPAID METERING SYSTEMS

Prepaid metering systems as can be inferred from the name are typically used to discharge or control water volumes supplied to customers to a pre-purchased amount. In South Africa this pre-purchased amount typically comprises of both the FBW allocation as well as a pre-loaded credit amount. To control the amount of water discharged to the consumer according to the credits purchased, the use of a control valve is necessary for these prepaid meters. This valve is usually electronically controlled and in addition to it, vending software and packages are another key aspect of prepaid metering systems. Both proprietary and open vending systems are available for use in South Africa.

Some of these products from suppliers in South Africa include the following;

3.1 Elster Kent Domestic and Communal Standpipe Prepayment Systems

The Elster Kent Prepaid Metering system is a proprietary token based vending system. This meter consists of the features below 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 of the above feature characteristics per the manufacturer's brochure are provided below;

3.1.1 Domestic Water Dispenser (DWD)

Per the manufacturer's brochure, this is designed to control dispensing of prepaid water for individual households. It consists of three main components, the Electronic Module, Latching Valve and Water Meter with pulse output. It has a multi-tier step tariff system to monitor the monthly consumption and charge the user accordingly. A monthly consumption profile is generated, which in turn is loaded back onto the token and uploaded to the Management System the next time the Consumer purchases credit.

This DWD can be programmed to allow;

- Multi-tier programmable stepped tariff levels.
- Credit Low Early Warning.
- Auto-Debit to deduct a predetermined amount of credit weekly or monthly, as a basic charge for sewerage, refuse removal, etc.

- Daily Limit to control the quantity of water dispensed per day.
- Daily Free Credit allowance.
- Arrears Payment facility to allow customers to pay off their arrears at the Vending Station. Arrear amount paid can be a fixed monthly charge or percentage per transaction.

The main features of this device are as below:

- Consumer lock with own token.
- Automatic Dispenser configuration.
- Monthly Consumer consumption profile.
- Secure Encrypted Tokens.
- Electronic Totalizer with 0,5l resolution.
- LCD Display indicates credit remaining.
- Leak Detection.
- Tamper Detection.
- Up to 7 years battery life.
- Water resistant enclosure (IP 67).
- Emergency water.

3.1.2 Above-ground Meter Box

This Elster Kent meter box‘s typical inlet and outlet connections are Ø20mm BSP female polymer threads. A sliding cover insert allows reading of water meter reading and serial number and for pre-paid options also facilitates reading of the electronic display.

Per the manufacturer’s brochure, this Elster Kent Polymer meter box also contains the following;

- A 15 mm (or 20 mm) Class"C" polymer semi-positive rotary piston water meter.
- A municipal 3-way ballcock positioned before the meter and a consumer 2-way ballcock position downstream of the water meter.
- Sliding couplings to connect the inlet and outlet of the water meter and allow replacement.
- Dual key operated locking mechanism for removal of the cover for maintenance.

A picture showing this meter box is provided in Figure 18 below;

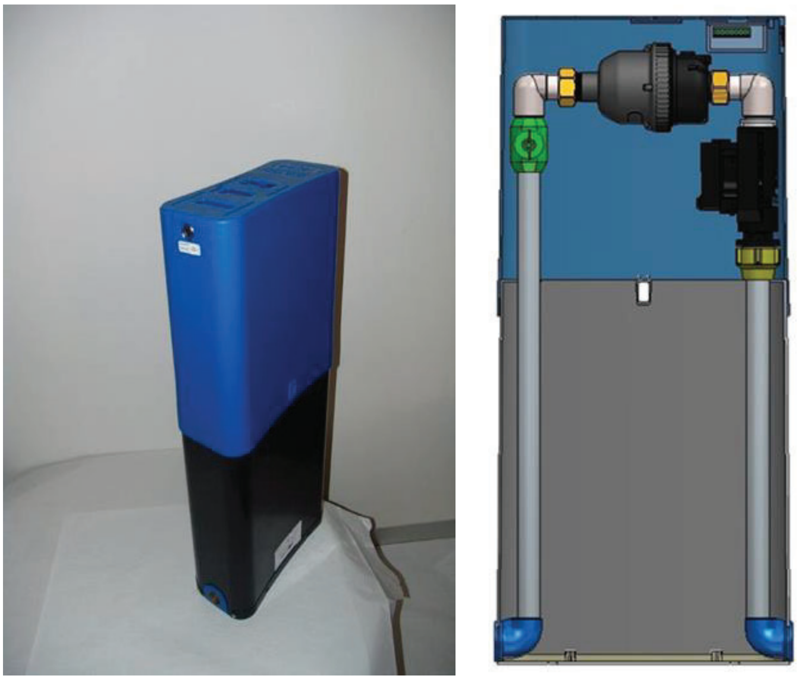

Figure 18: Prepaid Meter Above ground box (Elster Kent, 2014)

3.1.3 Tokens

Three different types of tokens exist for the Elster Kent prepaid metering system per the brochure; Consumer Token, Maintenance Token and Engineering Token. Pictures of these tokens are provided in the figures 19, 20 and 21 below.

Figure 19: Consumer Token (Elster Kent, 2014)

Figure 20: Maintenance Token (Elster Kent, 2014)

Figure 21: Engineering Token (Elster Kent, 2014)

The token benefits claimed by the manufacturer include the following;

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

3.1.4 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. Benefits of these system components according to the manufacturer include;

- " Quality proven components" (Elster Kent, 2014)
- "Ease of installation (no fittings needed)" (Elster Kent, 2014)
- "Pulse output water meter approved to Class C" (Elster Kent, 2014)
- "Approval No. SA842" (Elster Kent, 2014)
- "Electronics water resistant to IP 67" (Elster Kent, 2014)
- "Electronic totaliser with 0.5l resolution" (Elster Kent, 2014)
- "Up to 7 years battery life" (Elster Kent, 2014)

3.1.5 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 vendors 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).

3.1.6 System Requirements (H3)

Specified hardware and software form the system requirements for vending and monitoring of 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, Printer & keyboard,2 open serial or USB ports and Stiffy drive/CD writer"(Elster Kent, 2014). The system software however 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).

3.1.7 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).

3.1.8 Prepaid Meter Display

Before information is recorded and stored by the token and management systems, the meter display is able to indicate some of the following according to the manufacturer 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).

3.2 Utility Systems Prepaid Water Metering System

According to the manufacturer, Utility Systems prepaid water metering system was the first commercially implemented STS approved water metering system in South Africa(Utility Systems Corporation, 2016). This metering system is based on an open architecture approach founded on International Electro technical Commission (IEC) standards and it is not proprietary token based. With this metering system, water service providers and municipalities are not locked into a proprietary system but can purchase their products from any other manufacturer whose products conform to the same specifications. This ensures that suppliers are constantly challenged to provide the best technology, and water service providers do not run the risk of projects failing because suppliers are no longer able to provide goods or services.

The STS approach adopted by Utility Systems allows for multiple vending options through a wide variety of STS compliant vendors. The Utility Systems prepayment water metering system also incorporates a radio frequency and GSM (global system for mobile communications) based data and command transfer system (Utility Systems Corporation, 2016). This enables two-way communication between the water service provider and the meter.

With this Utility Systems prepaid water metering system, a 20-digit numeric token is printed in the form of a receipt. The consumer enters the 20-digit code into their in-home user interface which sends the allocation of water to the WMD located outside. The WMD is then credited with the litres purchased.

According to the manufacturer, Utility Systems prepaid water system is class C approved complying with STS and both SANS 1529-1 and SANS 1529-9. Further benefits associated with using utility systems prepaid metering systems are as follows:

- Offers vending through a number of third-party vendors such as EasyPay and Blue Label
- A number of options for the consumer to acquire credit for the meter, should the utility implement them
- The ability to purchase tokens online, by SMS and at an ATM
- The STS protocols were developed for pre-payment electricity and are now an IEC standard (IEC 62055-41, IEC 62055-51)

This Utility Systems prepaid metering system comprises of a Water Management Device (WMD) and User Interface Unit (UIU) to function as a basic prepayment system and more add-ons such as FDC, MDC, FST for additional functionalities as outlined in the respective subsection of each component below.

3.2.1 Water Management Device (WMD)

Refer to Utility System’s Water Management Device in section 2.1 above for the detailed WMD product features and specifications.

3.2.2 User Interface Unit (UIU)

The UIU is a remote display unit mounted inside the home which interacts with the WMD, Bulk WMD and Aquadata, which are generally installed in a meter box outside a consumer's home (Utility Systems Corporation, 2016). According to the manufacturer, this unit has a 10-year lifespan and is very user friendly. It is a lightweight, wall-mounted device with an easy-to-read digital display, a touch keypad, and can perform the following:

- Remotely display the meter reading as reflected by the WMD
- Display remaining allocation available to the consumer
- Allow for top-up/credit entry for pre-payment applications
- Provide various alarms for the consumer, such as leak indication and low credit
- Display the WMD serial number required for top-up
- Indicate battery life
- Remotely open/close the valve
- Indicate valve status

Figure 22 below depicts the Utility Systems UIU described above.

Figure 22: Utility Systems User Interface Unit (UIU)

This component shows the meter reading as reflected by the WMD which is located outside the premises. With the information displayed on the UIU, the municipality can generate and provide standard reports which can be upgraded and available immediately online. These standard reports include:

- Transactions by consumer vending point
- Sales summaries by day and month
- Monthly management summary
- Exception reports on low or non-existent purchasing patterns which could be an indication of theft.

3.2.3 Fixed Data Collector (FDC)

This device (shown in Figure 23 below) is used for the same purpose as the MDC, but in a fixed network application. The Utility Systems FDC is a robust, weather-proof unit that can be wall or pole mounted. The FDC is supplied in a variety of formats, two options being solar panel powered or mains powered. The FDC collects data from units in the field (WMD, Aquadata, Bulk WMD) via RF communication and automatically sends the data to the web via GSM communication. The FDC can be configured to send data as often as required and can store several thousand records.

Figure 23: Fixed Data Collector (FDC) (adapted from Utility Systems Corporation, 2011)

3.2.4 Field Service Terminal (FST)

The Utility Systems FST is a software package designed for use with the WMD, Aquadata and Bulk WMD electronic water controllers (Utility Systems Corporation, 2016). The application is available as a pre-installed package on a MS Windows platform notebook, together with other relevant Utility Systems software. The software provides for the configuration and testing of the Utility Systems' WMD electronic water-dispensing valves, and the Aquadata AMR unit as well as the analysis of data retrieved from these devices (Utility Systems Corporation, 2016).

The FST can be connected to the WMD either by means of an infra-red probe (IRP) or a radio frequency probe (RFP). When connected to the RFP, communication from the RFP to the WMD is via a radio frequency (RF) link. When connected to the MDC, communications from the MDC to the WMD is via a radio (RF) link, offering AMR/AMC/AMI capabilities.

Ancillary equipment to be used with the FST includes (Utility Systems Corporation,2016):

- IR Probe
- RF Probe
- USB Cable

An example of the FST ancillary equipment and applications is shown in Figure 24 below.

Figure 24: Field Service Terminal (FST) (adapted from Utility Systems Corporation, 2011)

The Utility Systems suite of products caters for both small and large scale projects. The FST enables the meter reader to perform electronic infield meter testing, interrogation and configuration.

According to the manufacturer, the Utility Systems FST has the following features:

- Configurable open duration within 24 hour period
- Configurable end of month date (AMR)
- In-field configuration, testing and interrogation of the USC product
- Display of current management settings of the USC product
- Setting the management parameters of the USC product
- Testing valve operation, flow measurement and communication operations

- Graphic display of consumption Profiles, alarms including leaks and tamper flags, end of month reading, duty cycle, silent time, message format
- Downloading of current and historic data from the USC product

The FST software allows for single-button selection of multiple pre-programmed sets of management settings which include:

- Configurable daily activation time
- Multiple/Double activation times
- Tamper Feature

Using this Utility Systems FST, data can be imported from up to 50 000 WMDs or Aquadata, and stored in a secure format. The data can be uploaded on a computer and profiles generated. The profiles are graphs showing water consumption against time displayed for each user in hourly, daily or monthly resolution.

According to the manufacturer's specifications, in order to successfully install and run the Software Suite, the following computer requirements must be met:

- CPU minimum speed of 600 MHz
- 0 MB of free disk space, either hard drive or solid state drive
- A minimum of 128 MB of RAM
- 32 Bit operating system
- Windows XP SP2 or Windows 7 (Ultimate or Business)
- Minimum screen resolution 800 x 480
- 2 x USB port
- Users must have Administration rights on the PC
- The FST enables the meter reader to perform electronic infield meter testing, interrogation and configuration.

3.3 Lesira Teq Prepaid Metering Products

A number of prepaid metering products are available from Lesira Teq. More detailed product specifications are provided on order. However, the Figures 25 and 26 below depict some of these products.

Figure 25: Different Lesira Teq Prepaid Metering Products

The above products work in conjunction with different support infrastructure, some of which is shown in Figure 12 below. Details of this support infrastructure are provided on order by the manufacturer.

Figure 26: Communication and Support Infrastructure for Lesira Teq Prepaid Meters

4. ADVANCED METER READING SYSTEMS

AMR systems for the purposes of this report and as defined in Section 2.4.5 above can be defined as advanced meters with mobile data transmission systems which are one-way in nature. These advanced meters require mobile units which can be either handheld walk-by or computer drive-by units to pick up and save meter readings. The utility then downloads said information for billing or other purposes.

Some of these products from suppliers in South Africa include the following;

4.1 Elster Kent E-Log Meter

The Emeris Log meter, also known as E-Log meter, allows for precise monitoring of the 24-hour consumption measured by a water meter by means of an E-Log data logger and a data collection and visualization software solution. This meter is easy to install and involves no costly IT projects.

The E-Log meter offers an array of options for effective management, control and analysis. The user can easily access metering data and events, from leak warnings or anomalous consumption through to analysis of the correct meter sizing. A picture of this meter is shown in Figure 27 below.

Figure 27: E-Log meter (adapted from Elster Metering)

The E-Log device is connected to the pulse output of the meter. The E-Log reads the meter periodically and logs the reading values in an internal memory. Periodically the E-Log transmits the logged data to a central data centre. The user can then access all the data through a dedicated, secure web portal. Figure 28 below demonstrates the operation of an E-log meter. The E-Log can also provide daily maximum and minimum flows as well as alerts such as potential leaks, bursts and low battery level.

Figure 28: Illustration of how an E-Log meter works (adapted from Elster Metering)

The features and specifications of an E-log meter are as follows:

- Integrated GPRS modem, 900/1800/1900 MHz
- Lithium battery, 14.5 Ah
- Battery life claimed to be longer than 12 years with monthly transmission (with daily transmission longer than 5 years)
- Built-in e-SIM card, provider-independent

4.2 Sensus 120 Meter

The 120 is a dry dial single-jet water meter. The 120 is pre-equipped with AMR capabilities through pulse or radio interface.

As it is a dry dial meter, the 120 meter uses magnetic transmission from the measuring chamber to the dry dial, resulting in high resistance to water impurities. The 120 meter has been designed to be shielded from magnetic manipulation and mechanical forces.

Other features of the 120 meter are as follows:

- A non-return valve to prevent the water travelling back through the meter
- High resistance to water impurities
- Insensitive to upstream disruptive elements
- Tamper proof
- 355o swivelling register for easy readability
- A High-Resolution Interface (HRI) module which is a Sensus product that acts as a universal sensor and is compatible with most Sensus meters. As this is a supporting infrastructure, details of the HRI are elaborated further on in the report.

The 120 meter is compliant with the EEC directives 75/33/EEC and 79/830/EEC, and with 2004/22/EC (MID), EN 14154:2007, OIML R49:2006 and ISO 4064:2014 specifications. The metrological class for the 120 meter is R80 and R40 for the horizontal and vertical installation respectively. As indicated earlier, Sensus products are stated to meet the South African ISO 9001 certification. Figure 29 below shows the Sensus 120 meter described above.

Figure 29: Sensus 120 water meter (adapted from Sensus)

The 120 EEC is available in 15 mm and 20 mm sizes whereas the 120 MID is available in 15 mm.

4.3 Sensus 120C meter

The 120C meter is a dry dial single-jet velocity meter with a 355º swivelling register. As it is a dry dial meters, the 120C uses magnetic transmission to turn the register and record the flow rate through the meter.

The 120C has numerous features and capabilities. These are as follows:

- Can be integrated with a HRI interface module for AMR capabilities through pulse and radio interface
- Tamper proof
- Resistant against aggressive water and high forces
- Environmentally friendly
- Non-return valve

The 120C conforms to the EEC 75/33/EEC and 79/830/EEC directive, and to 2004/22/EC (MID), EN 14154, OIML R49 and ISO 4064 specifications. The metrological classes for the 120C are R80 and R40 for horizontal and vertical installation respectively.

The 120C is available in 15 mm size. Figure 30 below shows the Sensus 120C meter described above. A table of the 120C meter's properties can also be obtained from the manufacturer's brochure.

Figure 30: Sensus 120C water meter (adapted from Sensus)

4.4 Kamstrup FlowIQ 2100 Meter (H2)

The Flow IQ21000 meter is an ultrasonic flow meter used for measurement of cold water consumption in households, multi-unit buildings and industry (Kamstrup, 2016). Being an ultrasonic meter, flow IQ2100 has no moving parts making it relatively less resistant to wear and impurities. Figure 31 below depicts this Flow IQ2100 meter.

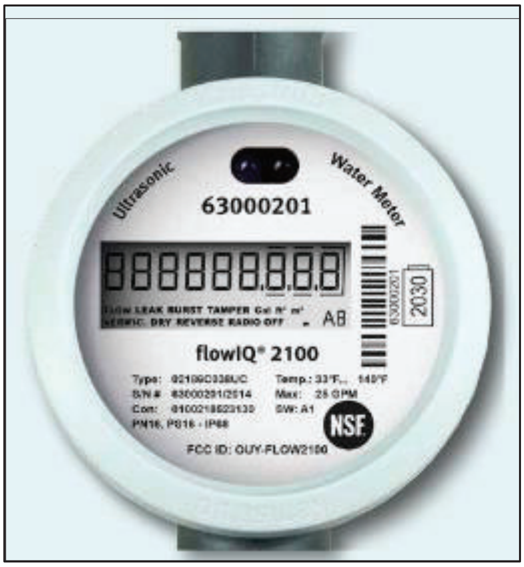

Figure 31: Flow IQ2100 meter (adapted from Kamstrup)

The meter can be installed in either horizontal or vertical positions. The consumption data is obtained by directly reading the meter or can be remotely read by RF which is built into the meter.

According to the manufacturer, the environmental report on Carbon Footprint indicate the meter to have a low environmental impact because of the meter's high reusability and absence of lead in meter housing and components. Another important advantage of FlowIQ2100 is leak, burst, and tamper detection. This is a significant driver to minimize the wastage of water – a benefit for the environment and the economy. Table 1 below provides the FlowIQ2100 specifications.

Table 1: FlowIQ2100 Specifications

Description	Symbol	Units	Specifications			
Metrological Properties						
Meter Sizes	DN	mm	15	20	25	32
Meter Class	Q_3/Q_1 or other		R160	R160	R160	R160
Minimum Flow Rate	Q_1	l/h	2.7	2.7	2.7	6
Transitional Flow Rate	Q_2	1/h	34	34	34	
Permanent Flow Rate	Q_3	m^3/h	5.6	5.6	5.6	
Overload Flow Rate	Q_4	m^3/h	Not Specified	Not Specified	Not Specified	Not Specified
Meter Features and Capabilities						
Built-in valve			No	No	No	No
Battery			No	No	No	No
SABS compliant			Not Specified	Not Specified	Not Specified	Not Specified
Other standards meter complies with			ISO 4064	ISO 4064	ISO 4064	ISO 4064
Any Alarm features?			No	No	No	No
Meter Functionality						
Is it capable of remote communication?			Add-on	Add-on	Add-on	Add-on
Which communication technology?			Pulse transmitter or Integrated radio technology	Pulse transmitter or Integrated radio technology	Pulse transmitter or Integrated radio technology	Pulse transmitter or Integrated radio technology
Is it uni-/bi-directional communication			AMR/AMI Bi-directional communication	AMR/AMI Bi-directional communication	AMR/AMI Bi-directional communication	AMR/AMI Bi-directional communication
STS compliance			Not specified	Not specified	Not specified	Not specified

4.5 Utility Systems: - Aquadata

The Aquadata (shown in Figure 32 below) is a radio module that acts as an AMR enabler for pulse output meters (Utility Systems Corporation, 2016). It is an intelligent device that enables utilities to remotely read and monitor the metered consumption of water. The automatic reading capability reduces labour costs, improves meter reading accuracy, and facilitates the provision of hourly water consumption data, and leak and tamper detection. It also supports a time synchronised water balancing-function (Utility Systems Corporation, 2016).

The Aquadata is compatible with a range of pulse output water meters, and provides meter readings via a radio signal to either a walk or drive by, and/or a fixed or mobile data collector. It connects to the water meter via a probe and can be easily installed or retrofitted above ground, indoors or outdoors.

Figure 32: Aquadata (adapted from Utility Systems Corporation, 2011)

According to the manufacturer, the introduction and implementation of Aquadata technology can overcome some of the common challenges faced by conventional billing systems, such as:

- Inaccurate meter readings and billing
- The inability to do accurate water balances and so account for all water consumption
- The lag between consumption and revenue collection
- Estimates of water usage
- Tamper and leak detection

Leak detection makes it possible to identify leaks at the consumer's premises, helping curb water wastage. Tamper detection identifies any attempt to interfere with the meter's recording of consumption. This, together with accurate water balancing, helps reduce the potential for water loss through theft.

According to the manufacturer, Aquadata has the following features:

- Automatic meter readings by radio link
- Supports 90 days' consumption logging
- Stores up to 12 month-end consumption totals
- No in-field servicing required, interrogation via a field service terminal is, however, possible

5. ADVANCED METER INFRASTRUCTURE SYSTEMS

AMI systems, similarly defined in Section 2.4.5 above are advanced meters which differ from the AMR systems above by having fixed communication systems through which bi-directional transmissions can be sent or received from the field meters usually to a remote location. These types of metering systems are typically accompanied by software packages or suites which offer varied data management functions and options like pressure management, leak alarms, valve control and several others.

It is important to note that even as the advanced metering systems above have been categorized according to their primary functions, suppliers do offer products with a combination of the above functions either as in-built or as add on components.

Some of these products from suppliers in South Africa include the following;

5.1 Sensus iPERL meter

The iPERL is a solid-state water meter with remnant magnetic field technology to measure the flow rate through the meter. The iPERL has both AMI and AMR communication capabilities. The iPERL was designed mainly to record information regularly and relay this information efficiently with special considerations for any discrepancies such as water leaks.

Features of the iPERL are as follows:

- Tamper proof and fraud resistant
- Has alarm functionality such as leak detection, tampering or abnormal usage reporting
- Capable of data capturing, and has an internal memory with a claimed capacity of 2880 data points which is equivalent of over one month of 15 minute resolution data
- Has bi-direction communication capability
- Stated to be highly accurate
- Has a battery with a claimed life span of 15 years.

The iPERL complies with the EN 14154, OIML R49 and in South Africa with ISO 9001 specifications. The meter class for the iPERL is R800 and is available in sizes ranging from 15 mm to 40 mm. Figure 33 below shows the Sensus iPERL meter.

Figure 33: Sensus iPERL meter (adopted from Sensus)

5.2 Aquiba A200 Meter (H2)

5.2.1 Overview

The Aquiba A200 DN20 is an AMI, mag-flow water meter designed for residential use. The A200 consists of a highly accurate sensor, powerful processor, bi-directional ZigBee communication capabilities and a data archive. Figure 34 below shows the Aquiba A200.

Figure 34: Aquiba A200 (adapted from Aquiba)

5.2.2 Operations and functionality

Residential sensor technology accurately measures flow at all flow rates relevant to revenue collection. The processor stores time-stamped readings in the archive and can run additional applications in real time to convert high volumes of data into discrete items of information. Data can be extracted via the optical port and certain information can be retrieved by radio (as supported by bi-directional ZigBee SEP 1.0).

The A200's secure optical port allows connection of an optical reader programmer (ORP) to allow for easy programming and data retrieval. The ORP simply clips onto the top of the meter and is held in place by magnets.

Data is transferred via USB cable to a PC running Aquiba Meter Explorer software. This software enables installation, configuration, commissioning and maintenance of the A200. It also performs basic data visualization and allows consumption data to be exported to third party applications for additional analysis.

5.2.3 Features and specifications

The features and specifications of the Aquiba A200 meter are as follows:

- Fully static mag-flow technology
- Accurate at all flow rates, over full service life
- No moving parts – no wear or jamming
- Eliminates under-registration issue
- High resolution, time-stamped data securely stored in data archive
- Low lifetime cost and low environmental impact
- Battery life claimed to be 15 years
- Factory refurbishable for extended operation
- Supports network and household leakage detection
- Secure ZigBee SEP 1.0 radio
- Field upgradeable firmware
- Generous processor and memory capacity for additional applications

5.3 Landis+Gyr Gridstream RF Water Module Meter

5.3.1 Overview

The Gridstream RF Water Module is a two-way, AMI device that enables near real-time access to critical water assets. The module logs water consumption values for each interval and transmits the data across the network four times per day. The Gridstream RF Water Module is a component that is connected to a conventional meter to make it an advanced meter.

Landis+Gyr has developed three different types of RF Water Modules that give users a variety of means to connect the module to existing water meters as well as different means of sending information. These are as follows:

- Gridstream RF interpreter
- Gridstream RF wall mount
- Gridstream RF pit

5.3.2 Gridstream RF Interpreter

The Gridstream RF Interpreter is easily mounted without disrupting the existing meter and deployed over the network. There are no wires and the radio and the encoder are sealed within a single unit for added security and durability. Figure 35 below shows an example of an RF Interpreter:

Figure 35: An example of an RF Interpreter (adapted from Landis+Gyr)

5.3.3 Gridstream RF Water Wall Mount

The wall module quickly and easily connects to most existing three-wire water meter encoders and is deployed over the Gridstream network. Figure 36 below shows an example of an RF wall mount:

Figure 36: An example of an RF Wall Mount (adapted from Landis+Gyr)

5.3.4 Gridstream RF Pit

The Gridstream RF pit module can be easily installed and directly connected to an existing three-wire encoder and deployed over the Gridstream network. Figure 37 below shows an example of an RF pit module:

Figure 37: An example of an RF Pit Module (adapted from Landis+Gyr)

5.3.5 Features and specifications

- Leverages full potential and scalability of Gridstream AMI network
- No costly infrastructure add-ons required
- Supports advanced capabilities such as leak detection, reverse flow, tampering and theft
- Easily connects to an existing encoder without service interruption
- Plug-and-play activation keeps deployment, on schedule
- Interoperable for future advancements in water measurement
- Two 3.6 volt AA Thionyl Chloride Lithium batteries with advanced power life management design
- Data is transmitted every 6 hours
- Each transmission includes register read and last 24 hours of 15-minute interval data
- Battery life is claimed to be 20 years.

In general, the key function required determines the complexity of each of the above systems with suppliers offering a range of products in each of the above categories.

6. COMMUNICATION AND SUPPORT INFRASTRUCTURE

As mentioned in Chapter 1, communication and information infrastructure in most cases is what is used to transform otherwise conventional meters into advanced meters. A few examples of this infrastructure for the different WMD, Prepaid , AMR and AMI systems has therefore already been provided in the some of the product descriptions above. This chapter will therefore focus on the generic communication products/systems developed by different suppliers which are intended for use on any of their meters regardless of type above. These generic systems can be adapted to the meters at varying degrees in order to achieve one or all of the four functionalities of the different product types above. Report 1 explains the typical communication infrastructure, i.e. transmitters, receivers, gateways and management systems. Examples of these types of products for different suppliers are therefore provided below;

6.1 Elster Kent Waveflow & Falcon Communication Module

6.1.1 Wave flow

Wave flow is an advanced battery-powered wireless transceiver and data logger for demanding advanced metering applications. It is a flexible platform that can be integrated into new water meter designs or connected with existing meters as an aftermarket add-on. Figure 38 below shows this Wave flow device.

Figure 38: An illustration of Elster's Wave flow data logger and transmitter (adapted by Elster Metering)

The Wave flow provides remote access to relevant meter information as it logs meter data periodically and transmits data either automatically or on demand. This allows utilities to speed up data collection and billing cycles. Wave flow integrates with Elster's Wavenis wireless technology for large scale automated metering networks as well as walk by collection. Wave flow can also be integrated into gas and electrical meters.

- The Wave flow's features and specifications are as follows:
- Radio module bi-directional communication
- Inputs for up to 4 pulse meters
- IP68 protection class
- Battery operated with a stated service life span of 10 years
- Designed for walk-by and advanced metering fixed networks
- Programmable data logging with storage capacity of up to 2100 readings
- Capable of data transfer to and from remote locations.

6.1.2 Falcon Communication Module

The Falcon Communication Module is a robust solid state pulser that forms the base of an AMR/AMI system. This pulser allows for bi-directional communication and can be installed to any Elster meter with a communication interface.

However, as this module acts only as a transmitter and receiver, it needs to be installed in conjunction with a data logger. As such, Elster Metering recommends use of any data logger or their TRC600 radios as they can be used to monitor the water network system. Figure 39 below shows the Falcon communication module.

Figure 39: Elster's Falcon Communication Module (adapted by Elster Metering)

The Falcon Communication Module is available in 2 types, the PR6 and PR7. The module complies with the EN 13757 standards.

The features of the Falcon Communication Module are as follows:

- The PR6 and PR7 are bi-directional pulse transmitters for use with data loggers or Elster's TRC600 radios allowing monitoring of the water network system
- When used in a Fixed Network system, backflow alarms will be generated automatically
- Fully self-contained PR6 and PR7 pulsers that do not need external power and are compatible with all major data loggers
- For residential meters, the battery life is designed to last for 12 to 14 years at normal use

- PR6 and PR7 pulsers are both easy and quick to fit to pre-equipped Elster water meters. A simple push fit system is used with residential meters. Both knurled thumbscrews and screws are used for bulk meters
- Tamper evident labels can also be used to monitor attempts to remove the pulse units
- The PR6 and PR7 pulsers are self-contained and do not require external power
- Both PR6 and PR7 have forward and backflow detections
- Robust IP68 design.

6.2 Reonet RealSens Communication Technology System (H2)

Per the manufacturer's brochure, RealSens is a robust metering, communication and control system turning utility distribution infrastructure into "smart grids" by integration of remote meter data with conventional back-office systems via a cloud-based database. This is achieved through its high-tech, low-cost data acquisition and secure communication capabilities which is based on a bi-directional, license-free, ultra-low-power, radio frequency mesh network, integrated with GSM, Fiber Optic or WI-FI networks.

Under certain circumstances it is necessary to commence a metering automation process with a walk-by drive-by (WBDB) system, for example such as when meters are not simultaneously available in a dense and contiguous geographical area, for connection to a remote metering system. For situations like this, RealSens is available as a super-efficient WBDB system, in which the need for complicated and expensive route planning software is not required. This WBDB mode of RealSens can easily be transformed into a fixed mesh network system when the density of meters connected to the RealSens system justifies it.

Per the manufacturer's brochure, the RealSens System components are as below;

The **RealSens Sync software**, which was developed as an aid in meter auditing processes as well as in the WBDB implementation of RealSens to collect meter-reading data. This software can be installed on most Windows mobile handheld devices.

RealSens Meter Interface Units (**RS-MIU**) connect by data cable to the meter output interface. Each MIU can accommodate up to four channels, allowing four meters to be connected to one MIU. RS-MIUs are housed in half-spherical enclosures that are rugged and waterproof to IP68 standard.

The RealSens Repeaters (**RS-Repeater**) operate as range extenders and are designed so that they can be strapped to lampposts or fixed to flat vertical walls. The long battery life and rugged construction makes the RS-Repeater a maintenance-free installation and its small profile renders it unobtrusive.

The RealSens GSM Gateway (**RS-Gateway**) acts as a router between the RF mesh network and the GSM network. The Gateway unit can "wake up" the selected MIU and communication path components, from which data can be requested on demand. The RS-Gateway is housed in a rugged outdoors enclosure. It requires an external power source, which could include solar power, and it is optionally equipped with a standby battery that will operate the unit independently in case of mains power failure.

RealSens Manager (**RS-Manager**) is a powerful software suite that remotely configures and manages the entire radio mesh network. RS-Manager continually monitors the RealSens™ system behaviour and it automatically reports any system problems, such as signal strength, "no reads" at scheduled times, tampering, leaks on consumer properties, or any other anomalous behaviour. RS-Manager automatically manages downloads at pre-set intervals.

The RealSens GSM Gateway transfers data to a cloud-based database (**RS-DB**) by establishing a direct connection to the server through an access point name (APN) via GSM/GPRS. Once connection is established to our cloud server, data is transferred using the RealSens™ server, which will then store each reading in the database. This data can be either exported or imported to other systems through various file formats, e.g. Excel, CSV, ASCII, Text or direct database access. These systems can be meter data management systems (MDMSs), billing systems, reporting systems, geographical views in Google Earth™, network management systems, geographic information systems (GISs) in Google Earth™, maintenance systems or consumer information systems (CISs).

Per the manufacturer, the above general system specifications are as below;

- Designed for reliability, simplified low-cost installation, ultra-low power usage and robustness
- Remote configuration and system operation from friendly user-interfaces and cloud-based database server
- Ultra-low power and "long-range" wireless technology with significant power advantages over other systems
- Real-time bi-directional communication capability, allowing for the control of endpoint devices
- Easy network/device setup using GIS technologies that can be carried out remotely
- RealSens does not restrict the number of endpoints that can be connected within a mesh network
- Long battery life with local life monitoring (>10 years – normal operation)
- Narrow band RF communications
- Operates in 868 MHz ISM frequency (major worldwide license free frequency)
- The mesh network can accommodate up to 5 repeater hops
- ETS300-220, FCC part 15 compliance (certification ready)
- RF power output 32 mW, +15 dBm for individual devices
- Programmable output power from 0 dBm to +15 dBm (32 mW) (5 dBm steps)
- Automatic Frequency Error Correction
- Sensitivity control can be manually set
- Adaptive Frequency Hopping

- Continuous phase 2-level FSK modulation using Frequency Hopping Spread Spectrum
- (FHSS) techniques
- Receiver standby algorithms to reduce power consumption
- Various security algorithms available on request
- Quality of service management
- Fast RSSI detection (Received Signal Strength Indicator) provides signal strength for both directions of data communication at each hop
- Fully managed data packet routing algorithms allowing identification of failed segments of backbone, etc.
- Frequency switching at various positions on the RF Mesh network to avoid unnecessary waking up of unneeded devices, thus ensuring longer battery life
- Large number of deployment/installation tools such as automatic network configuration, based on GIS and live signal strength analysis

The RealSens system architecture is depicted in Figure 40 below;

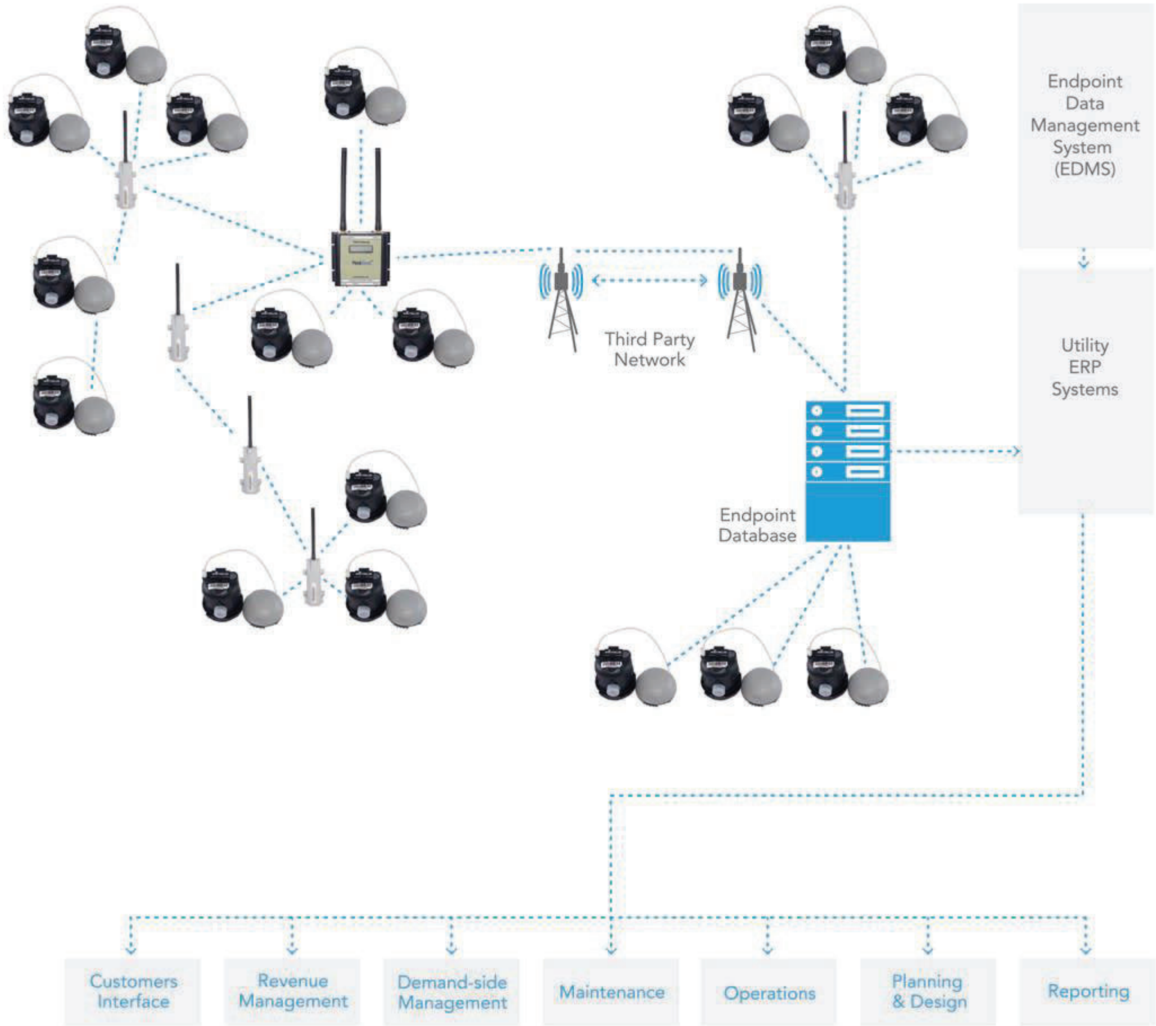

Figure 40: RealSens System Architecture

6.3 Itron 100W ERT

The 100W ERT helps utilities and municipalities find small leaks before they become costly for the utility (Itron, 2016). This device (shown in Figure 42 below) enables advanced capabilities such as two-way communication to the meter and time synchronized interval meter data. This device can be deployed in an AMI or AMR.

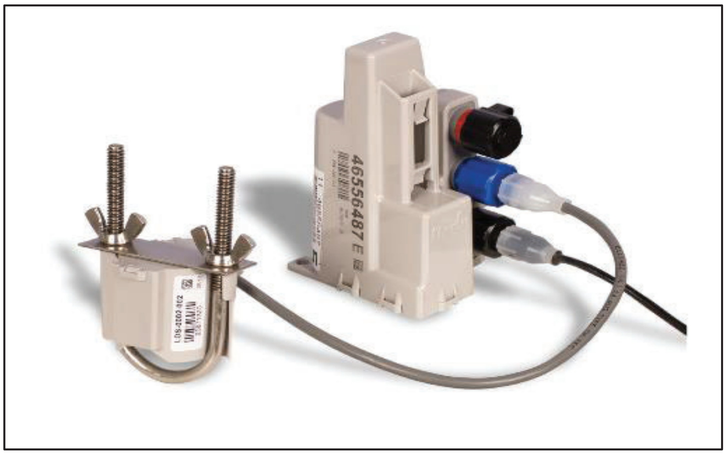

Figure 41: **100+ Leak Sensor (adapted from Itron)**

The 100W ERT module connects to a Leak Sensor via an in-line connector as shown in the figure above. This 100W ERT can be used as a stand-alone leak detection system unattached to a water meter in either AMI fixed network, or AMR. The 100W ERT module collects and stores the data from the Leak Sensor. The Leak Sensor sampling the pipe conditions every 22.5 minutes or 64 times daily enables the 100W ERT to store eight quietest analyses daily and has a capacity to hold 20 days' worth of data.

This device is compatible with water meters from Itron and other water meters enabling water utilities to consolidate all water meters under a single reading system. This device is powered by advanced lithium battery technology. The device is designed to have a battery life of 20 years in both fixed network and mobile modes.

6.4 Itron AnyQuest Handheld

AnyQuest is a mobile data collection solution comprised of multiple components working together to create and collect enhanced data (Refer to Figure 42 below). It includes high performance radio modules, rugged handheld terminals, user-friendly mobile reading and pc software to transfer data from and to the central systems (Itron, 2016).

AnyQuest Handheld is the handheld and advanced Itron solution for mobile meters. AnyQuest Mobile meter reading software offers analysis and control of enhanced reading data (Itron, 2016).

Figure 42: AnyQuest Handheld (adapted from Itron)

AnyQuest Handheld includes Itron AnyQuest mobile meter reading software to optimise radio reading. Inclusion of the software enables the following:

- Uploading/Downloading routes from/to the host computer
- Programming of all Itron radio meter modules
- Fast group reading via polling mode
- Graphical display of all enhanced data such as fixed date readings, leakage & backflow data, alarms, consumption profile

Inclusion of integrated radio interface assures relatively long reading distance since the antenna is always in a defined and optimal position during the reading process. It requires no additional wires, batteries or communication protocols (BlueTooth). An external magnetic car antenna can be connected in order to increase the reading distance and comfort.

According to the manufacturer, the AnyQuest Handheld has a large memory capacity to store reading data of more than 4000 radio meters. Furthermore the software and reading data can be stored in a flash memory avoiding the risk of lost reading data. The battery charging can be done by cradle, direct charger, cigarette lighter or a car mount.

7. ADVANCED METERING SUPPLIERS IN SOUTH AFRICA

The water metering manufacturers in South Africa have different product ranges and services in both the conventional and advanced metering categories which are available on the market. Some of these are mentioned above; however, detailed descriptions of these products are available through the product brochures and manufacturer websites. In South Africa, some of the water meter manufacturers worth mentioning include:

- Elster Kent
- Aqua Loc
- Sensus
- Reonet
- Lesira Teq
- Kamstrup
- Itron
- Utility systems

The product websites at which their various advanced and conventional metering options can be viewed are listed below.

7.1.1 Elster Kent

https://www.elstermetering.com/en/products-and-solutions

Tel: +27 (0) 11 470 4942

E-Mail: Leonardus.Basson@Honeywell.com

7.1.2 Aqua Loc

http://www.aqualoc1.co.za/?q=node/2

Tel No: l+27 11 474 1240

Email: sales@aqualoc.co.za

7.1.3 Sensus

https://sensus.com/products/

Tel: +27 (0) 11 466-1680

Email: info.za@sensus.com

7.1.4 Reonet

http://www.reonet.co.za/content/page/our-technologies

Tel: 0861REONET/0861736638/011 4670705 (Gauteng)

Email: info@reonet.co.za

7.1.5 Lesira Teq

http://www.lesira.co.za/products.html

Tel: +27(0) 12 440 9885

Email: info@lesira.co.za

7.1.6 Kamstrup

https://www.kamstrup.com/en-us/products-and-solutions/water-meters

Tel: +27 87 357 8659

7.1.7 Itron

https://www.itron.com/na/technology/product-services-catalog

7.1.8 Utility systems

http://utility-systems.co.za/

Tel: +27 (0) 31 700 4143

Email: enquiries@utility-systems.co.za

Details on some of the advanced meter products from the above suppliers are provided in the relevant sections above. Several other product ranges not mentioned in the previous chapters are currently available on the market produced by the different water metering manufacturers above. Other supporting infrastructure and software systems required to set up advanced water metering systems are also available.

8. REFERENCES

Elster Kent. (2014) Product Brochures.

Itron, 2016 (https://www.itron.com/na/about/Pages/default.aspx). Last seen 16/04/2016

Itron, 2016 (https://www.itron.com/aunz/PublishedContent/F11142-Flodis_MID_pb_EN_10-10.pdf). Last seen 16/04/2016

Kamstrup, 2016 (https://www.kamstrup.com/en-en/about-kamstrup), Last seen 16/04/2016

Kamstrup, 2016 (http://www.iflowinc.com/wp-content/uploads/2014/03/2100-data-sheet-June-2014.pdf.). Last seen 16/04/2016

Utility Systems Corporation, 2016 (http://www.utility-systems.co.za/background.html). Last seen 11/08/2016

Utility Systems Corporation, 2016 (http://www.utility-systems.co.za/pre-paid-water-metering.html), Last seen 16/04/2016

Utility Systems Corporation, 2016 (http://www.utility-systems.co.za/water-management-device.html), Last seen 16/04/2016

Utility Systems Corporation, 2016 (http://www.utility-systems.co.za/bulk-water-management-device.html), Last seen 16/04/2016

Utility Systems Corporation, 2016 (http://www.utility-systems.co.za/user-interface-unit.html). Last seen 16/04/2016

Utility Systems Corporation, 2016 (http://www.utility-systems.co.za/aquadata.html). Last seen 16/04/2016

Utility Systems Corporation, 2016 (http://www.utility-systems.co.za/mobile-data-collector.html), Last seen 16/04/2016

Utility Systems Corporation, 2016 (http://www.utility-systems.co.za/field-service-terminal.html), Last seen 16/04/2016

Utility-Systems-Corporation, 2011. product brochures.

APPENDIX B

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

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)
WAN	Wide Area Network
WBKMS	Web-based Knowledge Management system
WCDMA	Wideband code-division multiple-access
WMN	Wireless Mesh Network
WRC	Water Research Commission of South Africa

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 and
- 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 and subsequently 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 obtained 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 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 major 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. The 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 43 shows water cost prices for different municipalities in 2003.

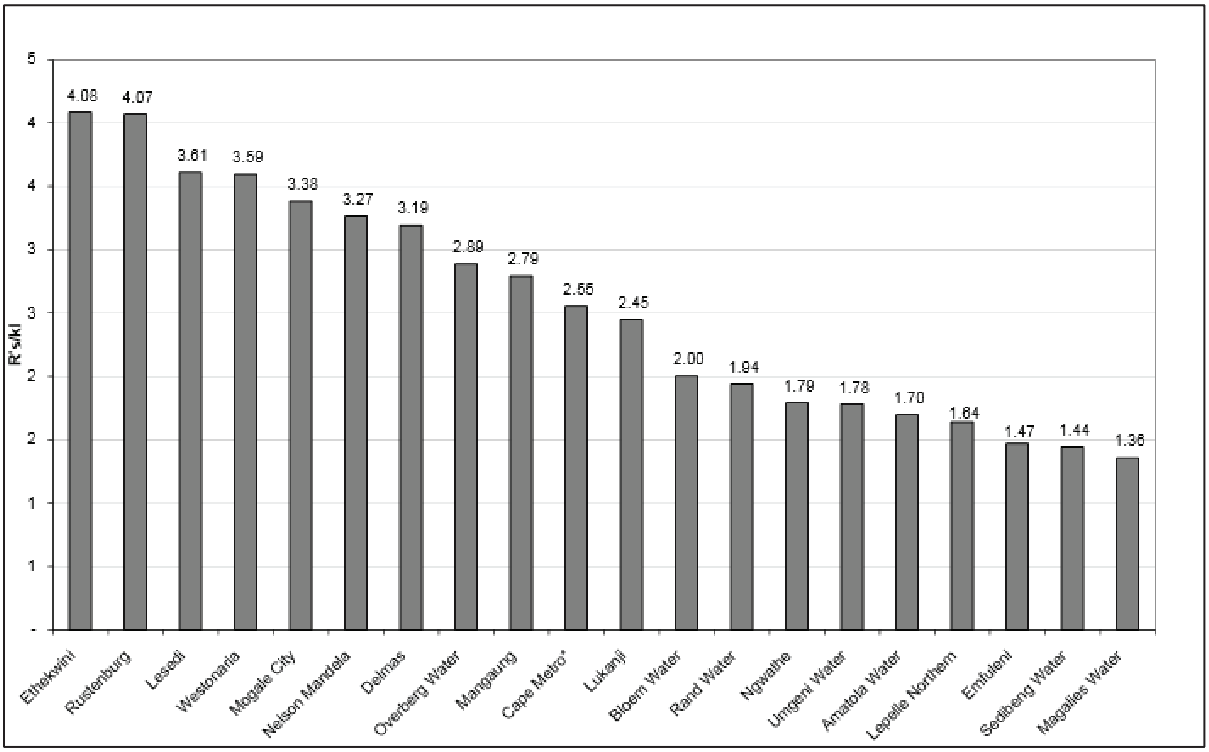

Figure 43: Bulk Water Prices in 2003(Eberhard)

The cost prices were adjusted for inflation to 2016 values using inflation calculator for South Africa showing them to vary between R2.65 to 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 (2013) and GIBB (2015), the cost of water in 2016 in Cape Town and Durban were 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 DWAS 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 AUD0.75/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 for properties is a function of stand size, but also of a large number of other factors such as income and climate. For 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 the 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), the municipalities have to set the tariffs in a way that high volume users cross subsidise the free basic water allocation. However, with municipalities that are too poor to achieve that, the constitution provides for an inter-governmental transfer, the “equitable share of revenue” from the national level. On the one hand, findings of the feasibility study in eThekwini indicate that value of the free basic water allowance as provided by the National Treasury as 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 utilizes different water tariff structures.

Table 2-3 compares the water tariff structures for FY2015/16 for domestic consumption in the different South African metropolitan municipalities. Although all municipalities use the increasing block tariff structure, each municipality charges different water prices for different quantities consumed.

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	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

Table 2-3 indicates the different water tariffs for non-domestic consumption in the City of Johannesburg, which have different rates for industrial and commercial users. The rates for industrial users are given in brackets.

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 the Average Annual Daily Demand (AADD) and the stand areas. This is illustrated in Figure 44 and Figure 45 below.

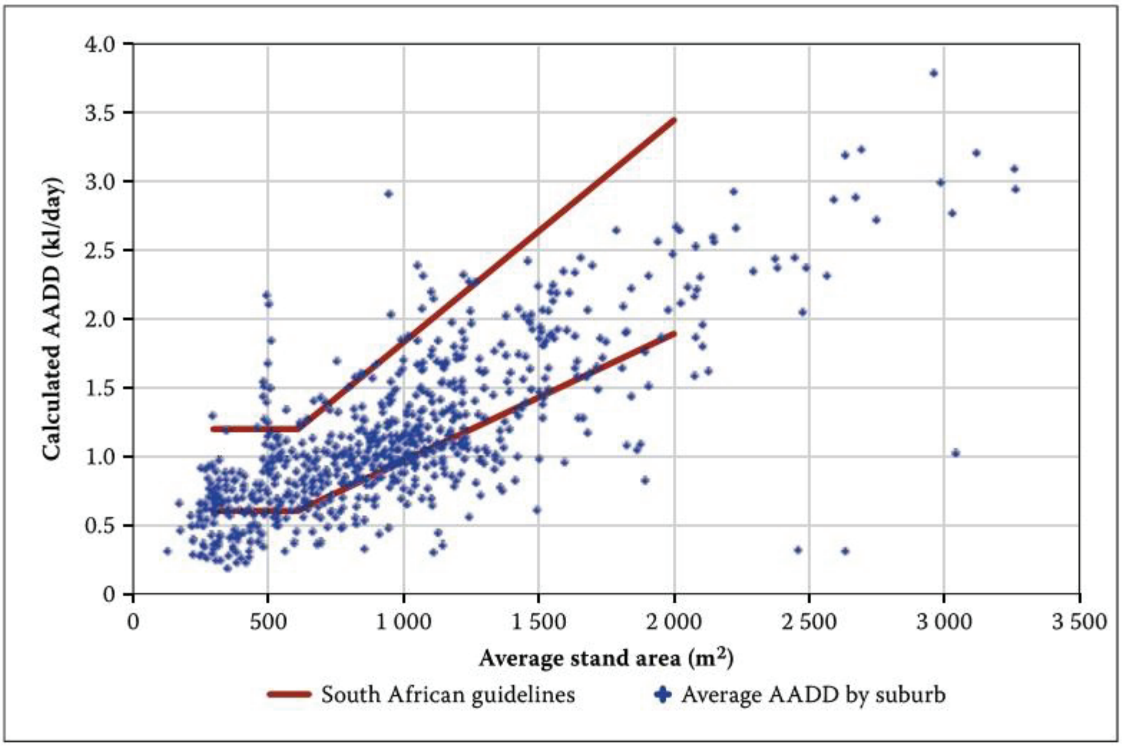

Figure 44: The average demand and stand area of 739 suburbs throughout South Africa and current South African guidelines (Griffioen & Van Zyl, 2014)

Figure 44 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 is illustrated in Figure 45.

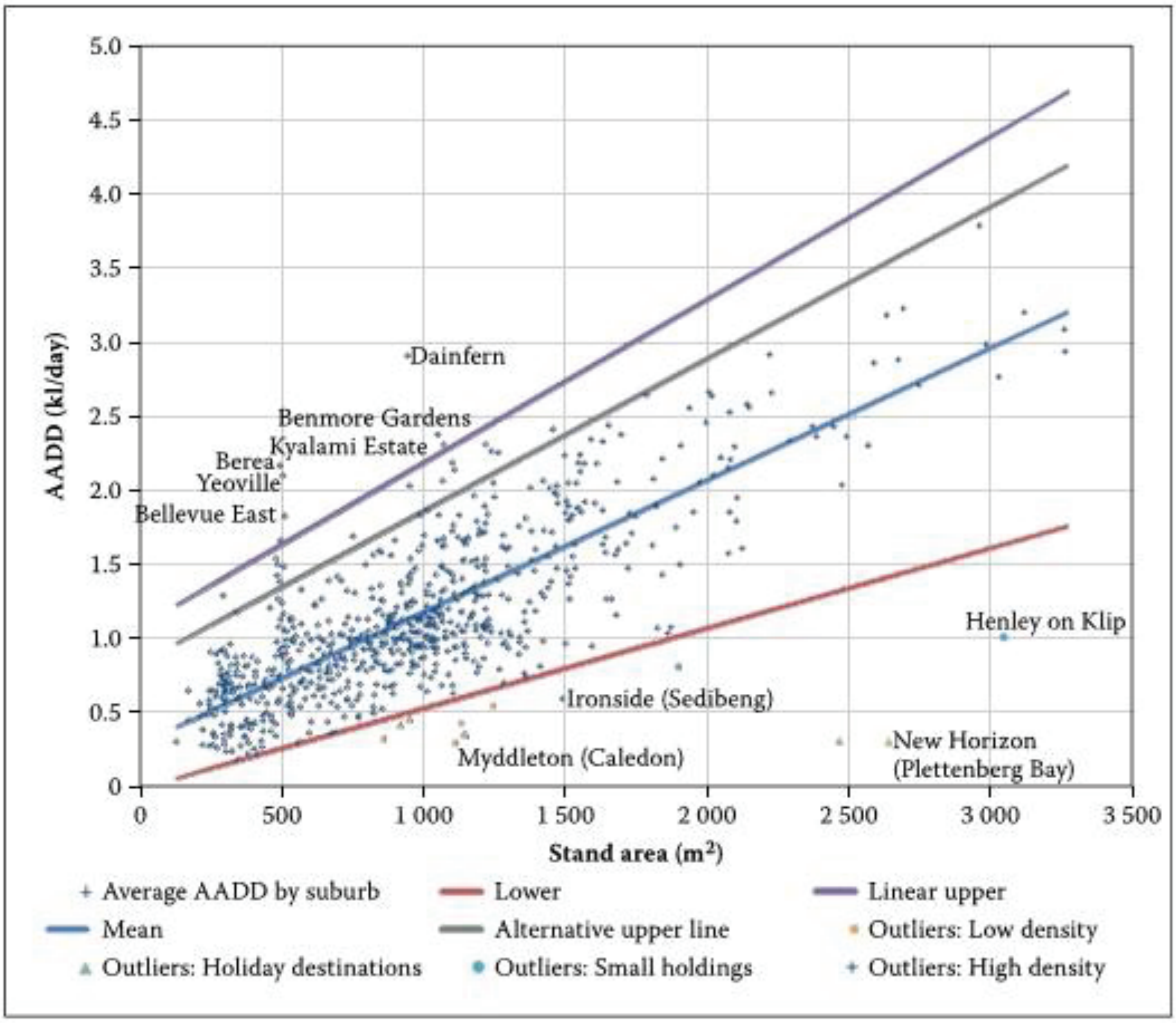

Figure 45: Proposed new design envelope curves for estimating the AADD of properties (Griffioen & Van Zyl, 2014)

Figure 45 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 on 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 that prior to installation prepaid meters a flat rate of R50 per month was charged in 2004, which is R97.43 in 2016 terms.

The Table 2-4 below shows the flat-rate tariff rates 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 and
- Other parameters.

2.3.1 Current Water Consumption

Three types of current consumption are used:

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

A summary description of the required input parameters are given in **Table 2-5**. The input parameters (with suggested typical, low and a 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 known 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 numbers 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

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, it was established that 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 low income areas, a study on feasibility of prepaid metering system in eThekwini, the extent of illegal connections 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 6 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 (with suggested typical, low and a high values) 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 most predominate one is poverty. DWAF (2004) states that poverty is the root challenge to the inability to pay for water services.

A study in eThekwini (GIBB, 2015) showed that only about 10 of low income residents with conventional metering had their account in arrears. The eThekwini municipality is strict with non-payment for water; and 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 2 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 a 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 and therefore its impact on current and future water demand and the cost of the 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 & 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.

No	Parameter	Description
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.
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 incidences 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 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 extent of on-site leakage on 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, 2012).

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 program. This program reduced consumption from 19 kl/month/property to 11.5 kl/month/property (a 40%

reduction). The practitioners' survey indicate that in low income communities the fraction of demand that is on-site leakage ranges from 5% to 70% from 4 respondents.

A study in Spain on 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. Similarly, Gascón et al. (2004) found an average residential leakage rate of 17.0 ℓ/h per property while studying water consumption patterns in 4 different Spanish cities. The on-site leaks represented 8.9% of the average daily consumption.

In Australia, Beal & Flynn (2014) and Blom et al. (2010) found through case studies that the fraction of on-site leakage on consumption ranges from 6% to 20%. The results from practitioners also revealed 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 at which water meters are currently being read. Ideally these should be 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) Meter Reading Cost

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 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 this cost to range from R1.74 to R4.00. The results indicate that the R1.74 is the cost of reading a meter in informal settlements while the R4.00 is the cost of reading a meter in rural areas as the properties are clustered together in informal settlements and 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 ranges approximately from 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, 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 R6 administrative cost, R1 printing cost and R3 postage cost.

(e) Meter Operation & Maintenance Cost

The meter operation & maintenance cost (Item 3.11) is the cost of operating and maintaining the water meter. This cost is dictated by 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

The meter failure (Item 3.12) is the fraction of existing meters that needs replacement due to failure of the meter itself. 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 & van Zyl (2015) on the study on apparent losses investigated the meters installed in eThekwini in the period; 6th June 2005 to 28 March 2010 (5 years). As part of the observations of the study it was observed that in that period approximately 19% of the meters were replaced that period, which translates into a fraction of approximately 4% per year. Based on a study done Mutikanga et al. (2011) the failure rate is be 6.6%/year. This, Mutikanga et al. deemed to be a high failure rate.

On the one hand, the 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 due to the meter failure 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 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 vandalized meters are not currently 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 with 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 community (Item 3.17) (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, electronics and 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 respectively.
4.2	Meter model	The models of meters proposed for conventional and advanced meters respectively.
4.3	SANS 1529-1 compliant?	Does each of 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 (if conventional and advanced meters are installed respectively) that will need replacement annually due to other reasons.
4.13	Total (/year)	The total fraction of meters (if conventional and advanced meters are installed respectively) that needs to be replaced per year due to all possible causes.

2.4.1 SANS 1529-1 Compliance

The 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 conforms 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 manufacturers. Manufacturers sometimes claim battery life exceeding 10 years. These numbers should be taken 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 some batteries have a lifespan of 5 years. Blom et al. (2010) support these findings as they found, from 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 7 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) indicates 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 4.8-11.3%/year due to battery failure.

A study on cost recovery by Marah et al. (2004) indicate that prepaid meters failure rate 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 range from 1% to 70% from 6 respondents. Heymans et al. (2014) reports that a performance audit of prepaid meters in Mogale 8 years after installation showed that 90% of the meters were faulty due water meter failure, vandalism, electronics and other components.

2.4.8 Failure due to Vandalism

The expected fraction of meters 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 of 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

No	Parameter	Description
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.
4.19	Meter reading cost (R/meter)	The cost of reading the meter. The costs should include all related costs, such as transport, labour and equipment.
4.20	Meter operation & maintenance cost (/meter/month)	The cost of operating and maintaining 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 if conventional and advanced meters are installed respectively.
4.23	Additional communication system operating costs (R/month)	Additional communication system operating costs not already included in the model if conventional and advanced meters are installed respectively.

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) state that the cost of purchasing a conventional water meter is R150/meter. This price appears to close to the low limit as 6 practitioners surveyed state that the price ranges between R300-R750/meter. In Australia, a study in 2010 showed that the cost of a conventional water meter was AUD36 (Blom et al., 2010). In 2016, this price equates to approximately AUD40.61/meter (Reserve Bank of Australia, 2016) and R426.33/meter in South African currency.

With regards to advanced meters, 6 practitioners state that the price ranges from R500-R2500/meter, with the most stated value as R2000/meter. In Australia, the cost of an advanced water meter in 2010 was AUD750 (Blom et al., 2010). In 2016, this price equates to approximately AUD846/meter and 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 R1000/meter. From the surveys collected, 5 practitioners state that the cost of installing a conventional meter ranges from R150-R1000/meter with majority of the values ranging from R400-R1000 per meter. Whereas in Australia, in 2010, the cost was AUD25 per meter (Blom et al., 2010). This equates, in 2016 values, to AUD28.20 per meter and R296.05 per meter in South African currency.

However, with regards to advanced meters, the cost of installing a meter will consists 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 AUD200. These values translate to AUD225.60 per meter in 2016 and 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 communication infrastructure required for the metering system. This varies greatly from application to application do to the large range of possible technologies and systems.

This consists 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 enables 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 & Lake (2014) conducted a feasibility study on the implementation of an AMR water metering system on 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 and $77 977.73. In South African currency, these costs range from R290 468.59 and 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, disposal cost of the old battery and labour. Based on a study done on 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 were R200 per meter and R300 per meter. Using America as a high income area proxy, it was found that the cost a battery, in 2013, was $15 per meter. This equates, in 2016 values, to $15.52 per meter and 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 include all related costs, such as transport and 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 (i.e. AMR or AMI).

For AMRs, meter readings 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 advance water metering systems. In this study, they found that the cost of reading an AMR ranged from $0.50-$0.80 per meter per month. In 2016 values, these equate to $0.51-$0.88 per meter per month and R6.76-R11.66 per meter per month in South African values. Mott-MacDonald, 2007) proposed that the cost of reading an advanced meter after implementation would be

£0.25 per meter per month. In 2016 values, this equates to £0.3 per meter per month and R5.19 per meter per month

With regards to AMI, literature such as Blom et al. (2010), indicate that meter reading cost could be eliminated due to technologies such as wireless communication networks. However, Blom et al. (2010) also states that the cost would be replaced by the cost of maintaining this networks. However, 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 & maintenance cost (Item 4.20) is the cost of operating and maintaining water meters after installation. This cost is dictated by 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 the cost price of R1 500.00 for prepaid meters, the typical monthly operation and maintenance cost of R18.75 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, 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 is 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 situation 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 (for both the conventional and advanced metering options).
4.26	Illegal consumption (kL/property/month)	The estimated average monthly consumption for properties with illegal connections (for both the conventional and advanced metering options).
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 respectively.
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 respectively.
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.

As for advanced water meters, reduction in unit consumption may incorporate the reduction of leakage and 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 level 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 did was make consumers reduce their consumption to free basic water with very few exceeding free basic water with a very little amount which can easily be paid making it a reasonable assumption that prepaid metering can achieve up to 100% payment level. However, since prepaid metering shuts consumers off water supply, it makes it susceptible to tampering in which case payment level can be assumed to be 100% minus extent of illegal connection.

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 results of evaluation 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 is an indication on how the robustness of the technology makes the technology suit the application. Compliance to national standards is used as a flag for technical feasibility of the project. Full technical compliance is much more complex and should be carefully investigated based on 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 highlights 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 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 on 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 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.

4. REFERENCES

AlAbdulkarim, L., Lukszo, Z. & Fens, T. (2012) Acceptance of Privacy-Sensitive Technologies: Smart Metering Case in The Netherlands. CESUN.

Arregui, F., Palau, C., Gascon, L. and Peris, O. (2003) Evaluating domestic water meter accuracy. A case study. In: Cabrera E and Cabrera E Jr. (eds). Pumps, Electromagnetic Devices, and Systems applied to Urban Water Management. Swets & Zeitlinger, Lisse. ISBN 90 5809 560 6. 343-352.

Arregui, F., Cobrera, E., Cobacho, R. & Garcia-Serra, J. (2006) Reducing Apparent Losses Caused By Meters Inaccuracies. Water Practice and Technology, 1(4).

Beal, C. & Flynn, J. (2014) The 2014 Review of Smart Metering and Intelligent Water Networks in Australia & New Zealand. , pp.1-52.

Blom, A., Cox, P. & Raczka, K. (2010) Developing a Policy Position on Smart Water Metering, s.l.: s.n.

Britton, T., Stewart, R. & O'Halloran, R. (2013) Smart metering: enabler for rapid and effective post meter leakage identification and water loss management. Journal of Cleaner Production.

Chris Hani District Municipality (2014) 2014/15 Tariff Structure Water and Sanitation An Annual Budget and Supporting Documentation for Chris Hani District Municipality, s.l.: Chris Hani District Municipality.

City of Johannesburg (2014) Determination of property rates and rebates for 2014/15 as amended in accordance with the regulations, Johannesburg: City of Johannesburg.

Couvelis, F.A. & van Zyl, J.E. (2015) Apparent losses due to domestic water meter under-registration in South Africa. Water SA, 41(5), pp.698-704.

Crause, R. (2013) South African Inflation Calculator. Available at: http://www.inflationcalc.co.za/ [Accessed July 4, 2016].

De Sousa-Alves, M. (2013) Update and Additions to Existing Long-Term Water Conservation and Water Demand Management Strategy – Water & Sanitation and Water Demand Management: City of Cape Town.

DWAF (2004) Draft White Paper on Water Services, Pretoria

Department of Water Affairs (DWA) (2014) Water Boards as Regional Water Utilities (Institutional Arrangements to Facilitate Turnaround) – Legal, Financial and Other Implications.

Dittrich, T. Battery concepts for smart utility meters – The requirements and proving their suitability. , pp.1-8.

Eberhard, R.E. (2003) Administered prices water: a report for National Treasury,

Ekurhuleni-Metropolitan-Municipality (2014) Tariffs: Sewerage Disposal Services and Incidental Charges, s.l.: Ekurhuleni Metropolitan Municipality.

Littlefair, K. (1998) Willingness to Pay for Water at the Household Level: individual financial responsibility for water consumption, London: Water Issues study Group School of Oriental and African Studies (SOAS) University of London.

Gascon, L., Arregui, F., Cobacho, R. & Jr, E.C. (2004) Urban Water Demand in Spanish Cities by Measuring End Uses Consumption Patterns.

GIBB (2015) Preliminary feasibility study for the use of prepaid/alternative domestic metering solutions, s.l.: eThekwini.

GIBB (2015) KST9: Preliminary Feasibility Study for the Use of Prepaid/Alternative Domestic Metering Solutions for eThekwini Water and Sanitation: Non-Revenue Water Branch

hellopeter.com. (2015) No water in my home. Retrieved September 30, 2016, from https://hellopeter.com/ilembe-district-municipality/reviews/no-water-in-my-home-1889639

Griffioen, M.L. & van Zyl, J.E. (2014) Proposed guideline for modelling water demand by suburb. Journal of the South African Institution of Civil Engineering, pp.63-68.

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.

KEMA (2012) The Critical Need for Smart Meter Standards: s.l.: Global Perspective.

Lugoma, M.F.T., van Zyl, J.E. & Ilemobade, A.A. (2012) The extent of on-site leakage in selected suburbs of Johannesburg. Water SA, 38(1), pp.127-132.

Malunga, M. (2017) Advanced Water Metering and Its Application in Low Income communities, s.l.: Not yet published.

Marah, L., O' Donovan, M., Finlayson, K. & Boderg, D. (2004) Institutional and Socio-Economic Review of the Use/Application of Electronic Prepayment Meter Technology in the Provision of Water Supply Services to Urban and Peri-urban areas. Water Research Commission Report.

Moffat, B., Motlaleng, G.R. & Thukuza, A. (2002) Households Willingness to Pay for Improved Water Quality and Reliability of Supply in Chobe Ward, Maun.

Mott-MacDonald (2007) Appraisal of Costs & Benefits of Smart Meter Roll Out Options Appraisal of Costs & Benefits of Smart Meter Roll Out Options, London.

Muller, M. (2008) Free basic water: a sustainable instrument for a sustainable future in South Africa. Environ. Urbanization 20 67-87. URL: http://eau.sagepub.com/cgi/content/abstract/20/1/67 (Accessed 24 April, 2008).

Mutikanga, H.E., Sharma, S.K. & Vairavamoorthy, K. (2011) Investigating water meter performance in developing countries: A case study of Kampala, Uganda. Water SA, 37(4), pp.567-574.

Mwangi, M. (2017) Advanced Water Metering and Its Application in High Income Communities, s.l.: Not yet published.

Reserve Bank of Australia (2016) Inflation calculator. Reserve Bank of Australia. Available at: http://www.rba.gov.au/calculator/ [Accessed July 4, 2016].

Sacket & Lake (2014) AMI Technology and Feasibility study consolidated Report, s.l.: s.n.

Seifried, C.M. & Converse, T.S. (2009) Canton's Meter Replacement Project Registers Savings, Canton.

SGS Economics and Planning (2011) Water meter cost benefit, Hobart.

Shirley, J.F. et al., 2014. (Agreement/Contract for Information and Review) Water Meter Reading Automation Project Agreement Amendments and Agreements, Sacramento.

Singh, N. & Xaba, B. (2006) Johannesburg Water's Prepayment Water Meter Appropriate Technology in the Implementation of Project Operation Gcin'amanzi in Soweto, Johannesburg: Johannesburg Water.

Sneps-Sneppe, M., Maximenko, A. & Namiot, D. (2012) On M2M communications standards for smart. M2M.

Sønderlund, A.L. et al. (2016) Effectiveness of Smart Meter-Based Consumption Feedback in Curbing Household Water Use : Knowns and Unknowns. , 142(12).

Sternberg, J. & Bahrs, P. (2015) Water Metering – The Tauranga Journey.

Utility-Systems-Corporation (2011) Product brochures.

Van Zyl, J. (2011) Introduction to Integrated Water Management. South Africa: Water Research Commission.

Van Zyl, H. et al. (2007) Water Consumption Levels in Selected, Johannesburg.

Van Zyl, J., 2011. Introduction to Integrated Water Meter Management 1st ed., Water Research Commission.

World Bank (2012) Designing a results framework for achieving results: a how-to guide, Washington DC: Independent Evaluation Group.

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