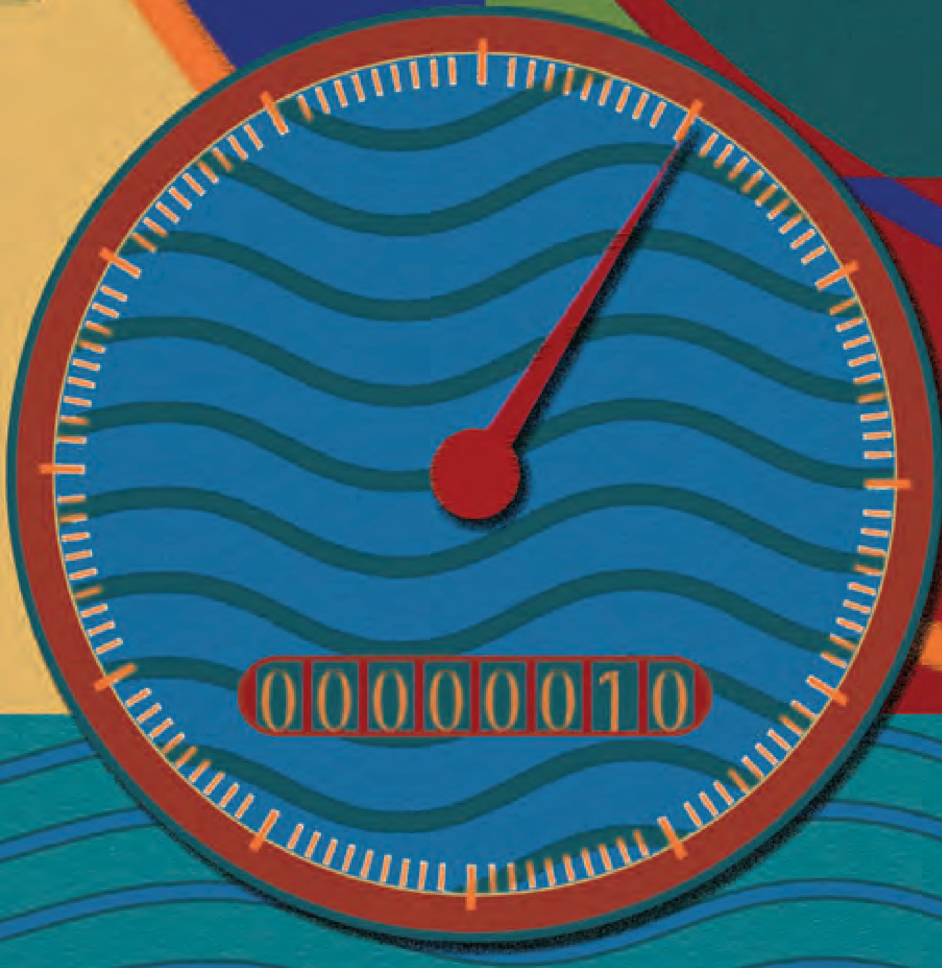
INTRODUCTION TO
INTEGRATED WATER METER MANAGEMENT

EDITION 1

JE van Zyl



WATER RESEARCH COMMISSION
TT 490/11

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Foreword

A reliable supply of clean and healthy water is undoubtedly the most important service that people need. South Africa has made great strides in addressing the inequalities of the past in the provision of water, but unfortunately the focus on providing more people with water has caused many distribution systems to be neglected, resulting in increased levels of leakage and non-revenue water, poor billing practices and a loss of income to municipalities. It is vital to maximize the volume of water metered in the utility, at the minimum possible cost. To achieve this goal, the proper selection, management and maintenance of meters are critical.

Currently there is a lack in the proper management of water meters and meter data, resulting in increased levels of water losses and reduced income for municipalities. In addition, initiatives of water demand management and conservation are hampered by a lack of good information.

This book covers all aspects of water meters and water metering in municipalities. It covers the theoretical principles of meters, legal and metrological requirements, meter types, best practice guidelines as well as practical aspects of water meter management (amongst others).

It is anticipated that this book will serve as a training aid and a valuable tool for water utility managers, engineering technical staff, operations and maintenance and meter reading personnel and researchers.

It thus gives me great pleasure to support and fully endorse this excellent new book on water metering. My wish is that that it will make a real difference to water management and service delivery both in South Africa and the rest of the world.

Acknowledgments

This guide book emanated from a project initiated and funded by the Water Research Commission as Project K5/1814: Integrated Water Meter Management.

Particular credit and thanks are due to Mr J Bhagwan of the Water Research Commission, who initiated the project and chaired the Reference Group. I would also like to acknowledge the other members of the Reference Group and thank them for their time and guidance: Mr K Bailey (Elster Kent), Mr B Bold (Sensus), Mr L Hlatshwayo (Department of Water Affairs), Ms S Mabaso (Department of Water Affairs), Ms M Machaba (Department of Water Affairs), Dr R McKenzie (WRP), Ms S Moshidi (Department of Water Affairs), Mr V Naidoo (Arcus Gibb), Mr S Scruton (eThekwini Water and Sanitation), Mr C Tsatsi (Department of Water Affairs), Mr D van Eeden (Sensus) and Mr T Westman (City of Tshwane).

A number of individuals contributed sections of the book and/or provided detailed feedback that were essential to make the book what it is. I would like to particularly acknowledge the contributions of Mr M Capper (Elster Kent), Mr F Couvelis (University of Cape Town), Mr R Davis (Ikapa), Mr I de Beer (Reonet), Ms K Fair (GLS), Mr M Kubwalo (Itron) and Mr M Rabé (Re-Solve). Many others provided advice or encouragement, including Mr B Beard (SABS), Mr E Johnson (GHD), Mr. R Kalil (Aqua-Loc), Mr A Leonie and Mr T Leonie.

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I would like to thank the University of Johannesburg for administrative support, the University of Cape Town for allowing me time to work on the project, and the many individuals and organisations not mentioned who contributed in various ways to this book.

Finally, I would like to thank my wife Hanlie and children Jean and Ankia for their unwavering love and encouragement throughout the writing of the book.

What others have said about *Introduction to Integrated Water Meter Management*:

"This book is a great resource for municipalities and will help them make informed decision in metering challenges." "I am very impressed with the way it is written, it talks to the practical issues and challenges."
Zolile Basholo, Manager of Water Demand Management & Strategy, City of Cape Town

"This informative book is easy to read and places the basics of water meter management at the finger tips of both professionals and novices alike. I highly recommend that this book is read by all water practitioners as it succinctly covers all aspects of meter management from selection, to installation, to operation and maintenance and finally to replacement."
Simon Scruton, Manager, eThekwini Water and Sanitation

"The various technical and managerial concepts in the book are dealt with in a practical and concise way and the numerous photographs, illustrations and diagrams are well selected. This book should be required reading for every water meter practitioner, regardless of their level of knowledge or skill."
Trevor Westman, Deputy Director: Water Loss and Meter Management, City of Tshwane

"As a billing agent, the book provides a lot of useful information on meters & billing. Excellent for billing & projects."
Kogie Govender, Sembcorp Siza Water

"Very concise and informative. A must have for every engineer working with utilities!"
Arno Marais, Chief Commissioning Engineer, Sasol

"Though targeted for people in the municipalities who deal with meters every day, the book is very handy even for consulting engineers, especially in this day & age where water management is a global concern."
Tellmore Masocha, African Innovative Solutions & Projects

"Brilliant and useful guide for basic water meter management and understanding of different water meter types for selection purposes."
Johan Pretorius, Aurecon

"This is a well structured and informative textbook and tool. It has been long overdue in the water industry."
Nathaniel Padayachee, Jeffares and Green

"this book is very useful for all parties involved in water distribution optimization and gives quick and simple answers to difficult questions."
Ignacio Pena, Joat Group

"Training is the key to improving skills in order to manage water, our most precious resource. Water meters are the 'cash tills' of the reticulation. This excellent book provides an outstanding reference for training."
Keith Bailey, General Manager: Sales & Marketing, Elster Kent

" This book is a must read for anyone in the water metering business, whether experienced or novice. The book is informative and the explanations are excellent."
John Alexander, Sales and Marketing Manager, Krohne

"*This book presents the essential basic concepts of water meter selection and management. It provides a balanced view of the different technologies of water meters currently available on the market and most importantly, the advantages and disadvantages of these different technologies. Written in an accessible style and format, this book is a must for water practitioners."*
Max Kubwalo, Itron

Table of Contents

1 INTRODUCTION

1.1 Why this Book?

It is impossible for a municipality to manage its water resources without knowing how much water it has and where the water goes. This is where water meters play a critically important role: water meters are used to measure how much raw water is taken from a resource such as a large dam, how much of this water leaves the water treatment plant, how much is purchased from bulk suppliers or sold to other municipalities, how the water is distributed within the water distribution system, and finally, how much of the water is delivered to individual consumers. If water meters are not managed correctly, it can have a negative impact on the income of a municipality. However, if water metering is approached correctly, it can increase the net income of a municipality, while empowering staff to manage the distribution system in the best possible way.

Water metering is particularly important for municipalities since it forms the basis for much of their income through the sale of water to their consumers. In South Africa, like in many other countries, there is a legal imperative on municipalities to meter consumers and manage water losses in compliance with legislation and standards.

In South Africa, like in many other countries, there is a legal imperative on municipalities to meter consumers and manage water losses in compliance with legislation and standards.

Many countries currently lack proper water meter management, with many municipalities and bulk water suppliers not having the capacity to undertake and manage optimal and integrated meter calibration, replacement, reading and information management systems. Often the divided responsibility between billing and meter management (typical of the institutional arrangements within most municipalities) results in poor billing, incorrect information capture, and poor maintenance. This is further compounded by the fact that where initiatives of water demand management and conservation are required, the data is not easily accessible to the departments responsible for this task, leading to the frequent lack of integration between domestic and bulk water metering.

The purpose of this book is to help address the need for better water meter management by providing a practical introduction to the technical and managerial aspects of water meters. Since water metering affects different departments within a municipality, as well as various external parties, it is important to look at this topic from a holistic perspective, which is why the title refers to *Integrated Water Meter Management*.

1.2 Why Water Metering?

Water metering is an excellent application of the principle "to measure, is to know", and knowledge of what is happening with the water in a distribution system is the key to properly managing this resource. Proper application of an integrated water meter management strategy creates win-win conditions for all parties involved.

While water metering has many direct and indirect benefits, there are four fundamental drivers for a comprehensive metering programme[1]:

- equity,
- water efficiency and losses,
- economic benefits, and
- system management.

1.2.1 Equity

Comprehensive water metering provides an equitable basis for charging consumers based on the amount of water that they consume. It makes consumers accountable for their own water use and empowers them to influence how much they pay for this service. It also allows cross-subsidisation to be done fairly, and needy consumers to receive a free basic amount of water.

1.2.2 Water Efficiency and Losses

Water supplied to consumers is taken from the environment, and thus using water more efficiently has direct benefits for the environment. Areas with high population density do not always have adequate natural water resources, and require water to be transferred from other areas at great cost. In the worst cases, municipalities are forced to provide water intermittently with devastating consequences for water quality, pipelines and water meters. Intermittent water supply should be avoided at all cost.

Metering shows the value of water to the consumer and creates strong incentives for consumers to use water more efficiently[2]. In fact, it has been shown that installing water meters in itself reduces water consumption. Research conducted in the UK shows that the use of water in metered households is 10-15% lower than in the unmetered ones[3]. This difference was found to be up to 50% in a Canadian study[4].

When water is particularly scarce, water meters are essential for managing water demand and ensuring that consumers adhere to water restrictions.

By comparing the readings on network and consumer water meters, municipal engineers are able to estimate the level of water losses in a water supply system and identify illegal connections. All water networks lose some water, but the level of losses has to be carefully monitored and managed to avoid them reaching unacceptably high levels. A well placed metering system in the distribution system will also assist technical staff in efficiently identifying the location of large leaks.

Network and consumer meters are used in combination to estimate and manage the water supply system, including revenue and losses.

1.2.3 Economic Benefits

Measured consumption forms the basis of most water accounts, and thus affects municipal revenue directly – water meters are the cash registers of water suppliers. It follows that a well managed and accurate water meter system will improve water sales and thus municipal income. Many of the technical benefits of water meters, such as accurately measuring municipal water purchases, reducing water losses, and identifying and removing illegal connections also have a positive impact on municipal finances.

Water meters are the cash registers of water suppliers. They are essential for effective revenue management.

Water tariffs can be used to increase municipal income, cross-subsidise needy consumers and manage water consumption. However, such a tariffs policy cannot be implemented without a well established metering system[4].

1.2.4 System Management

On a technical level, water meters are indispensible for knowing how much water is distributed and where it goes. Water meters are used to measure water entering a water supply system, whether from raw water sources, water treatment plants or bulk water suppliers. Meters in the distribution network measure where the water is transported to, and finally, consumer meters are used to measure how much water is delivered to each metered consumer in the system.

A pipe of a certain diameter can only carry a certain amount of flow, and thus pipes have to be upgraded as water demands increase due to economic growth or new developments. The same goes for municipal storage tanks, pumps and other components of the network. To identify and plan for problems created by network components, technical staff uses water meter data to understand the water demand patterns in the system and to project future demands. The demand data is critical to building accurate computer models for simulating water distribution systems, investigating reasons for hydraulic problems such as low pressures, identifying future problems, and planning expansions and improvements to the system.

A reliable and well run distribution system with a good income reflects positively on the management of the system. It improves the public image of the municipality by providing consumers with a better, more reliable service and accurate bills.

The data obtained from a good metering system allows management to take informed decisions on capital investments, maintenance, staffing and various other aspects of the water supply system.

The bottom line is that an integrated water meter management system allows a municipality to provide better services to the community, while at the same time improving its income.

1.3 About this book

1.3.1 Who Should Read this Book?

The book is primarily aimed at municipal managers and staff who deal with any aspect of water metering, whether from a practical, technical, financial, or purely management perspective. The book does not require the reader to have a technical background or prior knowledge of water metering, although such knowledge will undoubtedly help with understanding the concepts covered. The book will also be useful to bulk water suppliers, government agencies, consultants and NGOs dealing with any aspect of water metering or water meter data, including:

- High-level planning and management
- Operational control and management
- Maintenance and asset management
- Treasury and billing systems
- Water demand management
- Water loss control
- Water meter selection
- Water meter purchasing, installation and replacement
- Refurbishment, testing and reading of water meters.

1.3.2 How are the Chapters Organised?

This book consists of seven chapters, each dealing with a particular aspect of water metering. The chapters and the way they relate to each other are shown diagrammatically in Figure 1-1.

The first two chapters are critical to the understanding of the book and are recommended for all readers. *This chapter* gives the background to the book and an overview of the role and importance of water metering. *Chapter 2* introduces the basics of water metering, including legislation and standards, the basic components of water meters, metrology and meter classes.

Chapter 3 discusses the types of water meters commonly used and how they function. It is important reading for people dealing with water meter selection, operation and maintenance. Other readers might glance through the chapter and then refer back to it as required.

Chapters 4, 5 and 6 deal with important aspects of water metering and can be read more-or-less independently of each other, although reading all three chapters in sequence is recommended. *Chapter 4* deals with water meter selection, *Chapter 5* with the life-cycle management of meters in the field, and *Chapter 6* with meter reading and the management of meter reading data.

*The final Chapter (*Chapter 7) concludes the book with a discussion of how different aspects of water metering can be integrated to get the maximum benefit for all parties concerned.

1.3.3 A Few Tips for Getting More out of this Book

The illustrations, photographs and diagrams used in the book were carefully

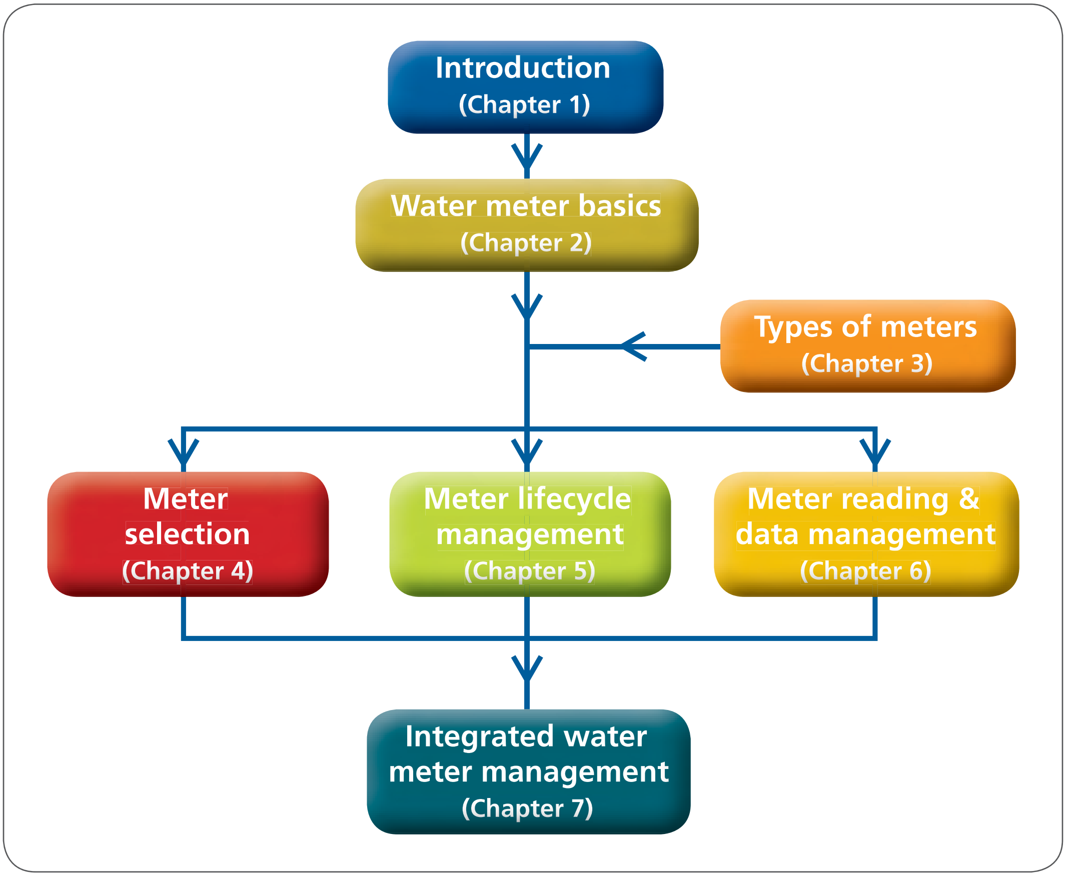


Figure 1-1 Chapter layout of this book

selected to assist with understanding the concepts covered. Two types of text boxes are used in the text to highlight important points made in the book, and to provide examples or case studies:

A number of appendixes with useful information are provided in the back of the book. Information provided includes:

- A *glossary* with important terms and abbreviations used in water metering.
- *Organisations* dealing with metrology, standards and other aspects of water meters.
- *Meter suppliers* and software for water metering.
- *Recommended reading* for more information on specific aspects of water metering.

Text box highlighting important information	Text box giving an example or case study

Water Meter Basics

2

2.1 Introduction

Millions of water meters are in use around the world today, and every day thousands of new meters are installed and old meters replaced. The huge market for water meters means that many companies are involved in the field, and that new technologies are continuously being introduced. Since most water meters are used to measure the volumes of water that are sold to consumers, they have to comply with strict legislation and standards that protect the consumer from exploitation. All of these factors can make the seemingly simple task of selecting the right water meter for a particular application a daunting prospect for an inexperienced person.

To understand the field of water metering, it is important to start with the basics. Thus the goal of this chapter is to introduce the basic concepts, terms and standards that apply to water meters. The chapter covers the following:

- A description of what a water meter is, and what components it consists of. While many different types of meters are available, they all have the same basic components.
- An overview of the legislation and standards that water meters typically have to comply with.
- An introduction to the field of water meter *metrology. Metrology* deals with water meter accuracy, including the definition of terms and standards. Certain words have very specific meanings in water meter metrology, and it is important to be familiar with these when dealing with water meters.
- The classes of water meters that are used to classify water meters in terms of their performance. New international standards have been proposed that will eventually replace the conventional standards still in use in many countries. Both systems of meter classification are discussed.
- An overview of other requirements besides accuracy that water meters have to comply with.

2.2 Water Meters and Their Components

A water meter is a device that measures the volume of water that passes through it. Some documents distinguish between *water meters* and *flow meters* based on the measuring mechanisms used by the meter. However, in this book the term *water meters* is used generically to refer to any type of water measuring device.

A water meter is a device that measures the volume of water that passes through it.

All water meters consist of four basic components. These components are indicated in a section through a typical water meter shown in Figure 2-1, and consist of:

1. A device to detect the flow passing through the meter, called the *sensor*. In Figure 2-1, the sensor consists of a paddle wheel that is rotated by the movement of the water passing through.
2. A device that transmits the signal detected by the sensor to the other parts of the meter, called the *transducer* or *measurement transducer*. The transducer of the meter in Figure 2-1 consists of a spindle that is rotated by the paddle wheel.
3. A device to keep track of the flow that has passed through the meter, called the *counter*. The counter of the meter in Figure 2-1 consists of a set of counter wheels or numbered discs, similar to the odometer of a car.
4. A device to communicate the readings to the meter reader, called the *indicator*. The indicator of the meter in Figure 2-1 consists of the numbers on the counter wheels that are visible on the face of the meter.

All water meters consist of **four basic components**: a ***sensor*** to detect the flow, a ***transducer*** to transmit the flow signal, a ***counter*** to keep track of the total volume having passed through the meter, and an ***indicator*** to display the meter reading.

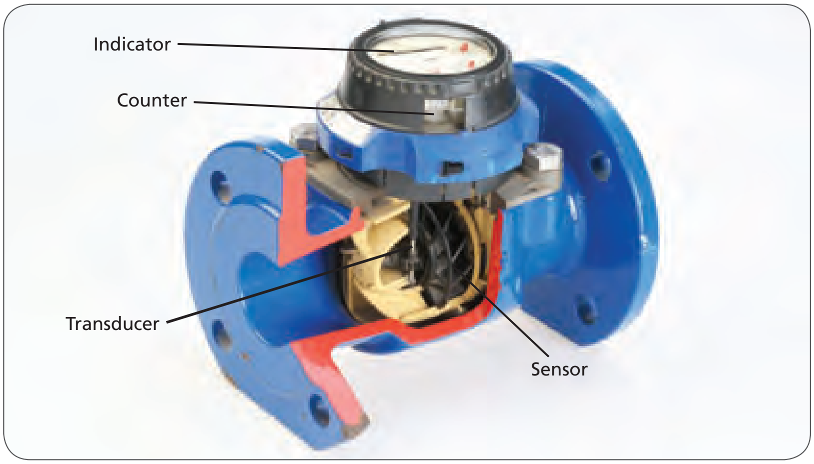


Figure 2-1
Section through a water meter showing the sensor, transducer, counter and indicator (meter supplied by Sensus)

While the four basic components are always present in any water meter, many different types of devices are used for each component. There are also many additional components that may be installed on a water meter to perform specific functions. Thus it is necessary to look at the meter components in more detail.

2.2.1 Sensor

The *sensor* or measuring element is the device in a water meter that detects the flow passing through the meter. The types of water meters (discussed in Chapter 3) are mainly distinguished by the mechanisms used by their sensors.

Some sensors can detect the volume of water passing through the meter directly by counting off little 'packets' of water passing through. Meters with these sensors are called *volumetric* or *positive displacement* meters. However, most types of sensors don't measure the volume directly, but measure the flow velocity and then convert the velocity into a volume. Meters using these sensors are called *inferential* or *velocity* meters (they *infer* the volume from the velocity measurement).

Figure 2-2 A rotating positive displacement meter sensor (sensor provided by Elster Kent)

Different *positive displacement sensors* are used. The most common types use a rotating disc, but oscillating pistons are also frequently used. Nutating disc meters are volumetric meters popular in the USA, but are not used much in Europe or Africa. An example of a volumetric sensor is shown in Figure 2-2.

Volumetric meter. A flow meter with a *sensor* that measures the volume of water passing through it directly by counting off 'packets' of water. It is also called a *positive displacement meter*.

Velocity meter. A flow meter with a *sensor* that measures the velocity of the water passing through it, and then converts the velocity into a volume. It is also called an inferential or *velocity meter*.

The *sensors* used by *inferential meters* typically consist of rotating impellers with radial or helical vanes as shown in Figure 2-3. Magnetic and ultrasonic meters are also classified as inferential meters, even though

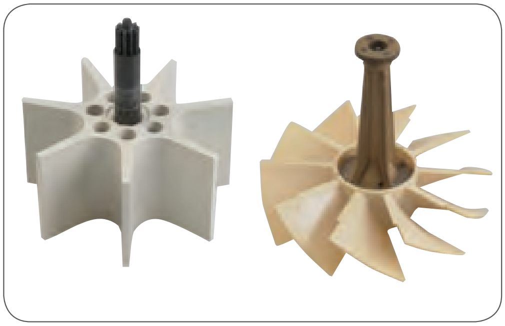


Figure 2-3 Radial and helical vane impellers

Water Meter Basics

they don't employ mechanical moving parts in their sensors.

2.2.2 Transducer

The *transducer* or measurement transducer transfers the signal picked up by the sensor to the rest of the meter. The simplest transducer consists of a thin mechanical spindle that is rotated by the sensor, such as the one shown in Figure 2-1. A disadvantage of this type of transducer is that it can generate friction, reducing the meter accuracy and causing wear in the meter over time. It is also very difficult to seal off water around the spindle if the transducer has to transmit the measurement signal into a dry chamber where parts of the meter is housed. (Wet and dry dial meters are discussed in Section 2.2.5.)

A type of transducer that is frequently used in meters with dry compartments uses small magnets to transmit the signal into the dry chamber. Meters using magnetic transducers require special protection to ensure that external magnetic fields do not interfere with the meter reading. Examples of direct and magnetic transducers are illustrated in Figure 2-4.

Other types of transducers employ electrical signals, which allow the signal to be transmitted to a counter located in a different location.

2.2.3 Counter

The *counter* or calculator is the part of a meter that accumulates the flow readings it receives via the transducer. It holds the total volume of water that has passed through the meter since its manufacture, just like the odometer of a car holds the total distance that a car has travelled. In fact, most counters use the same rotating disc counters used for the odometers of cars, although other types of gear mechanisms are also sometimes used. An example of a rotating disc counter is shown in Figure 2-5.

In some cases, the meter counter consists of an electronic device that keeps the volume reading of the meter in its internal memory.

2.2.4 Indicator

The *indicator* is the part of the meter that displays the measurement to a meter reader. When a rotating disc counter is used, the indicator simply consists of the numbers on the discs that are displayed on the face of

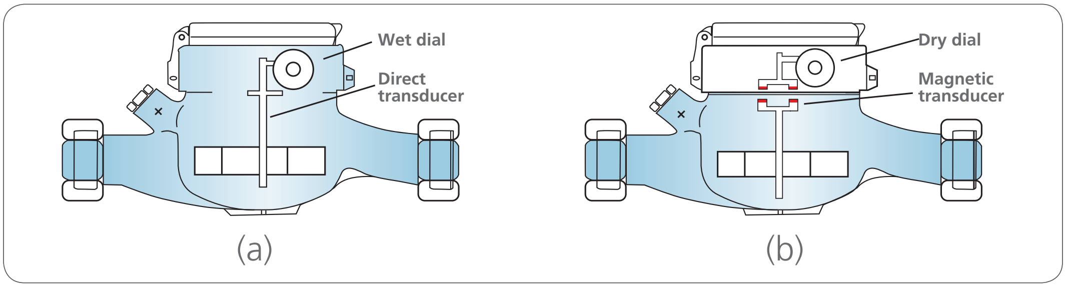


Figure 2-4 Diagrams of a) direct transducer in an open wet dial meter and b) a magnetic transducer in a sealed dry dial meter.

Figure 2-5 A rotating disc calculator

the meter. Other types of indicators that are used include rotating pointers and electronic displays. Examples of meter indicators are shown in Figure 2-6.

The indicator and counter are sometimes contained in a sealed, dry chamber and at other times in a wet chamber – one that is filled with water. A discussion of wet and dry dial meters follows in Section 2.2.5. The indicator should be supplied with a dark cover to prevent algae from growing.

The indicator should have a transparent window and should show the meter reading in an easily readable, reliable and clear way. The element on the indicator that displays the lowest value is called the *control element*, and the interval used on this element is known as the *verification scale interval.*

In most countries, including South Africa, water meters are only allowed to display their readings in cubic meters (m^3) as the unit of measurement. (Note that 1 cubic meter is equal to 1000 litres of water.) Two clearly contrasting colours (for example black and red) have to be used for the cubic meter values and fractions of a cubic meter as shown in Figure 2-6(a). Where separate dials or pointers are used, these have to be clearly marked with a multiplying factor to show the units they are measuring, as shown in Figure 2-6(b).

2.2.5 Wet and Dry Dial Meters

The counter and indicator of a water meter may be housed in a dry or wet (water-filled) housing. In dry dial meters, the counter and indicator are placed in a sealed chamber. A high level of water-tightness is ensured when the chamber carries an IP68 rating (from the standard IEC 60529[6]), and are sometimes called extra-dry chambers. However, it is important to note for how long the meters were subjected to the IP68 test – the longer the test, the better the seal. Dry dial meters often use magnetic transducers, and thus require

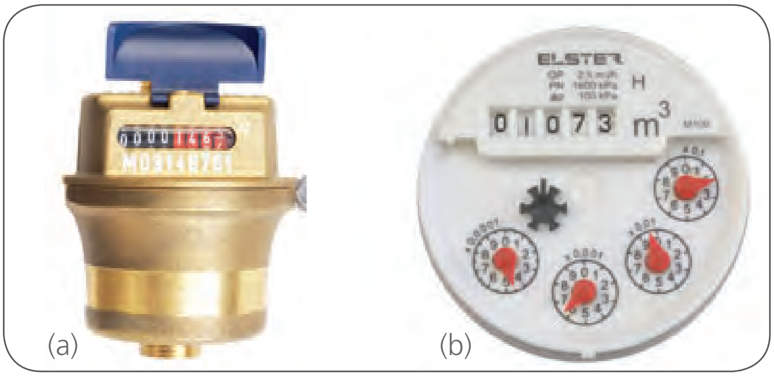


Figure 2-6 Examples of meter indicators

special protection against magnetic fields that may interfere with the meter reading.

An advantage of dry dial meters is that their counters and indicators do not come into direct contact with the water, and are thus protected from suspended particles that may create problems due to settling or obstruction of the counter gears. In addition, the transparent window covering the dial doesn't have to be strong enough to sustain the water pressure in the network, which reduces the cost of the meter. On the negative side, if any damp gets past the seal, condensation can form on the inside of the meter window, making the meter impossible to read. In some cases, meters are provided with a mechanism to remove damp from the inside of the window.

In wet dial meters, the chamber housing the counter and indicator is either filled with water from the network (i.e. water may move between the counter and sensor parts of the meter), or housed in a sealed chamber that is filled with a mixture of water and glycerine (to stop algae from growing). A benefit of wet dial meters is that damp is not a problem. However, open wet dial meters are not suitable for dirty water, or water with high iron content. Dirt from the water can get stuck in the counter mechanism causing the meter to malfunction. In addition, the transparent window housing of an open wet dial meter has to be strong enough to withstand the full pressure in the distribution network, adding to the cost of these meters. Better quality meters use 14 mm armour plate glass lenses.

2.2.6 Additional Meter Components

Meters can have various additional components to improve their accuracy or make them easier to use. For instance, an adjustment device may be fitted that allows the manufacturer to make final calibration adjustments to the meter. Other additional components may allow data to be stored in the meter, show the water price, or set a fixed volume to supply before the flow is automatically discontinued. Some meters have mechanisms to transfer data electronically to (and even from) data loggers or remote stations.

Most meters can be logged using additional equipment. This is an important function since it allows the flow through the meter to be recorded and analysed, and for the meter to be fitted with an automatic meter reading system at a later stage if desired.

Special signal transducers are required to transmit the meter readings to a logger unit that stores the data. The transducer receives an optical or magnetic pulse (signal) from the meter, and sends it through to the logger. Such a pulse is generated each time a certain volume of water has passed through the meter. The value of the pulse depends on the meter, and can vary from fractions of a litre to several litres. Another important issue when logging water meters is to ensure that the logger can distinguish between forward and reverse flow when flow reversal is likely to occur. Finally, it is a good idea to verify the volume registered by the logger against the volume accumulated by the meter over the same time period to ensure that all pulses were correctly logged.

Its is important to note that additional meter components, such as electronics or prepaid systems, cannot operate independently of the meter.

2.3 Legislation and Standards

Most water meters are used to measure water that is sold to consumers, and thus they have to comply with strict legislation and standards that are local to the country in which the meters are used. This section includes the South African legislation and standards that relate to water metering, as well as the most common international standards.

> It is a legal requirement that each consumer water meter installed in South Africa must comply with the standard SANS 1529, and must be tested by a registered verification officer in an accredited test laboratory. Any meter in the field that does not comply with the accuracy requirements of SANS 1529 must immediately be withdrawn from service.

2.3.1 Legislation

The main laws that have a bearing on water metering in South Africa are the Municipal Services Act[1] and the Trade Metrology Act[2].

Municipalities are required by law to meter all consumers.[3]

The South African Trade Metrology Act requires consumer water meters of sizes 15 to 100 mm to comply with the requirements of SANS 1529[4] and that municipalities must ensure that all meters under their control are kept in a verifiable condition at all times. This means that municipal meters have to be verified before installation and at intervals specified by the Act. The verification has to be done by a qualified and registered Verification Officer in a SANAS Accredited Test Laboratory in terms of SANS 10378[4].

Water meters larger than 100 mm cannot be tested in South Africa and many other countries since large enough testing facilities are not available. However, it is still required that the meter undergoes certain tests at the SABS, and that the suppliers provide a verified accuracy curve for the meter.

Any meter that becomes defective, or does not comply with the accuracy requirements specified in SANS 1529, must be immediately withdrawn from service.

2.3.2 Standards

International water meter standards tend to be very similar on major issues such as meter accuracy and classification (except for the US standards, which tend to follow their own approach). However, in recent years most international standards have undergone major revisions that have substantially changed the way water meters are classified (see Section 2.5 for more details).

Many countries have not yet adopted the new standards, and in any case it will take many decades before the new standards become the norm due to the long service lives of many meters currently installed. The approach followed in this book is to use the conventional meter standards, but to include discussions of the new standards to allow the reader to understand both systems.

An example of the conventional meter standards can be found in the document SANS 1529: *Water Meters for Cold Potable Water*, which currently consist of four parts (the numbering of the parts was not done sequentially to allow more parts to be added in future):

- 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.
- Part 9: Requirements for electronic indicators used with mechanical water meters, electronic water meters and electronic prepayment water measuring systems.

The new international standards are available in a number of documents, with very similar requirements (efforts are currently underway to merge them into a single standard). The main international standards are:

- International Organization of Legal Metrology: *OIML R49: Water meters intended for the metering of cold potable water and hot water*[6]. Note that it uses the French acronym OIML even for the English language acronym.
- International Organization for Standardization: *ISO 4064 Measurement of water flow in fully charged closed conduits — Meters for cold potable water and hot water*[7].
- European Union standard: *EN 14154 Water meters*[8]. This standard was developed in response to Directive 2004/22/EC[9] of the European Parliament, called the Measurement Instruments Directive (MID). As a result, the acronym MID is often used to refer to the European standard.

Like the SANS standard, the international standards are often made up of a number of parts dealing with different aspects of water metering. The standards published by the OIML are available as a free download from their website www.oiml.org.

2.4 Metrology

It is important to understand that any measurement, irrespective of what is measured or how carefully the measurement is taken, has a limited accuracy. In other words, any measurement includes some degree of error, and thus there is some level of uncertainty included in the measurement.

Metrology is the science of measurement.

Metrology is the study of measurement accuracy, including how to determine the accuracy of a given measurement device and what sort of accuracy is required when measuring different things. In the broadest sense, metrology is the science of measurement.

There are different branches of metrology, such as for scientific measurements or industrial processes. The branch of metrology that is most important for water meters is called *legal metrology*, and deals with the legal requirements of measurements and measuring instruments in order to protect consumers and ensure fair trade.

It is important to understand and correctly use the metrology terms when dealing with water meters.

2.4.1 Definition of Meter Accuracy

The volume of water that passes through a water meter is called the *actual volume*, or V_a. However, since no meter is 100% accurate, the meter will not register all the water passing through it, but show a reading or *indicated volume* (V_i), which is normally slightly lower or higher than the actual volume. The difference between the indicated volume and actual volume (V_i - V_a) is called the meter *error*. When the *error* is expressed as a fraction (percentage) of the *actual volume*, it is called the *relative error*.

New water meters must be tested under controlled conditions in highly accurate testing laboratories. The meter error determined in this way is called the *intrinsic error*. The actual meter *error* will be different from the intrinsic error, since field conditions can vary greatly from those in a laboratory, and accuracy reduces with meter age.

2.4.2 Meter Error Curves

Permanent flow rate (q_p), is the flow rate for which the meter is designed.

Water meters are designed for a specific flow rate, which is called the *permanent flow rate* or q_p (Q_3 in the new international standards). The meter should be able to work at the *permanent flow rate* (or a lower flow

Actual volume, V_a: The total volume of water passing through the water meter, irrespective of how long this took.

Indicated volume, V_i: The volume of water indicated by the meter. For a perfect meter, this will be equal to the actual volume. However, most meters will indicate slightly higher or lower readings.

Error: The difference between the ***indicated volume*** and the ***actual volume***, or $V_i – V_a$.

Relative error: The ***error*** divided by the ***actual volume***.

Intrinsic error: The meter error determined under controlled conditions in a highly accurate testing laboratory accredited for this purpose.

Example of a meter accuracy calculation.

A water meter has an initial reading of 123.456 m^3. After exactly 200 l of water has passed through the meter over a period of 5 minutes, the meter reading is changed to 123.654 m^3. To determine the flow rate through the meter, and the relative error of the meter at this flow rate:

Actual volume V_a = 200 l.

Actual flow rate = ***actual volume*** / time = 200/5 = 40 l/min, or 2 400 l/h.

Indicated volume V_i = 123.654 – 123.456 = 0.198 m^3, or 198 l.

Error = $V_i – V_a$ = -2 l, i.e. the meter under-registered the volume by 2 l.

Relative error = ***error*** / ***actual volume*** = -2/200 = -1%. This means the meter under-registers the flow by 1% at a flow rate of 2 400 l/h.

rate) continuously for its design life without exceeding the permissible error.

Although a meter is designed for the permanent flow rate, the actual flow through a meter is not constant, but varies a great deal. Thus water meters should not only be accurate at the permanent flow rate, but over a wide range of flow rates.

The *relative error* of a meter is not the same for the full flow range of a water meter. For instance, mechanical meters tend to under-register at low flow rates and over-register at higher flow rates. In addition, as water meters age they tend to reduce in accuracy and generally under-register more.

It is useful to draw a graph of a meter's relative error as a function of the flow rate through it: this curve is called the meter's *error curve*. An example of a typical meter error curve for an inferential meter is shown in Figure 2-7.

To understand the accuracy curve better, consider a mechanical flow meter installed in a pipe with the supply valve completely closed, so that no flow occurs through the meter. Now the valve is opened very slightly to allow a very small flow to occur in the pipe. As the water moves across the meter sensor, it pushes against the sensor in an attempt to move it. However, the sensor is held back by friction forces, and at very small flow rates the water cannot overcome these friction forces to get the sensor moving. Thus the sensor remains static and the meter doesn't register the small flow passing through it.

If the flow is now gradually increased further, a point is reached where the water is just able to get the sensor moving, and for the meter to start registering a flow. This flow rate, the smallest that the meter is able to register, is called the *starting flow rate* q_{start}. It can be seen from Figure 2-7 that the meter under-registration error at the starting flow rate is large, which means that a lot of the flow through the meter will not be registered.

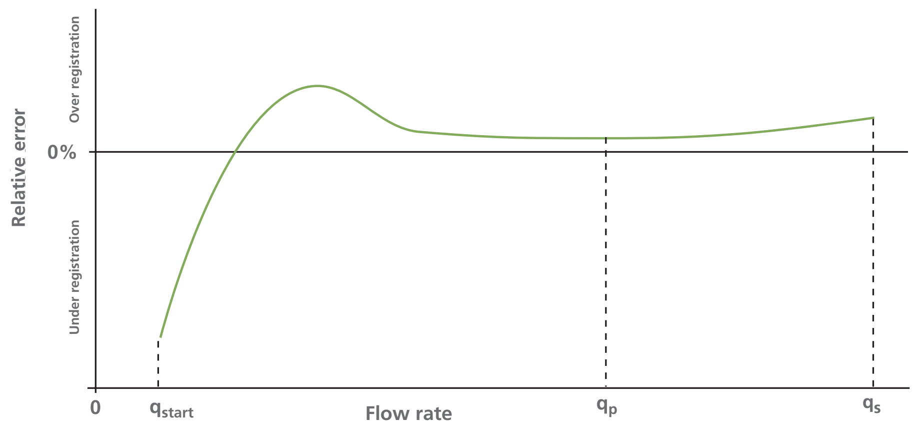


Figure 2-7 Typical error curve for an inferential meter

As the flow rate increases, the meter error reduces and becomes positive, i.e. it over-registers the flow. The positive error increases for a while before it reduces again (causing a bulge in the accuracy curve) and stabilises close to the zero-error line. This stable zone continues past the permanent flow rate and represents the ideal flow rate where the meter will produce the best results.

While the meter is designed to operate q_p continuously at the *permanent flow rate*, it is able to handle higher flows without detriment to the meter, as long as these higher flows last for only short periods at a time.

The *overload flow rate* q_s (Q_4 in the new international standards) is shown on the very right of the error curve in Figure 2-7, and should never be exceeded. If the flow rate through the meter is greater than the overload flow rate, even for a short period, the meter may sustain permanent damage. To define this point, the *overload flow rate* is defined as the highest flow rate at which a meter can operate for a short period without sustaining permanent damage.

Starting flow rate or q_{start}: The lowest flow rate at which the meter is able to register flow passing through it.

Overload flow rate, q_s: The highest flow rate at which the meter should be able to operate (within the required accuracy) for a short period without permanent damage to its accuracy.

2.4.3 Accuracy Requirements

The standards that specify the required accuracy of water meters have to take the typical accuracy curves of meters (Figure 2-7) into account. Thus they specify the *maximum permissible error* (MPE) of a meter as an outline or 'envelope' as shown in Figure 2-8. The *maximum permissible error* is the largest *relative error* that is allowed, irrespective of whether the error is positive or negative.

The maximum permissible error envelope is divided into two zones called the *lower* and *upper zones* respectively, and the meter is allowed to have a larger error in the lower zone than the upper zone. SANS 1529 specifies a minimum permissible relative error of 5% in the lower zone, and 2% in the upper zone as indicated in Figure 2-8.

The start of the *lower zone*, or the maximum flow rate at which the relative meter error should be less than 5%, is called the *minimum flow rate* q_{min} (Q_1 in the new international standards). The start of the upper zone, or the maximum flow rate at which the relative meter error should be less than 2%, is called the *transitional flow rate* q_t (Q_2 in the new international standards). The upper zone continues up to the specified *overload flow rate* q_s.

Simply put, the meter accuracy curve must

Maximum permissible error (***MPE***): The maximum allowable ***relative error***, irrespective of whether the ***error*** is positive or negative.

Minimum flow rate, q_{min}: The lowest flow rate at which the water meter is required to operate within the ***maximum permissible error***.

Transitional flow rate, q_t: A flow rate between the ***minimum flow rate*** and ***permanent flow rate*** at which the ***maximum permissible error*** of the meter is reduced.

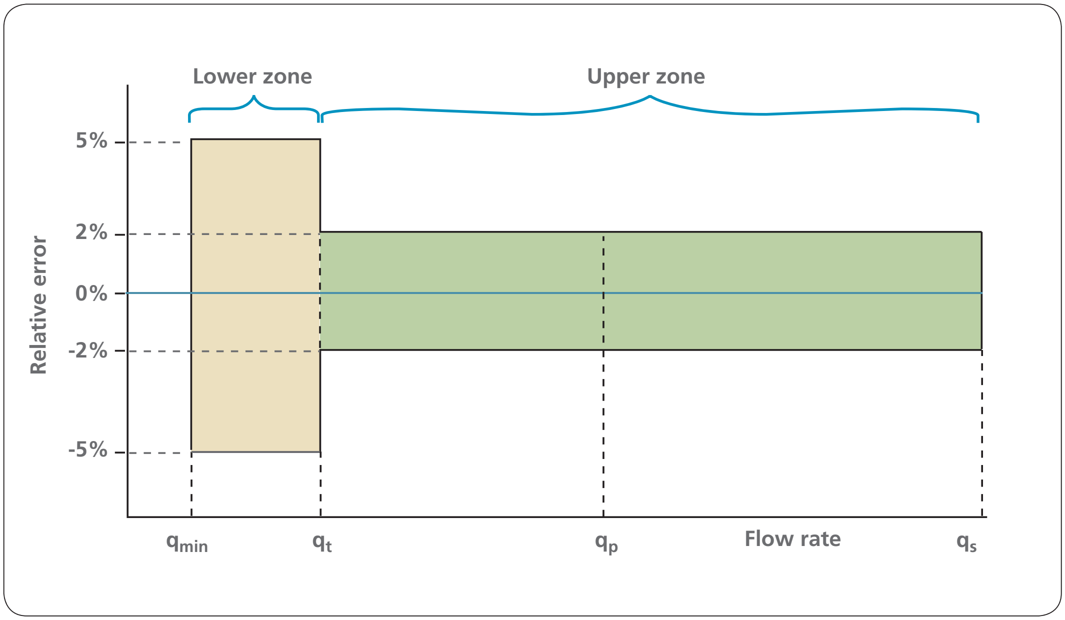


Figure 2-8 SANS 1529 requirements for meter accuracy

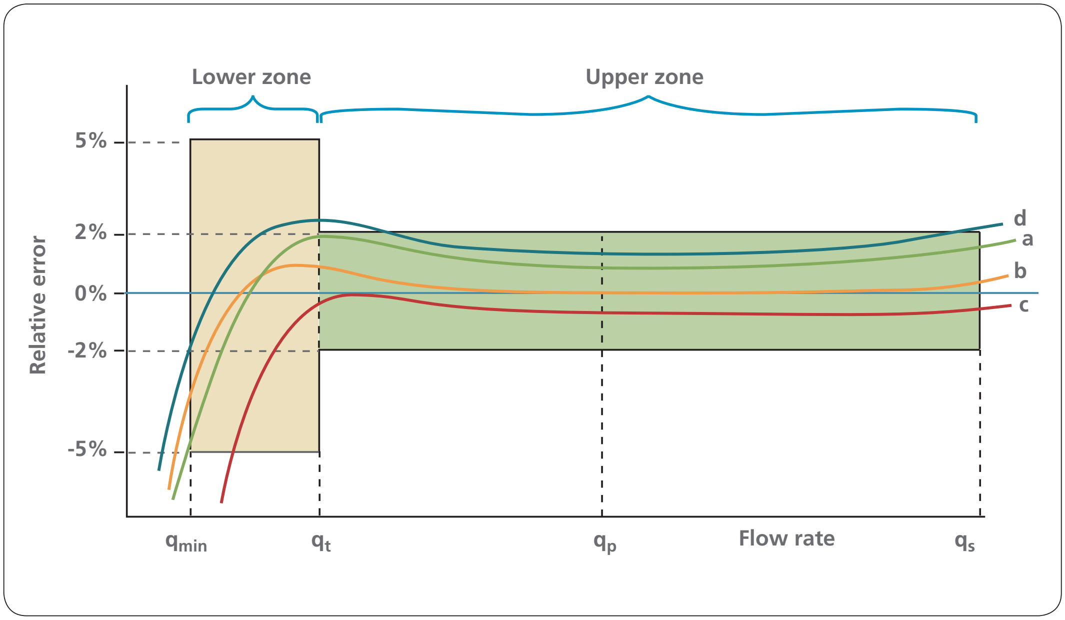


Figure 2-9 Examples of meters meeting the SANS 1529 standard (a and b) and not meeting the standard (c and d)

plot fully inside the specified accuracy envelope to comply with the standard. If any part of it falls outside the accuracy envelope, the meter is rejected. Figure 2-9 shows four meter accuracy curves plotted on the SANS 1529 requirements. Meters a and b fall fully within the accuracy envelope, and will thus be accepted. However, meters c and d have parts that fall outside the envelope and will be rejected.

It is important to realise that error envelopes defined by the standards are minimum requirements. The actual values for a meter can be (and mostly are) better than those specified by the standards.

2.5 Meter Classes

Meter classes are used to classify meters according to their accuracy performance. As discussed in Section 2.3.2, the conventional meter standards are being replaced in many countries by new standards that use a completely different approach to defining meter classes. However, the conventional standards will still be in use for many years even in those countries that adopt the new standards, and thus both metering class systems are discussed.

2.5.1 Conventional Meter Classes

Conventionally four classes of meters are defined and denoted by the letters A, B, C and D. The accuracy requirements are the same for all four classes, namely a maximum permissible error of 5% in the lower flow zone and 2% in the upper flow zone.

The differences between the classes lie in how high the transitional and minimum flow rates are allowed to be in relation to the permanent flow rate. Class A has the lowest performance and class D the highest performance. The requirements for the highest allowable minimum and transitional flow rates are given in Table 2-1 for meters with permanent flow rates up to 10 m^3/h. Table 2-2 does the same for meters with permanent flow rates larger than 10 m^3/h. Note that class A meters may not be used for trade purposes, i.e. at consumer connections.

In all cases, the overload flow rate of a meter has to be at least twice its permanent flow rate.

When water meters are taken out of the field and tested, they are allowed to show larger errors than new meters. The maximum permissible errors for these meters

Table 2-1 Meter classes defined by SABS 1529 for permanent flow rates up to 10 m^3/h

Increasing stringency ↓

Meter class	Minimum flow rate (q_{min})	Transitional flow rate (q_t)
A	0.04 q_p	0.10 q_p
B	0.02 q_p	0.08 q_p
C	0.01 q_p	0.015 q_p
D	0.0075 q_p	0.0115 q_p

Example: Consider a meter with a permanent flow rate of 1 m³/h or 1 000 l/h. The minimum accuracy requirements for this meter is shown in Figure 2-10 for classes A to D.

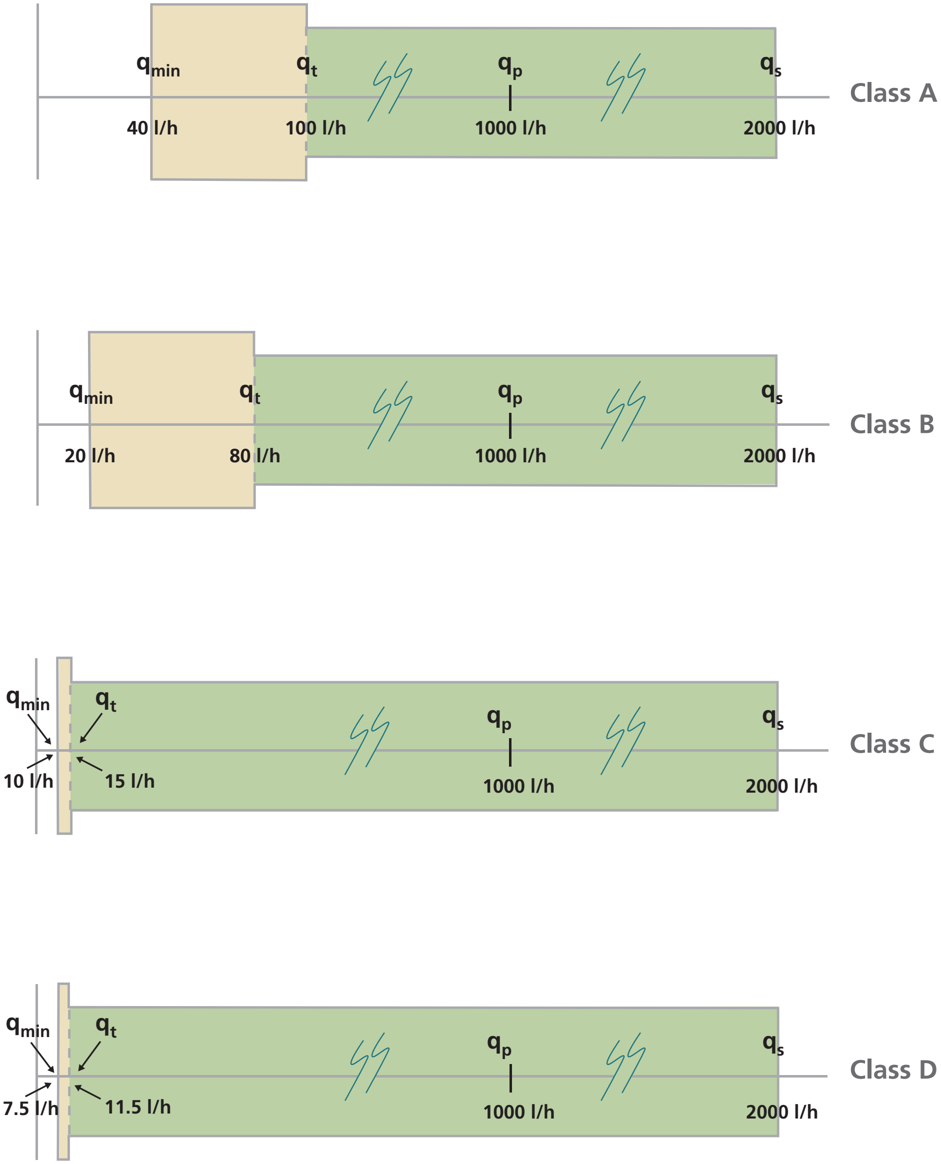


Figure 2-10 SANS1052 accuracy requirements for a meter with a permanent flow rate of 1 000 l/h for classes A to D.

Table 2-2 Meter classes defined by SABS 1529 for flow rates exceeding 10 m^3/h

Increasing stringency ↓

Meter Classes	Minimum flow rate (q_{min})	Transitional flow rate (q_t)
A	0.08 q_p	0.3 q_p
B	0.03 q_p	0.2 q_p
C	0.006 q_p	0.015 q_p

are 8% in the lower flow zone and 3.5% in the higher flow zone. Meters not satisfying these requirements may not be reinstalled in the field.

2.5.2 New Meter Classes

The new international standards such as OIML R49[5] follow a completely different approach to defining meter classes. They use the same definitions for the minimum, transitional, permanent and overload flow-rates, but instead of using the symbols q_{min}, q_t, q_p and q_s respectively for these parameters, the new standards use the symbols Q_1, Q_2, Q_3 and Q_4.

For any meter, the permanent flow rate is specified first. The minimum flow rate is then determined by using one of the following values for the ratio of the *permanent flow rate* to the *minimum flow rate* (Q_3/Q_1):

10	12.5	16	20	25
31.5	40	50	63	80
100	125	160	200	250
315	400	500	630	800

This ratio defines the meter accuracy range, and is often used with the letter R to describe the meter. For instance, a meter with a Q_3 to Q_1 ratio of 160 will be described as a R160 meter.

The ratio of the *transitional flow rate* to the *minimum flow rate* Q_2/Q_1 is fixed at 1.6. Finally the ratio of *overload flow rate* to *permanent flow rate* Q_4/Q_3 has to be 1.25.

The OIML standard specifies two meter classes (Classes 1 and 2) based on the maximum permissible error, rather than the width of the flow zones. Class 1 has the highest accuracy requirements with a maximum permissible error of 3% in the lower zone and 1% in the upper zone. For Class 2 meters, the maximum permissible error is 5% in the lower zone and 2% in the higher zone. These requirements are summarised in Table 2-3.

Only meters with permanent flow rates larger or equal to 100 m^3/h may be Class 1 meters (although these meters may also be Class 2 meters). Meters with flow rates less than 100 m^3/h may only be Class 2 meters.

2.6 Other Requirements

The South African standards have many other requirements with which water meters must comply. Some of these requirements are given in this section to provide an overview of the standards. However, it is important to consult the latest edition of

Table 2-3 Meter classes defined by IOML R49

Meter Class	Applicable to	Maximum permissible error	
		Lower zone	Higher zone
1	Only meters with $Q_p \geq 100$ m³/h.	3%	1%
2	All meters with $Q_p < 100$ m³/h. May be applied to meters with $Q_p \geq 100$ m³/h	5%	2%

the standards first hand when important metering decisions are made.

2.6.1 Materials

Water meters may only be constructed of copper alloy, plastics and stainless steel, except for 40 mm and larger Woltmann meters, which are allowed to use other ferrous materials. Parts of water meters that are in contact with the water are required to be of sufficient standard or coated to prevent corrosion or leaching of chemicals from the material into the water. In particular, certain countries (including South Africa) require brass components that come into contact with the water to be dezincification resistant (DZR). Plastic meter parts should be made of virgin plastic and should not be exposed to the sun. Thus exposed plastic meters should always be installed in meter boxes.

2.6.2 Flow and Water Quality

Acceleration devices, which are used to increase the speed of a meter at flow rates below the *minimum flow rate* to reduce under-registration, are not allowed.

All meters, except Woltmann meters and single jet meters of 50 mm and larger, should have an integral strainer or filter to protect its working parts from damage.

Meters should be able to withstand accidental flow reversal and have to indicate the reverse flow, although the reverse flow doesn't have to be measured at the normal meter accuracy.

2.6.3 Operating Conditions

Water meters are tested under controlled laboratory conditions, called *reference conditions*. However, the actual conditions under which a meter works in the field, including flow rate, temperature, pressure, humidity and electromagnetic interference, can be significantly different and are called the *metering conditions.*

The range of conditions under which a water meter is required to operate within its maximum permissible errors is called the *rated operating conditions,* and the extreme conditions under which a meter should be able to operate outside of its required accuracy (but without damage or permanent deterioration in its performance) are called the *limiting conditions*.

Values for the maximum admissible pressure, minimum admissible temperature and maximum admissible temperature of meters have to be specified by manufacturers.

2.6.4 Pressure

The average pressure that a meter operates under is called the *working pressure*. SANS 1529 assumes the working pressure to be 1 600 kPa unless otherwise specified. SANS 1529 specifies that meters have to be tested at pressures three times the working pressure, but not lower than 4 000 kPa and not higher than 6 000 kPa.

Water flowing through the meter will undergo a certain *pressure loss*, which will vary with flow rate and the type of meter. The allowed pressure loss through a meter is specified in groups by SANS 1529 as shown in table 2-4.

Table 2-4 Pressure loss groups defined by SANS 1529

Group	Maximum pressure loss
P100	100 kPa
P60	60 kPa
P30	30 kPa
P10	10 kPa

2.6.5 Seals and markings

Meters must be sealed in the factory after assembly and verification so that it is impossible to tamper with the meter without visible damage to the meter or seal.

The following markings should be added to the meter body:

- Manufacturer
- Permanent flow rate in m^3/h
- Serial number
- Direction of flow (i.e. an arrow)
- Meters for which parts can be exchanged in the field must have a mark on the body to indicate that the body has been approved for this purpose
- South African approval number (referring to type approval of meter model)
- Metrological class A, B, C or D
- If the meter is only suitable for horizontal or vertical installation, the letter H or V respectively should be displayed
- Working pressure if other than 1 600 kPa
- The pressure loss class.

3 Types of Water Meters

3.1 Introduction

A large number of water meters are available on the market today, and it can be an overwhelming task to select the right meter for a given application. Fortunately, when dealing with water distribution systems, it is possible to substantially narrow down the options.

The purpose of this chapter is to introduce the types of water meters that are commonly used in water distribution systems.

3.2 Classification of Water Meters

Water meters are generally classified based on the mechanism used by the meter to measure the flow passing through it. A classification of the meters discussed in this book, and the sections in which they are covered, is shown in Figure 3-1.

The first important distinction is whether the meter mechanism is based on mechanical, electromagnetic or ultrasonic principles. *Mechanical meters* have moving parts that detect the flow, such as a piston or impeller. *Electromagnetic* and *ultrasonic meters* have no moving parts, but detect the flow through the meter using electromagnetic principles or ultrasound waves. Electromagnetic and ultrasonic meters are discussed in Sections 3.8 and 3.9 respectively.

Mechanical meters make up the vast majority of meters used in water distribution systems. For instance, mechanical meters account for more than 99% meters installed in Tshwane[1]. Ultrasonic and electromagnetic meters are only applied in special cases, such as in very large pipes or where a particularly high accuracy is required.

Mechanical meters are categorised into volumetric, inferential and combination meters. *Volumetric meters* directly measure the volume of flow passing through them. Most volumetric meters use a rotating disk to measure the flow, and are known as *rotating piston meters*. These meters are discussed in Section 3.3.

Inferential meters do not measure the volume of water passing through them directly, but infer the volumetric flow rate from the velocity of the water. Two categories of inferential meters are commonly used: those meters using a radial vane and those using a helical vane *impeller*. *Radial vane* impeller meters are further classified into *single jet* and *multijet* (short for multiple jet) meters. *Helical vane* meters are also called *Woltmann meters*, and use a propeller-like vane to pick up the water velocity.

Single jet, multijet and Woltmann meters are discussed in Sections 3.4, 3.5 and 3.6 respectively.

Combination meters don't use a unique mechanism to measure the flow, but are

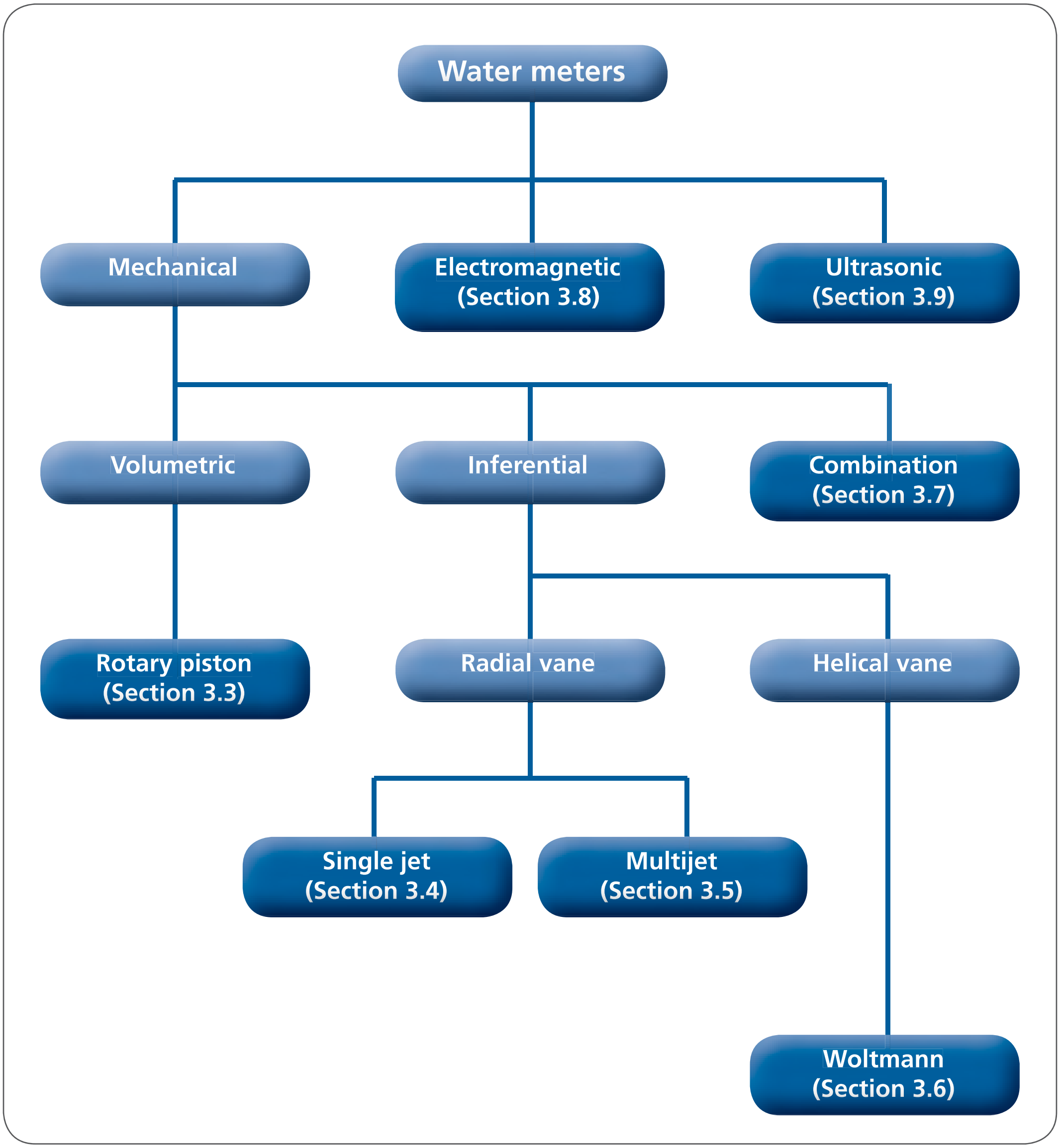


Figure 3-1 Classification of the common water meters covered in this chapter.

made up of two meters of different diameters that are combined to measure a particularly wide range of flow. They are discussed in Section 3.7.

3.3 Rotary Piston Meters

3.3.1 Mechanism

Rotary piston meters are *positive displacement* meters that use a rotating cylindrical piston to measure 'packets' of water moving from the inlet to the outlet of the meter. A simplified illustration of the meter mechanism is shown in Figure 3-2. (The figure shows a solid piston, but in actual meters the inside of the piston is hollow, and is used to carry more water.) However, the mechanism remains the same.

The cylindrical piston sits at an offset from the centre of the meter chamber, and divides the chamber into two compartments that are isolated from each other. The cylindrical piston rotates in a clockwise direction along the edge of the meter chamber.

In Figure 3-2(a), the piston has just moved across the meter inlet to create a small compartment where water is entering the meter (shown in light blue). The second compartment (shown in dark blue) is connected to the meter outlet. As the cylindrical piston moves along the meter chamber edge in a clockwise direction, the outlet chamber decreases in size, pushing water out through the outlet. At the same time the inlet compartment increases in size, and more water enters the meter through the inlet.

Figures 3-2(b) to (e) shows the progression of the piston along the meter chamber edge. In Figure 3-2(e), both the inlet and outlet are closed simultaneously, showing the 'packet' of water that is moved from the inlet to the outlet each time the cylindrical piston has made a full rotation. The process in Figure 3-2(a) to (e) is repeated, and since each rotation transports exactly the same volume of water, the volume passing through the meter can be accurately determined by counting the number of rotations.

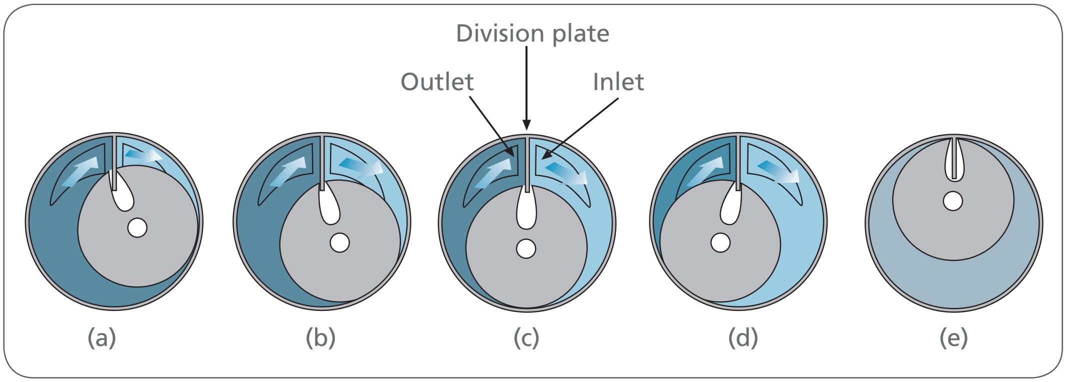


Figure 3-2 A simplified illustration of the mechanism of rotary piston meter. The rotary piston moves in a clockwise direction.

3.3.2 Characteristics

Positive displacement meters are popular for their combination of accuracy, long life and moderate cost, and are the meter of choice for most domestic applications[2].

Rotary piston meters come in many different shapes and sizes as can be seen from Figure 3-3. The meter housing is typically made out of brass or plastic, and the internal components from plastic. Wet and dry dials are used. It is important to note that plastic body meters have to be installed in valve chambers to protect them from the sun.

Rotating piston meters are sensitive to sand or other suspended solids in the water that can get stuck between the piston and

Figure 3-3 Examples of rotary piston meters. (meters provided by Elster Kent, Itron and Sensus)

chamber wall, jamming the meter. Thus it is important that these meters should only be installed in systems with very good water quality, and they should always be provided with built-in strainers.

A rotating piston meter in good working order is highly accurate, and it is the only type of domestic water meter available in Class D. These meters are very sensitive to low flows and are especially suitable for applications where low flow rates or on-site leakage frequently occur, such as domestic consumers.

The accuracy of rotating piston meters is dependent on water not leaking past the piston from the inlet to the outlet compartment. It is therefore important that they are manufactured to strict tolerances. As rotating piston metres age and wear through use, water is able to leak past the piston more easily, and thus the meters tend to under-register with age.

If air is forced through the meter, the metering error can be quite severe and the wear on the moving parts of the meter is increased substantially. It is recommended that an air valve is installed at an elevated point upstream of the meter to remove air from the system.

The typical metrological characteristics of commonly used rotating piston meters are summarised in Table 3-1.

Table 3-1 Metrological characteristics of common rotating piston meters

Class	Size (mm)	q_{start} (l/h)	q_{min} (l/h)	q_t (l/h)	q_p (l/h)	q_s (l/h)
C	15	1	10	15	1000	2000
C	15	3	15	22.5	1500	3000
C	20	4	25	37.5	2500	5000
C	25	6	35	52.5	3500	7000
C	30	11	50	75	5 000	10 000
C	40	18	100	150	10 000	20 000
D	15	3	7.5	11.5	1000	2000
D	20	6	18.75	28.75	2500	5000

Note: These are typical values supplied by meter manufacturers, and thus may be better (but not worse) than the requirements of SANS 1529.

Rotating piston meters have been in use for decades, and are very popular for domestic applications throughout the world. They have excellent sensitivity at low flow rates, and remain accurate irrespective of installation position. The main disadvantages of rotating piston meters are that they are sensitive to suspended solids in the water, prone to relatively high pressure losses, and that they can be more bulky and expensive than other meter types.

3.3.3 Application and Installation

Rotating piston meters are commonly used for domestic meters up to a diameter of 25 mm. The meter body must show an arrow indicating the flow direction through the meter, and it is very important to install correctly. Volumetric meters are not sensitive to the velocity profile of the flow entering the meter, and can be installed in virtually any position without significant loss in accuracy. They can also be placed close to bends or pumps.

3.4 Single Jet Meters

3.4.1 Mechanism

Single jet meters are *inferential* meters that use a single flow stream or jet to move the sensor, which consists of an impeller with radial vanes (also called a fan wheel). The rotation speed of the impeller is converted into a flow rate, which is registered on the meter. A cutaway view of a single jet meter is shown in Figure 3-4.

3.4.2 Characteristics

It is critical for the accuracy of a single jet meter that the path of the water through the meter is precisely controlled. Thus the inside of the meter has to be manufactured to strict tolerances. Traditionally the meter chamber is made out of brass, but plastics are also becoming popular. Brass chambers make the meter expensive, especially in larger diameters. Single jet meters are thus mostly used in the size range of 15 to 40 mm. Examples of single jet meters are shown in Figure 3-5.

The typical metrological characteristics of commonly used single jet meters are summarised in Table 3-2.

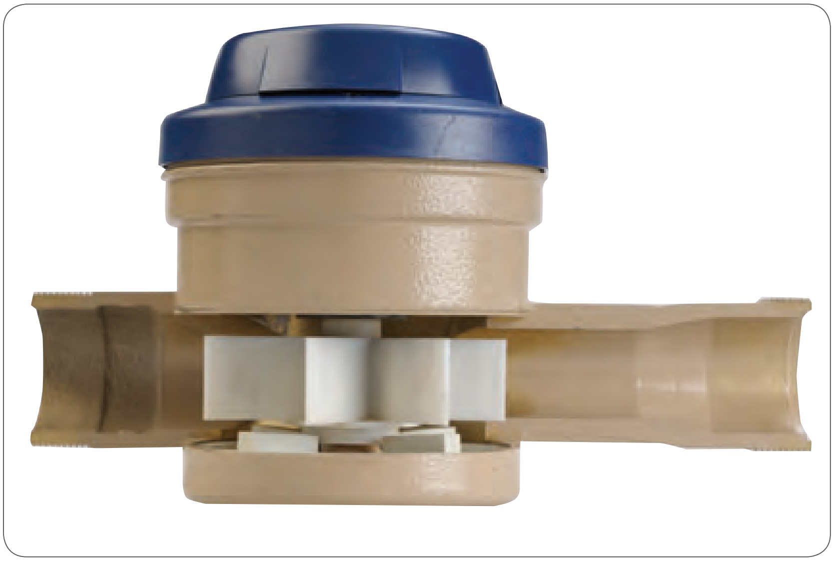


Figure 3-4 Cutaway view of a a single jet meter (meter provided by Itron)

Figure 3-5 Examples of single jet meters (meters provided by Sensus and Itron)

Types of Water Meters

Single jet meters may be affected by disturbances in the velocity profile, but in practice they are not very sensitive to disturbances like bends close to the meter. More critical factors, especially in shorter meters, are changes in the velocity profile that are caused by partially blocked strainers or by the rubber gasket due to the meter connection being too tight[3].

The accuracy of single jet meters reduces due to wear in the moving parts as they age. It is especially the starting flow and accuracy at low flow rates that deteriorate, and thus older meters tend to under-register more at low flow rates. At higher flow rates, the error can be positive or negative, and may be exacerbated by sediments or deposits accumulating inside the meter.

Table 3-2 Metrological characteristics of common single jet meters

Class	Size (mm)	q_{start} (l/h)	q_{min} (l/h)	q_t (l/h)	q_p (l/h)	q_s (l/h)
B	15	8	30	120	1500	3000
B	20	13	50	200	2500	5000
C	15	5	15	22.5	1500	3000
C	20	6	25	37.5	2500	5000
C	40	22	100	150	10000	20000

Note: These are typical values supplied by meter manufacturers, and thus may be better (but not worse) than the requirements of SANS 1529.

Air moving through the meter will be registered as water, and thus will cause the meter to over-register. Reverse flow through the meter is registered, but only at about half the normal accuracy.

3.4.3 Application and Installation

Single jet meters are mostly used in small diameters for domestic and other low volume consumers. They are popular for domestic metering in many countries due to their low cost and high reliability. Most single jet meters have to be installed perfectly horizontally and upright to ensure accurate measurements (especially at low flows) and a long meter life. However, vertical single jet meters are also available.

3.5 Multijet Meters

3.5.1 Mechanism

Multijet meters are *inferential* water meters. Their operation is similar to that of single jet meters, except that they use a number of jets to drive the impeller at multiple points. This means that the forces on the impeller are better balanced than in single jet meters, which reduces wear on the moving parts and provides greater durability. A cutaway view of a multijet meter is shown in Figure 3-6.

3.5.2 Characteristics

Multijet meters are similar in construction to single jet meters, although they tend to be slightly larger in overall size. Multijet meters are available in both wet and dry dial versions. In the dry dial versions of the meter, the watertight compartment housing the counter and indicator is normally manufactured from polymer plastic. In more expensive meters the compartment is often made from copper with a tempered glass lens. Examples of multijet meters are shown in Figure 3-7.

Figure 3-6 Cutaway view of a multijet meter (courtesy of Sensus)

Multijet meters are available as cartridge meters, in which the meter mechanism is enclosed in a pre-calibrated cartridge and can be replaced without removing the meter housing from the pipe system.

Multijet meters are fitted with strainers on the inlet side of the meter, which can be removed for cleaning. A second internal strainer often covers the openings of the meter chamber. A clogged internal strainer can affect the accuracy of the meter, normally causing over-registration of the flow to occur.

Multijet meters normally use an internal bypass with a regulating screw to adjust the flow passing through the impeller. This allows the manufacturer to adjust the meter's error curve to achieve the best accuracy before sealing it to prevent meter tampering. On cartridge type meters, the calibration device is internal to the cartridge.

The typical metrological characteristics of commonly used multijet meters are summarised in Table 3-3.

Table 3-3 Metrological characteristics of common multijet meters

Class	Size (mm)	q_{start} (l/h)	q_{min} (l/h)	q_t (l/h)	q_p (l/h)	q_s (l/h)
B	15	10	30	120	1500	3000
B	20	15	50	200	2500	5000
B	25	25	70	280	3500	7000
B	30	25	100	400	5000	10000
B	40	53	200	800	10000	20000
B	50	68	450	3000	15000	30000

Class	Size (mm)	q_{start} (l/h)	q_{min} (l/h)	q_t (l/h)	q_p (l/h)	q_s (l/h)
C	15	10	15		1500	3000
C	20	12	25	37.5	2500	5000
C	25	15	35	52.5	3500	7000
C	32	15	40	90	6000	12000
C	40	20	100	150	10000	20000
C	50	30	75	150	15000	30000

Note: These are typical values supplied by meter manufacturers, and thus may be better (but not worse) than the requirements of SANS 1529.

Figure 3-7 Examples of multijet meters (meters provided by Elster Kent, Sensus and Itron)

Reverse flow is possible through multijet meters, although the measurement error of the reverse flow is substantially higher.

Multijet meters use reliable and tested metering technology and normally have long working lives due to the balanced forces on the impeller. They are not very sensitive to the velocity profile in the pipe and are tolerant towards small suspended solids in the water. Disadvantages of multijet meters include their sensitivity to the installation position, and that they are often bulkier than single jet meters. They are not very sensitive to low flow rates, and the starting flow rate can deteriorate significantly with time. Finally, if some of the jet openings get clogged by dirt, accuracy may be significantly affected.

3.5.3 Application and Installation

Multijet meters are mainly used for domestic applications, and are normally more cost-effective than single jet meters in diameters larger than 20 mm. The accuracy of multijet meters is not affected much by changes in the velocity profile. However, they must be installed in a horizontal and upright (facing upwards) position for correct operation and optimal accuracy.

3.6 Woltmann Meters

3.6.1 Mechanism

The Woltmann meter is an *inferential* meter that uses an impeller with helical vanes. It resembles a fan or boat's propeller. As water flows over the helical vanes, it causes the impeller to rotate, and the rotation is then transmitted to the dial via reduction gearing.

Two main types of Woltmann meters are used, called Horizontal (WP) and Vertical (WS) Woltmann meters respectively. Horizontal Woltmann meters have their inlets and outlets directly in line with the pipeline, and the axle of the helical vane is parallel to the flow. Water flows directly through the meter with little disturbance by the meter body as shown a section through a Horizontal Woltmann meter in Figure 3-8.

Vertical Woltmann meters turn the flow by 90º, pass it through the impeller and then turn it back to the original flow direction as shown in the section through a Vertical Woltmann meter in Figure 3-9.

Since Horizontal Woltmann meters are much more common than the vertical version, most of the discussion will focus on Horizontal Woltmann meters.

3.6.2 Characteristics

Woltmann meters are named after the German engineer Reinhard Woltmann (died in 1830), who first used helical vanes to measure flow velocities. Woltmann meters are affected by flow distortions or changes in meter dimensions that may interfere with the way water passes through the meter. Deposits in the meter can cause over-registration at medium flows and under-registration at low flows. If deposits are excessive, they may touch the impeller, causing severe under-registration. All Woltmann meters have dry, sealed dials.

Examples of horizontal and vertical Woltmann meters are shown in Figures 3-10 and 3-11 respectively.

The easy passage of water through Horizontal Woltmann meters reduces pressure loss through the meter. However, since the transducer needs to turn the circular movement of the impeller through 90º to connect it to the counter, greater torque is required, which reduces the meter's sensitivity to low flows. The second important disadvantage of Woltmann meters is that they are sensitive to disturbances in the flow passing through them. Bends or valves close to a Horizontal Woltmann meter can affect the meter's accuracy. Spiralling flow, which can be caused by two successive bends in different planes, is especially unfavourable for their accuracy.

Horizontal Woltmann meters are used in a

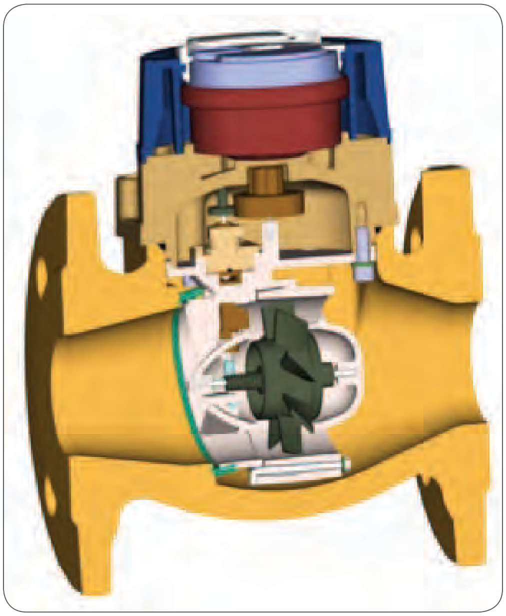


Figure 3-8 Section through a Horizontal (WP) Woltmann meter (courtesy of Itron)

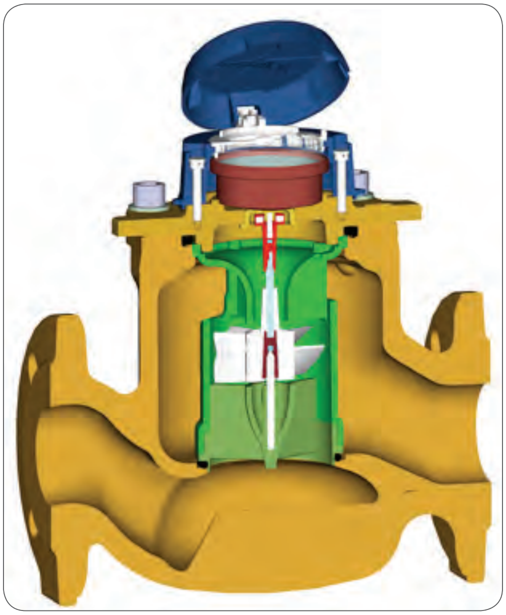


Figure 3-9 Section through a Vertical (WS) Woltmann meter (courtesy of Itron)

large range of pipe sizes, typically between 40 and 500 mm. In larger meters, the impeller will only cover a part of the meter cross-section, as illustrated in Figure 3-12.

Horizontal Woltmann meters are generally only available in Class B, although the metrological characteristics of these meters are often considerably better than the minimum Class B requirements. Manufacturers will often provide the measured as well as the legal metrological characteristics of the meter. The typical metrological characteristics of commonly used Horizontal Woltmann meters are shown in Table 3-4.

Horizontal Woltmann meters can handle difficult working conditions, and a moderate amount of suspended solids in the water can often be tolerated. The measuring range is very wide and the meter's working parts can often be replaced without removing the meter body from the pipe system. They can be installed in virtually any position. The main disadvantages of Horizontal Woltmann meters are their sensitivity to disturbances in the velocity profile, which often requires the need for a minimum length of straight pipe upstream and downstream of the meter, and their relatively low sensitivity to low flow rates.

Vertical Woltmann meters are less susceptible to disturbances in the flow pattern and more sensitive to lower flow rates. However, they have larger pressure losses than Horizontal Woltmann meters, and cannot handle the same maximum flow rates. Finally, they can also be significantly more expensive than Horizontal Woltmann meters.

Table 3-4 Metrological characteristics of common Horizontal (WP) Woltmann meters

Class	Size (mm)	q_{start} (l/h)	q_{min} (l/h)	q_t (l/h)	q_p (l/h)	q_s (l/h)
B	50	200	450	3000	15000	30000
B	50	200	750	5000	25000	50000
B	80	300	1200	8000	40000	80000
B	80	300	1800	12000	60000	120000
B	100	400	1800	12000	60000	120000
B	100	400	3000	20000	100000	200000
B	150	1100	4500	30000	150000	300000
B	150	1100	7500	50000	250000	500000
B	200	1600	7500	50000	250000	500000
B	200	1600	12000	80000	400000	800000
B	250	3000	12000	80000	400000	800000
B	250	3000	18000	120000	600000	1200000
B	300	10000	18000	120000	600000	1200000
B	300	10000	30000	200000	1000000	2000000
B	400	15000	30000	200000	1000000	2000000
B	400	15000	45000	300000	1500000	3000000
B	500	20000	45000	300000	1500000	3000000
B	500	20000	75000	500000	2500000	5000000

Note: These are typical values supplied by meter manufacturers, and thus may be better (but not worse) than the requirements of SANS 1529.

3.6.3 Application and Installation

Woltmann meters are widely used throughout the world. They are mainly used to measure the consumption of bulk users, or to determine the flow pattern in water distribution systems. For large diameter flow meters, manufacturers will express the permanent flow rate of the meter as the maximum monthly volume that the meter may register without causing a reduction in its service life.

Horizontal Woltmann meters can be installed in virtually any orientation without affecting their accuracy. The counter however should never be placed upside down. Since Horizontal Woltmann meters are very sensitive to the velocity profile passing through them, it is important to maintain a minimum distance of straight pipe upstream and downstream of the meter. The lengths of straight pipe required depend on the model of meter and the type of disturbances. The manufacturer's recommendations should be followed in this regard. Pipe reducers are not normally a problem, as long as the reduction is done gradually.

Figure 3-10 Examples of horizontal (WP) Woltmann meters. The top left picture shows the meter mechanism without the body. (Meters provided by Sensus and Itron)

Normally Horizontal Woltmann meters have larger errors in reverse flow, but certain models are designed to have similar accuracies in both directions. It is important to use such a bi-directional model when used in places where the flow direction may reverse, for instance in the water distribution network. If this is not done, an effort to use the meter in a water balance will be flawed.

Vertical Woltmann meters are very different, and may only be installed horizontally with the display facing upwards. Since Vertical Woltmann meters are not very sensitive to disturbances in the flow, significantly shorter straight lengths of pipes are needed upstream of the meters.

Figure 3-11 Example of a vertical (WS) Woltmann meter (meter provided by Itron)

Figure 3-12 A large Horizontal Woltmann meter (courtesy of Sensus)

3.7 Combination Meters

3.7.1 Mechanism

Combination meters are not really a separate class of meter, but rather a combination of two different classes, in such a way that they act as a single meter. The meters that make up the combination meter consist of a large meter, called the bulk or main meter, and a small meter, called the bypass meter. The main meter is typically a multijet or Woltmann meter, and the bypass meter a rotary piston, single jet or multijet.

An integral part of the combination meter is its control valve, called the changeover or commutation valve, which is installed in the same line as the main meter. At low flow rates, the changeover valve closes and all the flow is sent through the bypass meter, which has better accuracy at these low flow rates. Once the flow rate increases to a certain value, the change-over valve opens and the water flows through the large meter or in some cases through both meters. When the flow reduces to another critical value (lower than the opening value), the changeover valve automatically closes again.

A section through a combination meter, showing the main meter, bypass meter and changeover valve, is shown in Figure 3-13.

3.7.2 Characteristics

Combination meters have the widest measuring range of any meter. The meter reader must read both the main and bypass meters and combine the readings to obtain the total volume that has passed through the combination meter. Examples of combination meters are shown in Figure 3-14.

The changeover valve works automatically without an external energy source. The flow rate at which it opens is higher than the flow rate at which it closes. This is purposely done to avoid the valve fluctuating between the open and closed positions when the flow rate is close to the changeover point.

the meters when the switch-over valve is opened and closed.

A non-return valve is commonly fitted to the bypass meter, which means that reverse flow through the meter is impossible. Combination meters are manufactured in two basic configurations. In some cases both meters are encased in the same housing, resembling a single meter. The main benefit of this is saving space. In other cases, the bypass meter is installed on a visible separate pipe.

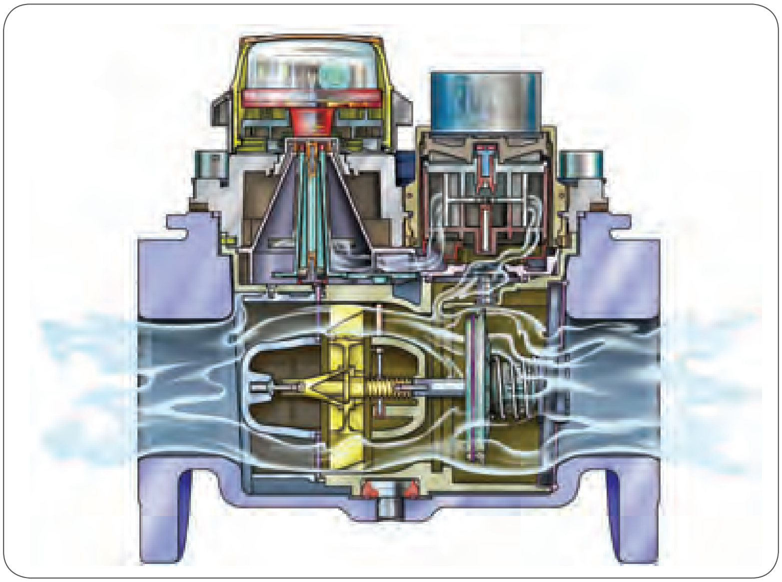


Figure 3-13 Section through a combination meter (Courtesy of Sensus)

The accuracy curve of a combination meter is made up of the accuracy curves of the two meters that it consists of, but with a certain area of overlap between the flow rates at which the changeover valve opens and closes. A typical accuracy curve for a combination meter is shown in Figure 3-15. The diamond shaped area in the middle of the curve indicates the overlap between

Combination meters are not normally certified metrologically, but each of the individual meters in the combination has to comply with the legal metrology requirements. The typical metrological characteristics of commonly used combination meters are summarised in Table 3-5.

Generally combination meters under-register more as they age. If not maintained, the changeover valve may start to leak, causing significant losses due to under-registration of these low flows passing through the main meter.

The main advantage of combination meters is their very wide measuring range. Disadvantages are their cost, the fact that both meters have to be read to obtain the combination meter reading, and the need for maintaining the changeover valve.

3.7.3 Application and Installation

Combination meters are normally used for consumers that have a large range of flows, such as housing complexes, hospitals and

Figure 3-14 Examples of combination meters (meters provided by Elster Kent, Sensus and Itron)

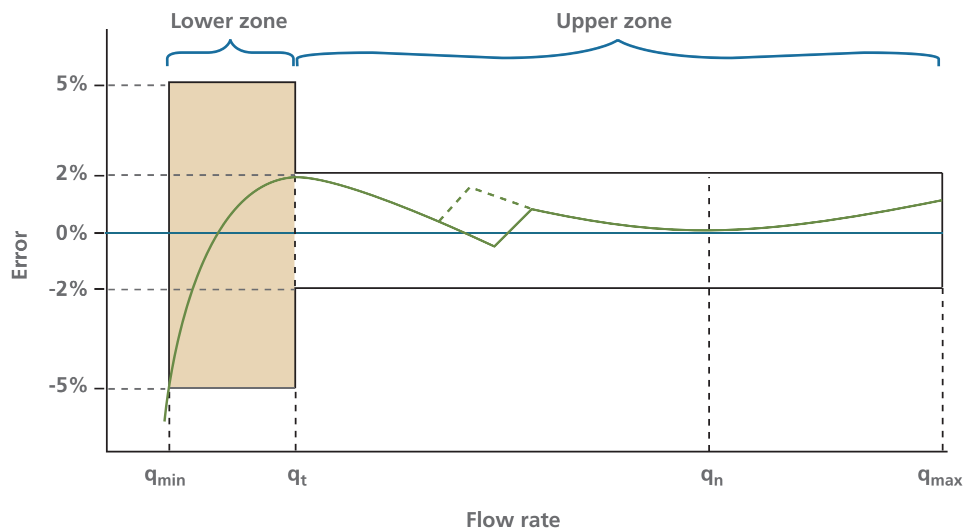


Figure 3-15 Typical error curve of a combination meter

Table 3.5 Metrological characteristics of common combination meters

Class	Size (mm)	Q_{start} (l/h)	Q_{min} (l/h)	Q_t (l/h)	Q_p (l/h)	Q_s (l/h)
B	50 x 20	10	25	37.5	25 000	50 000
B	60 x 20	10	25	37.5	25 000	50 000
B	80 x 20	10	25	37.5	60 000	120 000
B	100 x 25	13	35	52.5	60 000	120 000
B	140 x 40	38	60	2 000	150 000	300 000

Note: These are typical values supplied by meter manufacturers, and thus may be better (but not worse) than the requirements of SANS 1529.

schools. The installation of a combination meter has to comply with the requirements for both individual meters that make up the combination meter. It is important to adhere to the manufacturer's recommendations in this regard. Most manufacturers recommend the use of a separate strainer to protect the meter from suspended solids in the water.

3.8 Electromagnetic Meters

3.8.1 Mechanism

Electromagnetic or magflow water meters use a principle of electromagnetism, called Faraday's Induction Law, to measure the velocity of the water passing through it. Faraday's law describes the phenomenon that if a conductor moves through a magnetic field, an electric voltage is induced across the ends of the conductor.

In an electromagnetic flow meter, a magnetic field is created across the pipe. When water, which is an electrical conductor, moves through the magnetic field, a voltage is induced that is detected by electrodes in the body of the meter. The voltage is directly proportional to the flow velocity, which allows the flow rate to be calculated.

The voltage is measured by two electrodes placed at right angles to the magnetic field. If, for instance, the magnetic field is created between the top and bottom of the pipe, the electrodes will be placed on the sides of the pipe. Figure 3-16 shows the components of an electromagnetic flow meter. Note that the magnetic field is generated by the coils at the top and bottom of the pipe. The volumetric flow is determined from the flow velocity at the known diameter of the meter.

The sensor measurement is transmitted via an electric signal to an electronic counter, which converts the velocity readings to a volume. The flow rate is normally displayed on an LCD screen, but can also be obtained as an electronic signal to a telemetry system or flow logger. In some cases, all the meter components are combined in a single meter housing, while in others, the meter counter and indicator are in a separate location

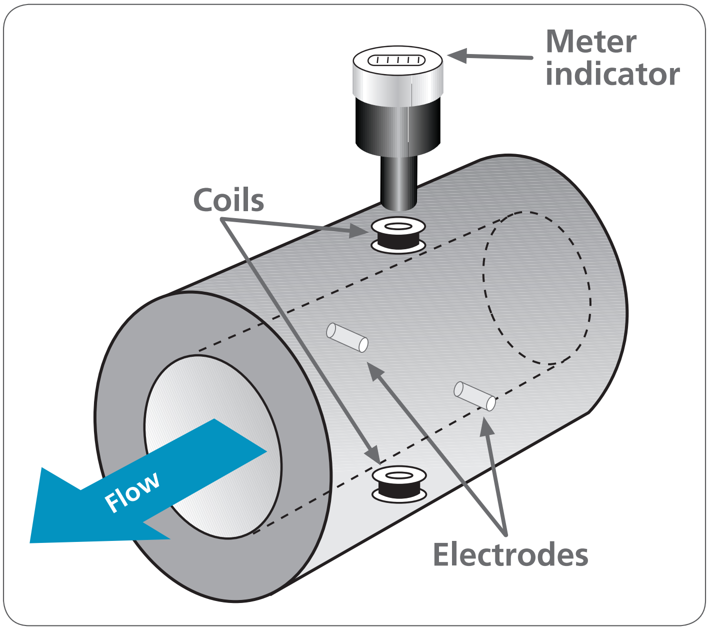


Figure 3-16 The mechanism of an electromagnetic flow meter (adapted from Arregui[3])

and connected to the sensor via a cable or remote connection.

3.8.2 Characteristics

Electromagnetic meters are very accurate within their measuring range (generally from 0.3m/s to 10m/s) and their accuracies are normally stated as a percentage of the reading plus a percentage of the full scale value. Most electromagnetic meters are configured for a fixed flow velocity range, typically from 0.5 m/s to 10 m/s. The meter is only able to measure flow in the defined velocity range, and thus it is important to select the correct meter for a given situation. Typical accuracy values range from 0.5% to 0.1%, but decrease at low flow rates.

Electromagnetic meters use electromagnets to create the magnetic field. Some meters use direct current (DC) to create a static magnetic field, while other uses alternating current (AC) to create a fluctuating magnetic field. It is important to know which type of current a meter uses, since DC meters typically have to be calibrated at installation and at regular intervals afterwards by setting the zero point when there is no flow through the meter. However, in AC meters, this is done automatically. Examples of magnetic flow meters are shown in Figure 3-17.

Advantages of electromagnetic meters are that they offer no obstruction to flow, produce virtually no pressure loss, have no moving parts subject to wear, are highly accurate and are immune to variations in fluid density, pressure, viscosity or temperature. Their accuracy can, however, be affected by deposits forming on the electrodes, air in the liquid, turbulence, and to some degree, water hammer (pressure transients). These meters can also be sensitive to damage from lightning strikes. Finally, they also need an electrical connection or batteries to operate.

3.8.3 Application and Installation

The electrodes of an electromagnetic meter should preferably be mounted on a vertical pipe, but since this is generally not possible, the meter should be mounted with the electrodes on the horizontal axis to avoid an electrode being situated in an air pocket at the top of the pipe. Some meters have an additional sensor to detect empty pipe situations.

On-site power or backup battery power (certain models only) is a necessity and it is possible to lose readings and volumetric totals if backup power is not available.

The general guidelines regarding upstream

Figure 3-17 Examples of magnetic water meters (courtesy of Sensus, Elster Kent and Krohne)

straight pipe lengths is 5 to 10 times the pipe diameter, with about 3 times the diameter on the downstream side. If possible these lengths should be increased, but the loss in accuracy due to obstruction is not as great as with some mechanical meters.

The meters should be adequately earthed to the pipeline, except where the pipes have cathodic protection, in which case the meter must be isolated from the pipe work by means of isolating flanges. Continuity of the pipe can be achieved by bypassing the meter with an earthing strap.

3.9 Ultrasonic Meters

3.9.1 Mechanism

Ultrasonic flow meters utilise the properties and behaviour of sound waves when passing through moving water. Two types of ultrasonic meters using different mechanisms are used, i.e. transit time and Doppler meters.

Transit time ultrasonic flow meters are based on the phenomenon that sound waves slow down when moving through the water against the flow, and speed up when they move with the flow. A transit time ultrasonic meter has two sound transducers mounted at opposite sides of the pipe at an angle to the flow, as shown in Figure 3-18. Each of these sound transducers will in turn send out an ultrasound signal to the other transducer. The differences in the transit times of the signals are then used to determine the flow velocity, and subsequently the flow rate.

Doppler ultrasonic flow meters use the so-called *Doppler effect,* which is the change in the frequency of a sound wave when it is reflected back from a moving object. A sound wave created in a moving fluid will hit small dirt particles or air bubbles moving with the fluid and bounce back towards the origin of the signal. The reflected ultrasound waves are detected by a receiver, and the change in the wave frequency is measured. This shift can then be related to the velocity and thus flow rate of the water. This mechanism is illustrated in Figure 3-19.

3.9.2 Characteristics

The accuracy of *transit time ultrasonic meters* depends on the ability of the meter to accurately measure the time taken by the ultra-sound signal between the sound transducers. Larger pipes have longer path lengths and thus the speed of the signal, and the flow rate, can be measured with higher accuracy. Transit time meters work better in clean fluids and thus are ideal for drinking water pipes. They measure the average velocity of a fluid, but are sensitive to the velocity profile in a pipe. In some cases multi-beam devices are used to improve the meter accuracy.

Permanently installed transit time meters are often called wetted transducer meters, since their sound transducers are in direct contact with the fluid. These meters are very reliable and typically have relative errors between 0.25% and 1%. They can be used on pipes ranging from 10 mm to greater than 2 m in diameter, although they are not often used on small diameter water pipes. The ideal flow velocity range for good accuracy is 0.5 to 10 m/s.

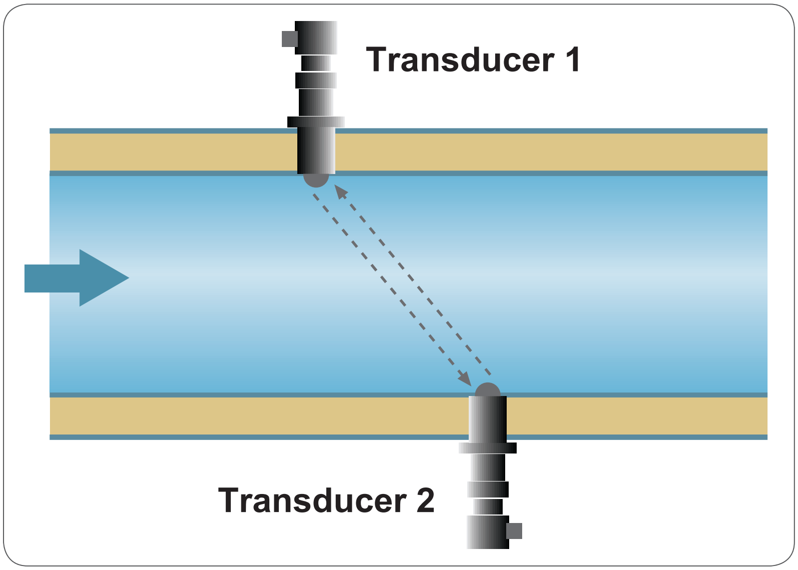


Figure 3-18 Operating principle of a transit time ultrasonic flow meter (adapted from Arregui[3])

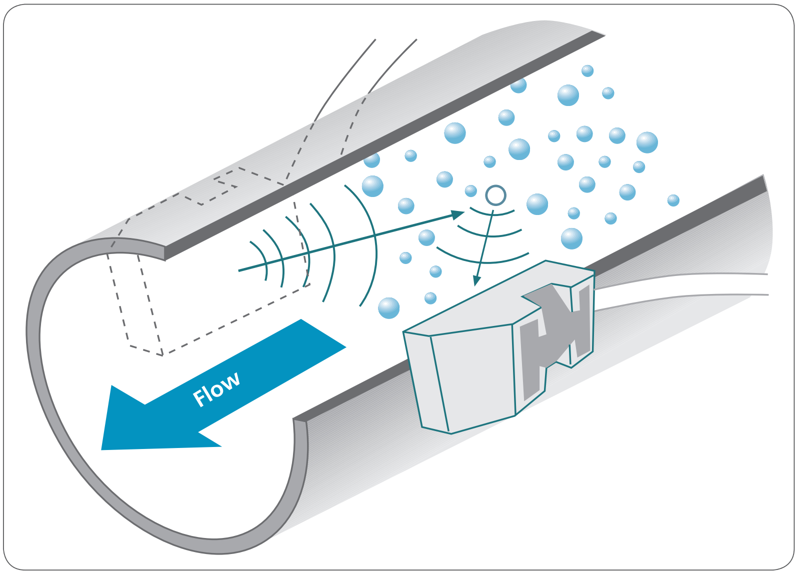


Figure 3-19 Operating principle of a Doppler ultrasonic flow meter (adapted from Arregui[3])

Clamp-on transit time meters use sound transducers that are clamped externally onto the walls of a pipe to provide portable non-intrusive flow measurement. They can be used on virtually any pipe material including metals, plastics, fibre cement and lined or coated pipes. A disadvantage is that the

Figure 3-20 Example of an ultrasonic flow meter (courtesy of Sensus)

ultrasonic pulses must traverse pipe wall and coatings, and thus the thicknesses and acoustic properties of these elements must be known. Deposits on the inside pipe surface can affect signal strength and performance. Modern clamp-on meters incorporate microprocessors that allow mounting positions and calibration factors to be calculated for each application and can provide accuracies of 0.5% to 2% under controlled laboratory conditions. In practice, however, various factors decrease the accuracies, including the accuracy of clamping and precise knowledge of the pipe's internal wall thickness. Examples of transit time ultrasonic flow meters are shown in Figure 3-20.

The advantages of transit time flow meters include high accuracy and reliability, making them cost-effective for use in large pipes. The clamp-on version of the meter is easy to install without the need to shut down the pipe. However, transit time flow meters are sensitive to distortions in the velocity profile of a pipe, require an electricity supply and are not suitable for dirty waters.

Doppler ultrasonic water meters can only be used for water that contains particles or air bubbles, and thus they are more suitable for dirty water applications such as raw water. A drawback of Doppler meters is that fluid particles in the water sometimes move slower than the water itself, or are concentrated in parts of the pipe with lower velocities (e.g. close to the sides or bottom of the pipe), which can result in a measurement error of 10% or more. They are also sensitive to disturbances in the velocity profile, and require an electrical supply. While they are not suitable as billing meters, they can be cost-effective as flow monitors if measurement accuracy is not critical.

3.9.3 Application and Installation

Ultrasonic meters are often the most cost effective metering option for very large diameter pipes, and thus are not commonly used for fixed installations in water distribution systems.

Ultrasonic meters are sensitive to disturbances in the flow, and require significant lengths of straight pipe upstream and downstream of the meter. The lengths of straight pipe required depend on the model of meter and the source of the disturbance. It is therefore important to adhere to the manufacturer's installation requirements.

The accuracy of transit time ultrasonic meters can be affected by suspended particles or air bubbles in the water. In some cases, transit time sound transducers are installed in the horizontal plane (i.e. on the sides of the pipe rather than top and bottom), since air bubbles will tend to rise to the top of the pipe.

Another important factor that may influence the accuracy of transit time ultrasonic meters is sediments in the pipe. Sediments can accumulate over time at the bottom of a pipe, even in clean drinking water networks. The sediments can disturb the ultrasound signal, and reduce the pipe diameter, which will introduce errors into the measurement. The recommended procedure to avoid sediments accumulating in the meter is to ensure that the flow velocity through the meter is between 2 and 6 m/s. At such high velocities, any sediment will be flushed out of the meter.

An advantage of transit-time ultrasonic water meters is that they can be clamped on the outside of a pipe. Clamp-on meters are easy to transport and can be easily installed in any location where the pipe is exposed without interrupting the flow. However, the accuracy of clamp-on ultrasonic meters in the field is generally not good and they cannot, for instance, be used to check the accuracy of in-situ meters. The reasons for this are that the meter reading is very sensitive to many parameters that are difficult to determine accurately for a pipe in the field, including the water temperature, exact properties of the pipe material (thicknesses and elasticities of the pipe wall and any coatings and linings used) and condition of the inside of the pipe (extent of deposits, sediments and biofilm growth). Due to their lower accuracy, clamp-on meters are mainly used to check, or get a rough estimate, of the flow in a pipe.

For clamp-on meters, it is important that the sound transducers make good contact with the pipe material, and therefore the connecting points on the pipe should be thoroughly cleaned. In painted pipes, it is recommended that the paint be removed at the contact points. For small pipe diameters, the sound transducers of clamp-on meters are often installed on the same side of the pipe, with the signal bouncing against the opposite pipe wall to reach the receiver. This stretches the travelling distance and time, and makes the meter more accurate. For large diameter pipes, the sound transducers can be installed on opposite sides of the pipe. It is recommended that several measurements are made in different planes of the pipe to ensure reliable readings.

Insertion Water Meters

An insertion water meter consists of a probe that is inserted into a pipe to measure the flow velocity at a particular point (or sometimes at a number of points) in the pipe. Depending on the type of insertion meter, it measures the velocity using electromagnetic principles, a turbine or differential pressure measurement. Insertion meters are relatively simple to install (once some basic modifications have been made to the pipe work) and can thus easily be moved from site to site. The velocity of water flowing in a pipe is not the same at all points, and thus it is important that the sensor of an insertion meter is positioned accurately at a representative point in the flow. Correct use and an undisturbed velocity profile are critical for accurate measurement, and thus manufacturers' guidelines regarding handling, installation and maintenance should be strictly adhered to. Insertion meters are often used to check the accuracy of in-situ flow meters.

3.10 Comparison

The water meters discussed in this chapter have large differences in their mechanisms, measuring properties and requirements. A comparison of the basic properties and requirements of the different types of meters is summarised in Table 3-6. It is important to use the actual values for any meter used in the field. Typical replacement costs for meters are also given in Table 3-7 as a rough guide.

Table 3-6 Comparison of the meters discussed in this chapter

Property	Meter Type						
	Rotary Piston (Section 3.3)	Single Jet (Section 3.4)	Multi Jet (Section 3.5)	Horizontal (WP) Woltmann (Section 3.6)	Combination (Section 3.7)	Electromagnetic (Section 3.8)	Ultrasonic (Section 3.9)
Classification	Mechanical Volumetric	Mechanical Inferential	Mechanical Inferential	Mechanical Inferential	Mechanical Varies*	Electromagnetic Inferential	Ultrasonic Inferential
Sizes commonly used (mm)	15 – 40	15 - 40	15 - 40	40 - 500	50x20 -150x40	300 - 2000	400 - 4000
Sensitivity to velocity profile	Insensitive	Medium	Low	High	Medium*	Medium	High
Sensitivity to water quality	High	Medium	Medium	Low	Medium*	Very Low	Low
Typical classes	B, C and D	B and C	B and C	B	B	Not categorised	Not categorised
Pressure loss	High	Low	Medium	Medium	High*	Very low	Very low
Orientation	Any	Mainly horizontal	Horizontal	Almost any	Horizontal	Almost any	Almost any
Minimum straight length upstream	None	0 - 5 d	None	5 d	5 d	5-10 d	10 d
Minimum straight length downstream	None	0 - 3 d	None	3 d	3 d	3 d	3 d
Electricity required?	No	No	No	No	No	Yes	Yes

Notes: * Varies – the values depend on the individual meter types used; # d is the diameter of the pipe, thus 10 d means a length of pipe equal to 10 times the pipe's diameter.

Table 3-7 Typical replacement costs of meters[4]

Nominal Diameter (mm)	Typical replacement cost (R)
15	R1 700,00
20	R1 800,00
25	R2 000,00
40	R2 200,00
50	R3 800,00
80	R5 000,00
100	R10 000,00
150	R16 000,00
200	R32 000,00
250	R50 000,00
300	R100 000,00
400	R200 000,00
450	R380 000,00

Prepaid meters and other meters with electronic displays

Consumers sometimes misunderstand prepaid or other water meters with electronic displays, believing that the electronic display is the meter. It is thus important to communicate to consumers that the display does not drive the metering process, but simply shows the information it obtains from the water meter, which might be hidden from the consumer's view. Figure 3-21 shows an example of a rotary piston meter with an additional electronic display.

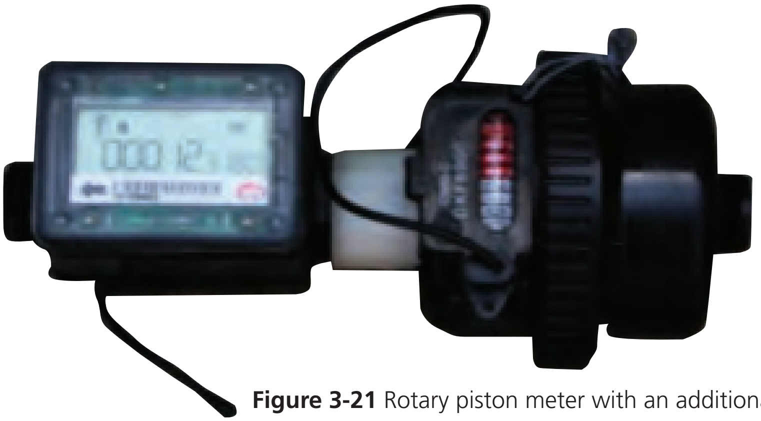


Figure 3-21 Rotary piston meter with an additional electronic display

Water Meter Selection

4

4.1 Introduction

The aim of this chapter is to provide a guide for selecting appropriate water meters for different applications in water distribution systems. It is important to have a consistent policy on where water meters are installed in the system, and to select the most appropriate water meter for each installation.

Selecting the right water meter model and size is very important. It is expensive to purchase and install a water meter, and thus the meter should perform well for an extended period of time before it has to be serviced or replaced. Meters that are cheaper may have much shorter life spans or higher maintenance requirements, and thus may not be the most cost effective option overall.

It is not easy to predict the long term performance of a water meter, as this will differ depending on the meter model, the system in which it is installed and the water consumption patterns of the consumer. Thus it is important that a municipality develops its own policy on water meter selection based on its own experience with different meters in its distribution system.

A municipality should have its own policy on water meter selection based on its experience with different meters in its distribution system.

Larger water meters are more expensive than smaller meters. In addition, larger meters of the same class have higher starting, minimum and transitional flow rates. This means greater levels of meter under-registration, which translates directly into lower levels of income for a municipality. Thus it is important that meters are not over-sized, as is often the case in South Africa and many other countries[1].

On the other hand, if a water meter is too small, the highest flows through the meter may exceed the meter's design parameters, causing permanent damage to the meter mechanism and rapid deterioration in meter accuracy. As a result, the meter will develop high levels of under-registration, and its service life may be substantially shortened. To get the greatest benefit from a water meter at the minimum cost, it is critical that the meter is correctly sized.

Most water meters in a distribution system are small domestic meters that are quite standard and not very difficult to select.

It is critical that water meters are correctly sized. A meter that is either too small or too large will cost a municipality more over its lifetime.

However, correct meters for non-domestic consumers and bulk domestic consumers such as blocks of flats are more difficult to determine, and can't be selected without analysis and good judgement.

It is necessary to follow a systematic procedure to select the best water meter for a given application. A meter should never be sized simply based on the size of the pipe it will be installed in. Such a selection does not consider the actual flow rate variations that can be expected to occur, and can thus easily result in a incorrectly sized meter.

A good guide to selecting the right water meter is to base it on the following questions:

- What is the purpose of the meter?
- Does the meter comply with the required standards and policies?
- Is the meter rated for the expected flow rates and operating conditions?
- Which is the most economical meter to use?

The first three questions are used to eliminate meters that are not suitable for an application, and the last to select the best meter out of those that are left. This procedure is discussed in the rest of this chapter and is illustrated in Figure 4-1.

Note that most manufacturers are able to provide software to assist with meter sizing. Appendix B lists some manufacturers that have meter selection software available.

4.2 Meter Application

It is necessary to distinguish between the location of a meter in the distribution system, and the application and purpose of the meter. The location of meters is important to ensure that all consumer usage is metered, but also that water distributed to different parts of the system is measured to identify consumption patterns and leakage.

Once it has been determined that a water meter should be installed at a given location, it is necessary to consider the application of the meter. Three major applications are identified and discussed: consumer, bulk transfer and management meters.

4.2.1 Where Should Meters be Installed?

To get the greatest benefit from a water metering system, it is important that meters are installed at locations that will support the management of the system on technical, financial and management levels.

It is generally considered good practice to install water meters at the following points in a distribution system[2]:

- Raw water withdrawals from dams, boreholes or other sources.
- Clean water production at the outflow of water treatment plants.
- Connection points to bulk water suppliers or other municipalities.
- Points in the system where it is important to know how much water is distributed, such as reservoir outflows, pump stations and off-takes to different areas.

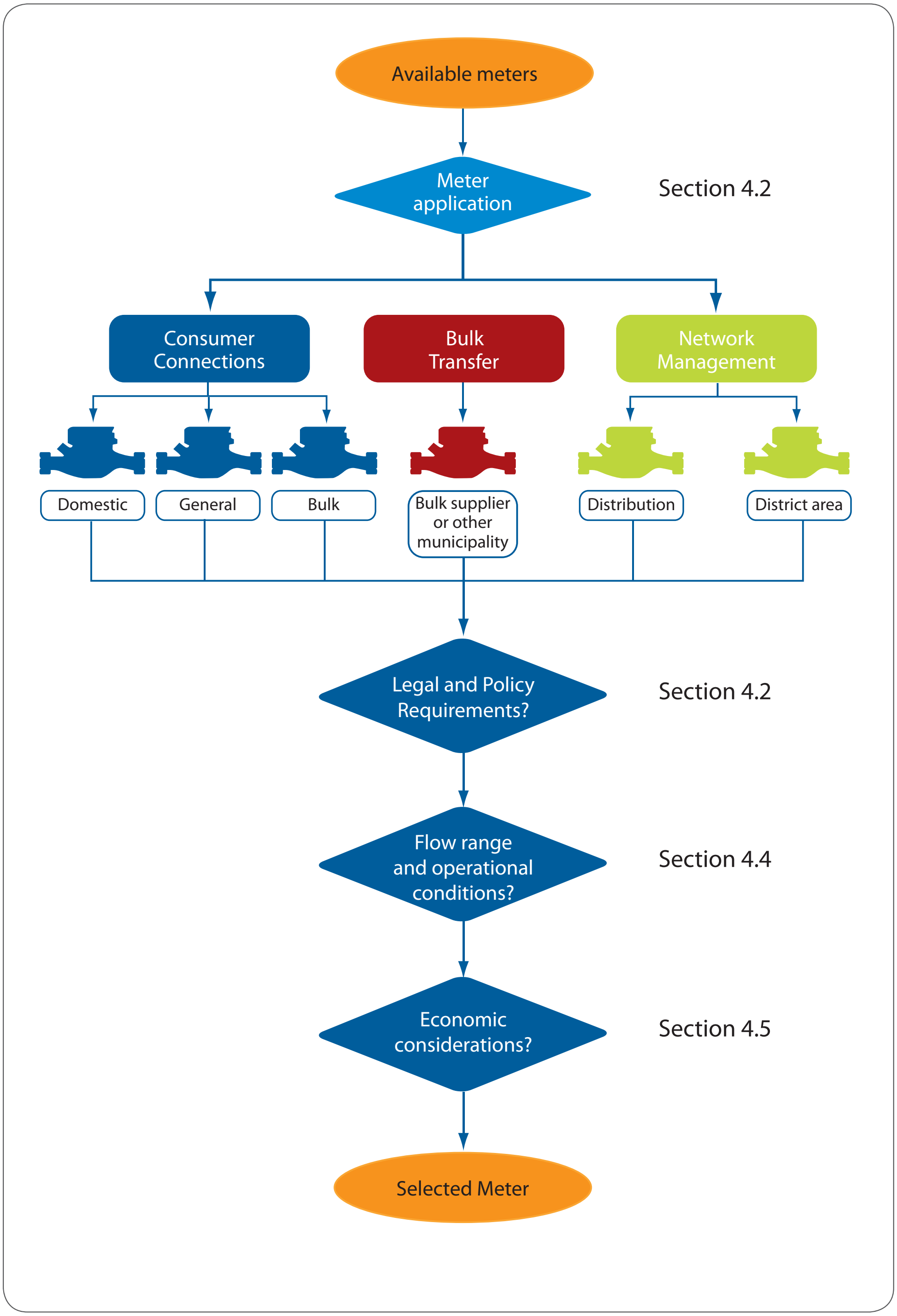


Figure 4-1 Steps in the meter selection process

- Supply points to district metered areas (DMAs)
- Consumers.

Figure 4.2 shows a typical water supply system with water meters at recommended locations.

District Metered Areas (DMAs) are commonly used to divide a water distribution system into smaller units that are easier to manage. DMAs are isolated from the rest of the system, except at one (or sometimes more) metered connection points. They typically consist of around 2 500 service connections[2].

Ideally, all consumers should be metered. Even if the water meter is not used for billing purposes, it is still important to measure the supply to a consumer for equity and water management purposes.

In many municipalities, fire hydrants on consumer properties have not been metered in the past. This is not recommended practice, since consumers can deliberately or unwittingly connect their consumption pipe work to the fire lines, resulting in significant levels of unmetered consumption in the system. If fire hydrants are not metered, it is possible to provide these connections with flow detection devices to identify illegitimate use. Other users that are often overlooked are public facilities such as parks, swimming pools and public toilets.

Case study: Tshwane generally installs water meters in the following locations:[3]

- Household or small domestic installations: 15-25 mm meters.
- General consumers such as flats, businesses, hotels, schools, etc: 40-150 mm meters.
- Very large consumers: meters greater than 100 mm.
- Reservoir inlet and outlet pipes: 50-800mm meters.
- Zone metering: 50-400 mm meters.
- Bulk transfers from bulk suppliers: 300-800mm meters.
- Own sources such as fountains and springs, boreholes and treatment plants: 100-500 mm meters.

4.2.2 Consumer Meters

Consumer meters measure the water delivered to different types of consumers, and thus are like cash registers for a municipality. In most cases, these meters' readings are used to bill consumers for the quantity of water consumed, and thus it is important that they accurately register the consumption. Strict legislation and standards, including SANS 1529, apply to consumer meters and have to be adhered to. For instance, class A meters may not be used as consumer meters.

Even when consumers are not billed for consumption based on their metered consumption, it is still recommended that all consumers are supplied with a water meter. This will allow the municipality to identify consumers with excessive consumption, for

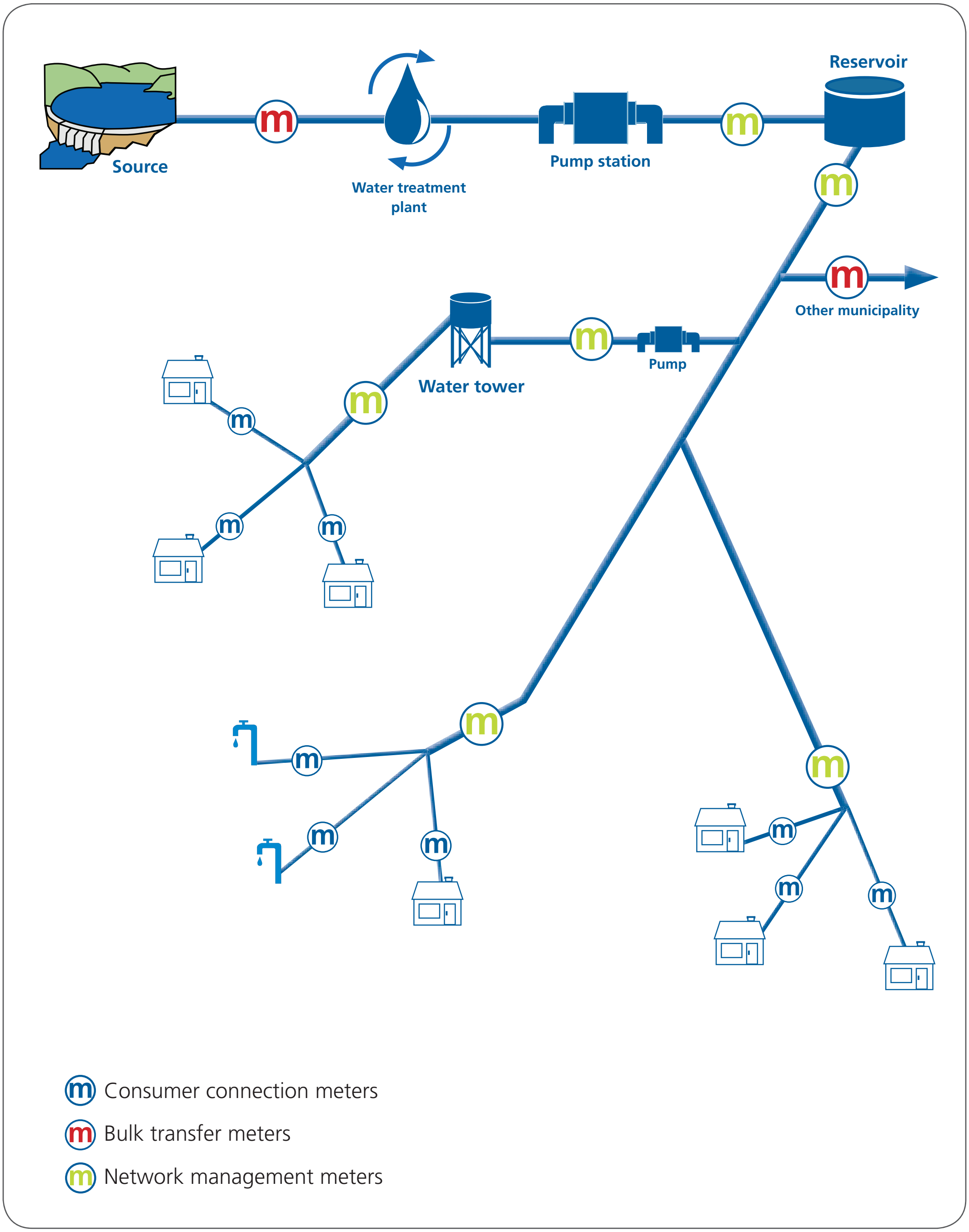


Figure 4-2 Typical locations of water meters in a distribution system

instance due to on-site leakage, and then take corrective action.

Consumer meter connections may be placed in two categories: small (up to 25 mm) and large (> 25 mm) connections. Generally, most meters in a municipality are domestic meters supplying single households. On the other hand, most of the water consumption is likely to come from industrial, commercial and institutional consumers, which are often collectively referred to as ICI consumers. Commercial and industrial users typically account for 50% of the income from water sales in a municipality[3].

In most cases a few large consumers are responsible for a large portion of the consumption in the system. The water meters installed at these consumers are particularly important, since meter inaccuracies may result in much greater losses to the municipality than for other consumers.

4.2.2.1 Small connections

Small connections are used for consumers that require water meters of 25 mm or less, including single housing units and ICI (institutional, commercial and industrial) users with low water consumption. The consumption behaviour of domestic users is similar in nature, and thus it is possible to have a simplified meter sizing procedure for estimating consumption or even selecting the meter size. On-site leakage often occurs on domestic properties, and thus sensitivity at low flows is important. ICI users in this category are small and use water mainly for human activities such as toilet flushing, washing and cooking.

4.2.2.2 Large connections

Large connections are those that require meters larger than 25 mm. Bulk consumers have the largest consumption in the distribution system, and thus the sizing and maintenance of their meters are very important.

4.2.3 Bulk Transfer Meters

Bulk transfer meters (sometimes called custody transfer meters) are used when transferring water from a source or bulk supplier to a municipality or from one municipality to another. Payment for the water is based on the meter readings, and since bulk transfers normally involve very large quantities of water, the accuracy of these meters is critical. Higher accuracies are often required than for other meters.

Bulk transfers are done based on a contract between the parties involved that should cover metering aspects of the transfer. Bulk suppliers are likely to have a metering policy in place, although municipalities sometimes install their own meters to verify measurements. Electromagnetic and three or five beam ultrasonic meters are commonly used in bulk transfers.

4.2.4 Management Meters

Management meters measure the distribution of water to different parts of the network. They are essential for many technical and management functions, including the estimation and management of water losses, pumping patterns, energy consumption, water demand patterns and hydraulic network calibration. Management meters are not used for bulk transfer or consumer billing, and thus the municipality has more freedom regarding the type and class of meter to use.

District area meters are management meters that measure flows entering a district metering area (DMA), and are important for estimating the demand patterns, future demand and leakage of discrete areas of the DMA. Since these estimates are done for discrete, relatively small sections of the network, they allow the municipality to better understand demand and leakage trends at different points in the network.

Management meters that are not district area meters are collectively called distribution meters.

4.3 Legal and Policy Requirements

All meters installed in the distribution should comply with applicable meter legislation. In addition, municipalities should develop their own policies to standardise processes that suit the conditions in that municipality.

4.3.1 Legal Requirements

In South Africa, national legislation specifies that consumer water meters must comply with the requirements of SANS 1529 and must be approved in terms of Section 18 of the Trade Metrology Act No. 77 of 1973 and Regulation Part II. For countries where such a legal framework is absent, it is still crucial for the water supply authority to only select meters that comply with a recognised water meter standard.

To get SANS 1529 approval, a meter has to pass a number of tests, consisting of:

- Type approval. A sample of the meter is put through a rigorous series of tests, including external inspection, pressure capacity, pressure loss, brass dezincification resistance, accuracy, endurance, magnetic interference and several additional tests for meters with electronic components.

- Initial verification test, in which meter accuracy is checked at a minimum of three flow rates.

- Verification test, in which each meter is tested for accuracy and sealed before it is installed in the field.

Samples of all consumer water meters sold in South Africa, whether manufactured locally or fully imported, have to be submitted to the SABS for approval. Once the product has been approved, the SABS will issue an approval number for that specific product. The approval number is prefixed by the letters SA, e.g. SA123, which must be clearly stamped into the body or counter of each meter.

Examples of SABS approved meters with their approval numbers shown are given in Figure 4-3.

Each consumer water meter sold in South Africa must be verified within the borders of the country for accuracy by a SANAS accredited test facility that meets the requirements of SANS 10378: 2003. The testing officer must be registered with the Depart-

Figure 4-3 Examples of consumer water meters showing their approval numbers (meters provided by Sensus)

ment of Trade Metrology as a verification officer. Each registered verification officer is issued with a pair of sealing pliers which bears a unique code. After verifying the accuracy of a meter, the verification officer seals the meter and marks his/her code on the seal. The year of verification is added to the other side of the seal. The verification officer's seal certifies that the meter's accuracy complies with the requirements of the Trade Metrology Act.

Imported meters that have been tested overseas must be re-tested in South Africa as described above, and the seals replaced with a seal with the verification officer's mark on it as required by the Trade Metrology Act. Figure 4-4 shows examples of seals on water meters.

Figure 4-4 Examples of water meter seals

The dezincification of brass is a problem in some areas of South Africa. In terms of the Trade Metrology Act, all brass water meters shall be manufactured from dezincification resistant brass (DZR) in compliance with SANS 6509.

In some countries, legislation requires water meters to be replaced at fixed intervals, for instance every five years. Such a policy might have certain quality control advantages, but is very unlikely to be the most cost-effective solution for a municipality. It is important that a municipality does not install water meters that are designed for a fixed replacement period in a system where meters are expected to serve for much longer periods.

4.3.2 Policy Requirements

A municipality should develop its own meter location and selection policy in line with its strategic objectives. Various considerations may be included in the policy, including where meters should be installed in the system, what classes of meters should be used and what meter models are acceptable. An example of a meter sizing table that may be used by a municipality is given in Table 4-1. Issues that may be addressed in a meter policy include the following:

- The meter classes or accuracy required for different applications. It is not sensible to install a meter with an accuracy of 0.25% when an accuracy of, say 5%, is all that is required. On the other hand, the measurement of water to consumers should be carried out more accurately to ensure equity and meters with acceptable accuracy should thus be used[4].

- The types of meters that are suitable for different applications, and preferred or prohibited meter types.
- Minimum installation requirements, including fittings, meter boxes to be used and straight pipe length requirements for different applications.
- Logging requirements, including which meters should allow for logging, and what pulse values should be used.

A metering policy can guide staff to select the right water meter for most general applications, only doing more extensive analysis and testing where the consumer or circumstances require it.

There are advantages to stick to a few tried and trusted meter models, since is easier and more cost-effective to train meter readers and technicians on fewer models, and it also means that fewer spare parts have to be held. On the other hand, there should be enough variety in the meter models used to

Example: Tshwane's list of allowable and preferred meter types for different applications.

Application	Typical meter size range (mm)	Allowable meter types (preferred meter type in bold)
Household, small consumer	15-25	**Multijet** Rotary piston
General consumer	40-150	**Woltmann WP** Woltmann WS Multijet Rotary piston
Large consumer	>150	**Woltmann WP** Electromagnetic
Reservoir outflows	50-800	**Woltmann WP** Electromagnetic Woltmann WS Insertion meters
Zone metering	50-400	**Woltmann WP** Insertion meters
Bulk supplier connections	300-800	**Electromagnetic** **Woltmann WP** Woltmann WS
Own sources	100-500	Electromagnetic Woltmann WP Insertion meters

ensure healthy competition between suppliers. Attention should be given to wider issues, such as logging equipment and communication infrastructure. Pre-paid water meters are known to use different communication standards, meaning that they are not interchangeable and that a municipality has to stick to the same supplier when maintaining or upgrading meters.

Table 4-1: Typical meter sizing table (adapted from Infraguide[2])

Meter			Application
Size (mm)	Type	Flow range (L/min)	
15	Positive displacement	1-55	Single family, duplex, small business (up to 10 staff)
20	Positive displacement	2-110	Large residences, homes with irrigation systems or swimming pools, flats with up to 6 units, petrol station without car wash, churches, small institutional users.
25	Positive displacement	3-185	Residences with pools and irrigation system, small to medium apartment buildings (6-17 units), small schools (up to 200 students), institutional (up to 50 staff), churches with other activities (e.g. day schools), large individual commercial buildings, group of commercial buildings (up to 10 units).
38	Positive displacement	5-375	Apartment buildings (18-40 units), old age homes (up to 50 units), schools (up to 400 students), medium-sized hotels (up to 30 units), large petrol stations without automatic car wash, small processing plants, small shopping centres, medium laundromats, restaurants, small hospitals (up to 100 beds), medical buildings.
50	Woltmann WP	7-600	Medium apartment buildings (41-120 units), duplex complexes (41-80 units), schools with small irrigation systems (up to 2000 students), medium hospitals, medium shopping centres, medium hotels, large petrol stations with workshops.
50	Combination	1-600	Schools with irrigation systems (2000-5000 students), medium hospitals, community centres, nursing homes, city halls.

75-100	Woltmann WP	40-1 900	Housing complex or apartment building (over 150 units), large laundromats, large institutional buildings, industrial plants, processing plants, hospital linen services, industrial cleaners.
75-100	Compound	2-1 600	Housing complex or apartment building (120-350 units), large hotel, hospital, high-rise office building, schools (over 2500 students), large shopping centres, large government buildings.

4.4 Flow Range and Operating Conditions

Water meters are expected to operate within the legally defined accuracy limits for an extended period of time. Thus it is important that a meter should be selected that can handle the flow rates and operational conditions expected at a given installation. The first aspect of an application to consider is the flow range that the meter is expected to handle, and the second includes all other operational considerations.

4.4.1 Flow Range

Each consumer has a certain water demand pattern that a meter will have to cater for. At the higher end of the flow range, it is important that the demand should never exceed the overload flow rate of the meter, and only exceed the permanent flow rate of the meter for short periods of time. At the lower end of the flow range, it is important that the meter should register low water demands and on-site leaks to minimise apparent losses due to meter under-registration.

A useful first step is to determine the annual average flow rate of the user. For existing users, the previous water meter readings in the billing system will provide this information, although these values may have to be adjusted for errors in the readings of the old meter. The consumption of similar users in the same municipality will provide a useful guide. The average water demand can also be estimated based on the type of user, the expected application of water, size and number of units served and the number of people or employees.

Once the annual average demand is known, the seasonal variation in demand can be estimated. Domestic consumers use significantly more water in summer than in winter. This is mainly due to watering of gardens in summer, although even domestic users without gardens tend to use more water in summer than in winter. Non-domestic users may also have seasonal trends in their water consumption due to seasonal variation in production or other water consuming activities. In towns that are popular holiday destinations, consumption of domestic users and businesses linked to the tourism industry may be substantially higher during holiday periods.

Water consumption also varies by day of the week. These variations are not normally large for domestic users, but can be substantial for commercial or industrial users that only operate during weekdays.

Finally, water consumption can vary greatly throughout the day. Domestic consumption typically has its peak early in the morning when people get up and prepare for the day, and a secondary peak in the early evenings. Commercial and industrial users often operate during specific hours when most of their consumption will occur.

It is possible to estimate the peak flow rate through the meter based on the types and numbers of fixtures on the property. *Loading units* are associated with different fixture types as shown in Table 4-2. Once the total number of loading units for a building has been determined, the peak flow rate through the meter can be read off the graphs in Figure 4-5.

Table 4-2 Loading units for different types of fixtures

Fixture Type	Loading Units
Bath mixer	4.0
Toilet with cistern	0.3
Toilet with flush valve	16
Shower head	0.6
Sink mixer	0.6
Basin mixer	0.4
Bidet mixer	0.2
Washing machine	0.6
Urinal	0.2
15 mm tap	0.3
20 mm tap	1.0

Domestic consumers can be grouped according to level of income, stand size and number of inhabitants for meter sizing purposes. The peak demand of domestic users without outdoor consumption rarely goes above 1 500 l/h[5], but can be significantly higher for users with large stands. For instance, tests on a 300 m^2 house on a 2 700 m^2 stand produced a peak demand of 2 500 l/h[6].

ICI consumption has much greater variation between different users, and thus it is important to consider the specific properties and needs of a consumer when determining their maximum consumption. Below are a number of points that should be considered[2]:

- Consider the types and number of water using fixtures. A large number of toilets or showers may mean that many people will use water simultaneously. Plumbing fittings may be designed for water efficiency, and thus use less water than normal fittings.
- Industrial processes using water may take water at a low, constant flow rate or in short intervals at much higher flow rates. Different processes may use water at different flow rates, and may be controlled manually, by timers or by demand.
- Landscape irrigation may be controlled manually or automatically. Automatic systems may employ timers or soil moisture levels to schedule irrigation periods.
- Consider the number of building occupants and hours of operation. Certain industries may have large numbers of staff on site for short periods only, before they disperse to other work sites.

Example: Determining the peak flow through a meter based on fixture loading units

Consider a house with 1 bath, 2 showers, 3 toilets, 2 wash basins, 2 sinks, one washing machine and 3 garden taps. First, calculate the total loading units for the house by adding up the loading units for the individual fixtures obtained from Table 4-2:

Fixture	Fixture loading units (from Table 4-2)	No of fixtures	Total fixture loading units
Bath mixer	4.0	1	4.0
Shower heads	0.6	2	1.2
Toilet with cistern	0.3	3	0.9
Wash basin mixer	0.4	2	0.8
Sink mixer	0.6	2	1.2
Washing machine	0.6	1	0.6
20 mm Garden tap	1.0	3	3.0
Total loading units for the house			11.7

Now look up the peak flow through the meter from Fig 4-5 (a) as 3100 l/h.

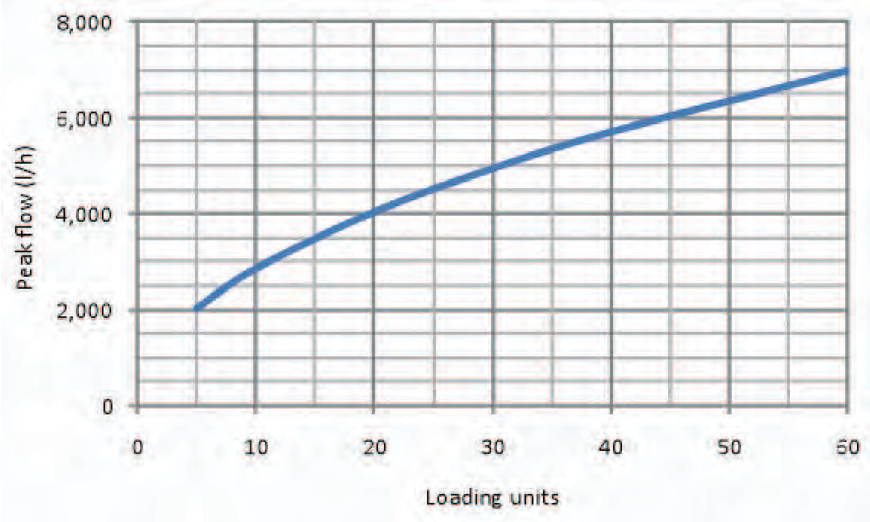
- Staff may work in shifts or take breaks at certain times, concentrating water demand into shorter periods of high usage.
- Buildings with flush valve toilets should normally not have water meters smaller than 25 mm.

The lower end of the consumer's flow range is important to estimate, since water meters are least accurate at flow rates lower than their transitional and especially minimum flow rates. If significant amounts of water are consumed at these flow rates, a significant fraction of the consumption may not be registered by the meter, and thus be a direct financial loss to the municipality.

An important source of low flows is leakage on consumers' properties. In a study in Johannesburg it was found[7] that around 65% of users in medium to high income residential areas had measurable on-site leakage. Dripping taps use between 0.13 and 1.25 litres per hour[8], while leaks from toilet cisterns can range between 0.4 to 14 litres per hour[9]. Comparing these flows to the typical starting flow of 6 l/h of a 15 mm class C meter, it is clear that such flows will mostly not be registered at all by the meter.

Another potential source of low flow rates occurs at properties where water is supplied to a user tank that closes with a ball valve. These ball valves can cause the tank inflow to be small when the tank is close to full. When the tank is full, normal household consumption may not lower the water level enough to open the ball valve fully, and thus a substantial portion of the tank inflow may occur at low flow rates. Studies in countries where consumer tanks are com-

(a)



(b)

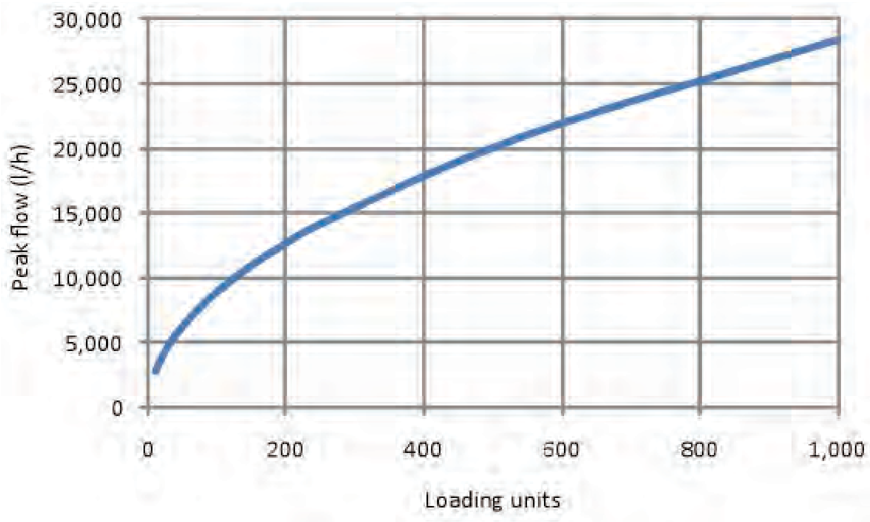


Figure 4-5: Relationship between peak flow and fixture loading units for buildings a) up to 60 loading units and b) up to 1000 loading units.

monly used have found apparent losses due to meter under-registration to be around 6%, even when the most stringent meter class D were used[10]. Where class B meters are used, these losses were found to be close to 20% for new meters, but increase to around 30% for meters that are 6 to 8 years old[11].

There are mechanisms on the market that claim to reduce low flow rates through the meter, such as special valves that supply low flows through a series of higher flow rate pulses, or special ball valves that do not reduce the flow rate as the tank fills up. However, it is advisable to do a feasibility study to ascertain the effectiveness of these devices in the field before they are used on a large scale.

If flow rates are not known, water meters one standard diameter smaller than the supply pipe are often used. However, this is not good practice since the real consumption pattern is not necessarily related to the supply pipe size. It should be noted that water meters are typically one size smaller than their end connections.

4.4.2 Operating Conditions

Besides the flow range through the meter, it is important that a meter is selected that suits the other operating conditions present at the installation site. While it is often possible to create installation conditions that comply with the meter supplier's recommendations, this is not always the case. In such cases, the appropriate meter should be selected from those that can be installed correctly at the site.

The most important operational conditions to consider when selecting a water meter are the following:

- ***Water quality***. The most important factor in water quality is solid particles, such as sand or even small pebbles, that may be suspended in or moving with the water. Particles may enter the system from the raw water source if the water treatment plant is not operating correctly, during repair work on the system, or through leak openings when the system is not pressurised. Rotary piston meters are very sensitive to suspended particles, which might cause them to stop operating altogether, and should not be installed in systems that don't have very good water quality (class D rotary piston meters are even more sensitive to suspended particles than the class C versions).

  Single jet and multijet meters can be affected by suspended particles, although not as much as rotary piston meters, and are thus preferred for domestic metering in systems with lower water quality. Blocked strainers that alter the flow profile through the meter can lead to significant errors.

  Woltmann WP meters are tolerant of bad water quality, and can even be used for raw water metering. Electromagnetic and travel time ultrasonic meters are not sensitive to suspended particles, as long as they do not settle in the pipe and thus affect the pipe diameter. Doppler ultrasonic meters require some suspended particles or bubbles to operate, although too many suspended particles near the pipe wall may cause wrong readings.

- ***Pressure.*** Water meters are designed to withstand much higher pressures than those in water distribution systems, and thus the system pressure would normally not be a problem. However, in pumping lines or bulk pipelines with water hammer problems, care has to be taken to ensure that the meter will not be subjected to pressures higher than its rating.

- ***Pressure loss***. Water will experience a pressure loss when passing through the meter due to friction and the effort required to turn the meter. Strainers can add significantly to the pressure loss through a meter, especially if they are blocked. In most water distribution systems, users are supplied at high pressures (above 20 m), and thus pressure losses through the meter is not a restricting factor. However, when the supply pressure is low during certain times of the day, it might be required to use meters with lower pressure losses.

- ***Continuous or intermittent supply***. Intermittent supply systems are systems that only provide water to consumers at certain times of the day. It is often a sign of a severely lacking supply system, and has detrimental consequences for water quality, leakage and the condition of the system. Suspended particles in the pipes are unavoidable due to ingress of sand through leak openings when the pipe is not pressurised. When the system is filled, air is pushed through the water meters, causing false readings and potentially damaging meters. Finally, reverse flow often occurs through the meters, creating further metering errors. If intermittent supply cannot be avoided, it is advisable to stick to simple and robust meter types, such as single jet or multijet meters.

- ***Data logging requirements***. There might be a specific need for logging the flow through a water meter at a certain resolution. In these cases it is important to consider the pulse values of different meters as a selection criterion. Most meters nowadays can be logged, although not all. It is important to ensure that meters have a reliable interface between the meter and the logger that will ensure reliable logger data. For instance, some meters will be able to send both forward and reverse flow signals to a logger, while most will treat all pulses as a sign of forward flow. In some cases meters standing still may dither around a certain value sending false signals to the logger.

- ***Theft and vandalism*** are problems in some areas, requiring special measures such as the use of plastic rather than brass meter bodies. Plastic bodied meters have to be installed in meter boxes to protect them from direct sunlight.

- ***Installation requirements***. Meters have to be installed strictly according to their manufacturers' specifications, which might include certain lengths of straight pipe upstream and downstream of the meter and specific meter orientations. Smaller meters are normally provided with threaded connections, while larger meters have flanged connections. Some installation locations may not allow for certain installation requirements, thus limiting the meters that can be used at these locations.

- ***Maintenance***. Maintenance is very important, especially for large meters, and thus manufacturers' maintenance requirements should be considered in the selection process. Meters with lower maintenance requirements are desirable, but it is important to note that no meter will work indefinitely without the need for maintenance or replacement

- ***On-site verification.*** If a need exists to verify the accuracy of meters in situ, provision needs to be made for the temporary installation of a verification meter. The installation requirements of the verification meter will have to be provided for, as well as a bypass to allow the meter to be installed without interrupting the water supply.

- ***Electrical supply***. Electromagnetic and ultrasonic metres normally need mains power supply. Some meters and related equipment operate with battery power (including pre-paid metering systems), and in these cases the working life and replacement possibilities of the batteries should be considered. Other related equipment, such as logging or communication equipment may also require an electricity supply.

- ***Meter reading.*** Different meter reading technologies are available, and it is important that the meter selection should consider the suitability of the meter and its installation position (above or below ground level) for the current and future metering technologies that may be used by the municipality.

4.5 Economic Considerations

The final step in the meter selection process deals with selecting the most cost-effective meter from those that have not been excluded by the preceding considerations. This means that the financial benefits and costs of each potential meter are estimated and used to determine the most appropriate meter for a given installation.

4.5.1 Costs and Financial Benefits of Water Meters

It is important to realise that the cost of a meter involves much more than just its purchasing price, but is made up of a number of components over the lifetime of the meter. The most important cost components are as follows:

- ***Price of the meter.*** The price of a water meter is a very important factor in meter selection, but should never be the only one. For instance, cheaper meters may have shorter service lives, or larger apparent losses than more expensive meters. Thus the other cost considerations should be considered with the meter price. However, when meters are projected to give similar performance and other costs, the price of the meter will obviously be the deciding factor.

- ***Installation cost.*** The installation cost of a meter is linked to its installation requirements and site conditions. Replacing an existing meter does not necessarily mean that the installation costs will be small, since refurbishment and upgrading of the installation is often required. In some cases, it is cost-effective to select a replacement meter with the same length as the old meter so that additional pipe work is avoided.

- ***Service life.*** The projected service life of a meter is a very important factor, since it determines how often the meter will have to be replaced. It is often more cost-effective to use more expensive, but higher quality meters that will have longer service lives, than cheaper alternatives.

- ***Cost of meter under-registration*** over its service life. Meter accuracy deteriorates as meters age, and normally this means that the meter will under-register more water. Meter under-registration is a direct financial loss for the municipality since it means that not all the water that is delivered to a consumer is paid for. It is thus necessary to estimate the under-registration losses of a meter over its lifetime based on the error curve of a new meter and the projected reduction in meter accuracy over time. Even though meter under-registration costs a municipality, the main motivation for meter accuracy should be to adhere to the legal requirements and not the cost of the under-registered water.

- ***Water price***. The price at which water is sold to the consumer is an important parameter, since this is the rate at which loss of income due to meter under-registration should be calculated. For municipalities that use block rates, the highest block rate applicable to the user should be used.

- ***Cost of lost sewage charge.*** If the municipal sewage charge is based on the water consumed, under-registration of the meter will cause additional financial losses due to a reduced sewage income.

- ***Maintenance costs.*** Meters, like any other working machinery, require maintenance to ensure that they work optimally over their service lives. Maintenance may include cleaning of strainers, cleaning and repair of meter boxes, fixing leaks and replacing damaged register covers. The specifications of meter manufacturers and policy of the municipality are important factors to consider.

- ***Operational costs.*** In some cases meters use electricity that will create operational costs. If solar energy or backup power have to be provided, these factors should be considered as part of the installation cost.

- ***Meter reading costs.*** Meter reading is a cost to a municipality, and using meters that are easier to read or may be read automatically, can reduce the meter reading costs. Future meter reading needs should also be considered.

Manufacturers' claims of meter performance are often based on laboratory tests that may not be valid under the conditions experienced in a specific distribution system. Thus it is important that a municipality should monitor the performance of different meter models in its own system to obtain an accurate picture of actual meter performance.

The main financial benefit of a meter consists of the revenue generated from water that is measured and paid for by the consumer. However, there are also indirect financial benefits derived from a meter, such as lower levels of leakage in the system due to better estimations of the levels and location of system leaks and the benefits derived from better system operation and planning.

If the total income generated through a meter is low due to low consumption, free basic water or lack of payment, it will be difficult to recover the cost of the meter. However, these meters are still important for water management in the system, and thus the financial considerations should aim at selecting the meter that will have the lowest cost over its working life.

4.5.2 Methods for Analysing Cost-efficiency

The difficulty with comparing the costs of a meter over its service life is that some of the expenses occur immediately (e.g. meter price and installation costs), some annually (e.g. cost of water under-registered) and some at the end of the service life (e.g. meter replacement cost). It is not a simple matter to weigh these costs up against each other, but various techniques have been developed to do this by taking factors such as inflation and interest rates into account. The most popular of the techniques are the *net present value* and *rate of return* methods, and it is recommended to investigate these methods and apply them when making big decisions about bulk meters or metering policy. Some methods for estimating the economics of meter replacement are discussed in Chapter 5.

5 Getting the Most Out of Water Meters: Operation and Maintenance

5.1 Introduction

The number of water meters used by a municipality often runs into tens or hundreds of thousands. Ensuring that each of these meters is in a good operating condition and complies with the legal metrological requirements is not an easy task, and calls for a carefully planned and systematic meter management system.

An effective meter management system needs adequate staff and financial resources. However, the cost of such a system is more than compensated for by the financial gains through higher efficiencies and lower apparent losses. It also aids the provision of a high level of service to consumers.

As with all types of working machinery, water meters have to be actively managed to ensure that they provide good service for a long period of time. All meters have finite service lives and have to be replaced when they either no longer comply with legal requirements, or it makes economic sense to replace them. It is always best to prolong the service life of a meter as much as possible.

A database containing information on all meters in a system forms the core of a good water meter management system, as shown in Figure 5-1. This database should be updated continuously as meters are checked and handled, and should contain relevant data on all meters installed in the network. Data that should be handled by the database include the meter reference number, size, make, date of installation, location, test and repair history. Handling of data on meters and meter readings are discussed in Chapter 6.

Four main components of a management system may be identified, and form the framework for this chapter. These components are linked to the central meter management database, but also to each other.

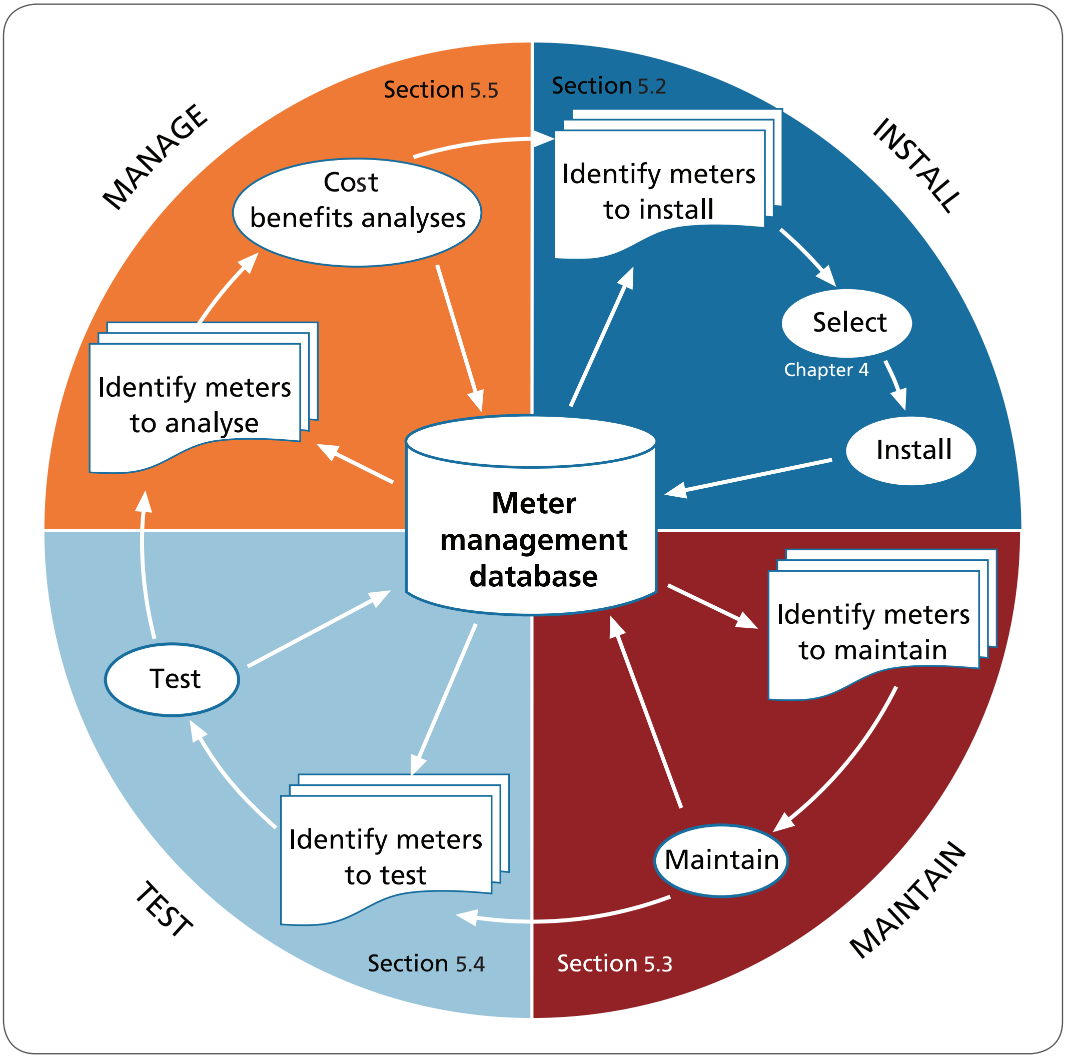


Figure 5.1 The water meter management process

The components are:

- ***Installation*** (Section 5.2) is the first step in a meter's service life, and is important to do correctly. Meters that are not installed in accordance with good practice and manufacturer specifications are bound to have shorter service lives and higher levels of under-registration.
- ***Maintenance*** (Section 5.3) is important to ensure that meters operate efficiently for the longest possible time.
- ***Accuracy testing*** (Section 5.4) need to be

Meters don't last forever and thus have to be tested at regular intervals and replaced if necessary.

done on selected meters. Without these tests it is impossible to know the actual performance of meters in the system.

- ***Analysis*** (Section 5.5) of meter accuracy and other data in the meter management database forms the basis for rational decision-making on meter replacement, service and selection.

Developing a fully operational meter management system can be a daunting task, and it may not be possible to implement it all at once. In such cases it makes sense to start with the bulk consumer and bulk transfer meters in the system. While these meters represent only a fraction of the meters in the system, they are normally responsible for a large proportion of the income of a municipality and thus the greatest potential benefits will be obtained from them. However, the ultimate goal should always be to develop a comprehensive management system that includes all water meters in the system.

5.2 Installation

Once a meter has been selected (see Chapter 4), it has to be installed in the system. Correct installation is critical since it will affect the performance of the meter for its full service life, and possibly also the performance of future meters when the meter is replaced. Incorrect installation may lead to high under-registration losses and shorten the service life of a meter.

Before the meter is installed, the connecting pipe work must be thoroughly flushed to remove any dirt that may otherwise block the meter strainer or damage the meter.

Meters can be installed outside the property boundary or inside the boundary where they are better protected against damage and vandalism. Meters outside the boundary are easier to access by meter readers, and are thus preferred by many municipalities. Finding and reading meters are made even easier if the meter is installed above ground rather than in a meter box, although this exposes the meter to damage from the elements and vehicles. In addition, air in the system water may collect in meters that are situated higher than the rest of the pipe work and above ground meters should thus be provided with air valves on the highest point upstream of the meter.

Metal-bodied meters can be installed in the open, but plastic meters must be protected from the elements by a meter box. Where a meter box is used, bricks or a small concrete slab must be placed as a foundation under the meter box and must be levelled to ensure that the meter box will also be level. The ground under the meter box must be well compacted. Sufficient space must be provided to access the meter for installation and maintenance purposes. A disadvantage of meter boxes is that they can fill with water due to rain or leakage, which can damage the meter over time and make it difficult to take readings.

Meter installation should only be done by staff that have been properly trained and have the right tools to complete the work in a competent manner.

A meter installation should comply fully with the municipalities' policies and manufacturer's requirements, including:

- Correct direction of flow through the

Case study: Incorrect meter installations.

Look at the multijet meters below and identify the installation problem in each. The correct answers are given at the bottom of the box.

Figure 5-2 Examples of incorrect meter installations

Answers:

(a), (b) and (c). Multijet meters installed vertically. Multijet meters are only approved for horizontal installation. (accuracy affected).

(d). Multijet meter face not horizontal (accuracy affected).

(e). Multijet meter installed close to rotary piston meter. The pulses generated by the rotary piston meter will affect the multijet meter's accuracy. The multijet meter is also installed vertically.

(f). Multijet meter face not horizontal (accuracy affected).

meter – an arrow on the meter indicates the correct flow direction.

- Correct orientation of the pipe work (e.g. horizontal or vertical).
- Correct orientation of the meter in the pipe (e.g. upright).
- Minimum straight lengths of pipe directly upstream and downstream of the meter. The straight sections of pipe should be installed directly to the meter and no reducers, valves or anything else should be installed between the meter and the straight pipe sections. Where straight pipes sections are not possible, flow straighteners or a different meter type should be considered.
- Some meters require the installation of a separate strainer upstream of the meter. The strainer should be accessible to facilitate cleaning or replacement.
- Isolating valves should be installed on both the upstream and downstream side of the meter.
- Meters using electricity need protection against lightning and electrical surges.

Large water meters often have additional installation requirements, such as:

- Allowance for in-situ testing of the meter.
- Flexible couplings to allow the meter to be easily removed.
- Necessary protection from shocks, vibrations and water hammer.
- Where a meter is installed in plastic pipes, it should be supported by concrete thrust blocks to prevent excessive pipe movements that can damage the pipe.
- Care should be taken that flange gaskets do not protrude into the pipe.

In cases where fire lines or hydrants are required on a property, it is recommended that the connection to the fire line is made downstream of the meter. The fire services should be consulted to ensure that all their conditions are met.

After the installation has been completed, it is recommended that the water is opened gradually to ensure that air is expelled slowly – a meter can suffer damage if subjected to high air flows. The following actions should be taken after each meter installation:

- The installation must be pressure tested to ensure that there are no leaks and that the meter is operating correctly.
- Where loggers or electronic flow reading and transmission equipment are used, the data recorded should be verified against the actual meter reading.
- As-built drawings should be drawn up.
- The meter management database should be updated with the new meter data.

5.3 Maintenance

Flow meters are often forgotten when it comes to routine maintenance. The proper maintenance of any metering device is essential to ensure it operates at its specified accuracy, and is of even greater importance for bulk consumer and bulk transfer meters. All meters require maintenance, although some may have lower requirements than others. Most meter manufacturers have a recommended maintenance and testing section in the operation manual for their meters.

A municipality should develop a water meter maintenance programme to suit their particular needs, circumstances and resources. Always keep the potential cost of not doing proper maintenance in mind. Maintenance is an ongoing process that should be done at a suitable rate to ensure that backlogs don't develop. A system that has a large backlog of required maintenance will need to invest higher levels of funds into maintenance until the required standard is met. Lower levels of expenditure will then be required to maintain the system at that level.

A problem with a bulk transfer or bulk user meter has the potential to cause much greater losses to the municipality than domestic and other small meters. Thus it is good practice to concentrate on these meters.

Water meter maintenance requires simple but important actions, such as cleaning of strainers, cleaning and repair of meter boxes, fixing leaks and replacing damaged registers and register covers. In certain cases,

The most common problems experienced with water meters in the field

1. Suspended solids in the water causing meter mechanisms to get stuck or damaged and meter strainers to get clogged. These solids enter the system most often due to:
   a. Large pipe bursts.
   b. Inadequate flushing of pipes after installations or repairs.
   c. High velocities in the network stirring up sediments that had collected at the bottom of pipes.
   d. Inadequate water treatment or malfunctioning treatment plants.
2. Service complaints after meter replacement or maintenance caused by:
   a. Valve on the house connection not re-opened after work.
   b. Network valve(s) not re-opened after work.
   c. Installation errors such as a non-return valve fitted the wrong way around.
   d. On-site leakage occurring, mostly on old and worn internal pipes and fittings.
3. Leakage from meter connections.
4. Vandalism to meters for scrap metal or in anger, often in 'retaliation' when indigent consumers are cut off.
5. Damage to meters to due high velocity air flow when drained pipes are refilled.
6. Consumer complaints of suspected meter errors.
7. Deposit of lime or metal oxides on the inside of meters due to high dissolved solid loads in the water.
8. Meters buried under soil and vegetation.

meters have to be removed from site and serviced before being placed back in the system. Where possible, large meters should be opened and a careful visual inspection made of the meter mechanism for any signs of damage or wear.

A checklist should be developed for use by meter inspectors in the field. This checklist should include the following information:

- Location and date.
- Inspector's name.
- Meter identification: make, model, size, serial number and current reading.
- Condition of meter installation: meter body, meter register, pipe work, leakage, upstream valve, downstream valve, meter chamber, strainer, signs of unauthorised connections and other.
- Actions taken: strainer cleaned/replaced, meter mechanism inspected and/or valve operation checked.
- Action required: cleaning, chamber repairs, meter test and/or leak repairs.

Knowledge of the system will guide a municipality on maintenance requirements of different meter models in different supply areas. The meter management database should be used to identify meters that need urgent inspection or maintenance, and information obtained from maintenance visits should be fed back into the database for future use. It is recommended that large water meters should receive a maintenance visit at least once a year. Domestic meters require less attention and meter readers may be used to report on leaks or problems that require attention.

Meters of 50 mm and larger can often be serviced instead of replaced. However, a municipality should have the capability to calibrate and test meters before servicing can be an option.

5.4 Meter Testing

Like any mechanical device, water meters deteriorate with use and generally under-register as they age. The starting flows and accuracy at low flows are the areas on the accuracy curve that tend to deteriorate most rapidly.

It is not possible to predict meter performance over time for all systems since there are so many factors that affect the way meters age, including water demand patterns, volume through the meter, water quality and environmental conditions. Thus each municipality should aim to understand the factors affecting meter accuracy and the performance of different meter models in its system.

It may also be desirable to log the flow through an existing meter in the system to characterise the flow pattern through the meter, or determine if the meter is correctly sized. It should be noted that the meter logged may have deteriorated significantly and the results should thus be interpreted in this light.

An important step in any meter testing programme is to ensure that the results of all tests are recorded in the meter management database for future reference and tracking purposes. Examining trends in meter accuracy records may help identify problem areas and direct the testing programme. It will also help identify when maintenance is required or when it is time to replace the meter.

5.4.1 Test Methods

When testing meters it is important to take the purpose of the test into consideration. If the accuracy of a meter needs to be verified for trade purposes, such as in response to a consumer complaint, the test methods used has to comply with metrology legislation and certification. If, on the other hand, the purpose of the test is to check the meter accuracy as part of a meter replacement study, the municipality can establish their own procedures that will satisfy the requirements for such a study. It should be emphasised that the accuracy of any meter test is very important – if the method used to test meters is not substantially more accurate than the meters being tested, the results of the tests are meaningless and cannot be used for any practical application.

Various methods are available for testing the accuracy of water meters. The most precise method is to remove the meter from the field and test it on a laboratory test bench. However, while such measurements are highly accurate and repeatable, they are not able to replicate site conditions that might affect the meter.

An alternative is to do field testing and thus obtain the accuracy curve of the meter as it operates in the field. No testing laboratories in South Africa can test meters larger than 100 mm, and thus field testing is often the only method available for large meters.

Any method used to test the accuracy of a meter should be substantially more accurate than the meter being tested.

If a water meter needs to be tested for trade purposes, such as in response to a consumer complaint, the test method has to comply with metrology legislation and certification.

Meters that are tested for other purposes, for instance as part of a replacement study, can be tested to the municipality's own standards. However, the accuracy of these tests are still very important.

In field tests a calibrated meter is installed in series with the meter being tested, and water is passed through both, often via an outlet such as a hydrant to waste. It is important that no air is present in the system and that the meters are tested under positive pressure. Thus the flow should be controlled on the downstream side of both meters. A number of field testing methods are available:

- A ***calibrated master meter*** is installed in line with the meter being tested. The meter can be left in place for some time before comparing the volumes through the two meters. This is an accurate method, but requires that allowance for this have been made in the pipe work. A simple way to test the accuracy of domestic meters is to connect the master meter to a tap on the property and control the flow rate through both meters using the tap. It is important to ensure that other fixtures are not used during the test, and to note that any on-site leakage will not be measured by the master meter.
- An ***insertion flow meter*** is installed directly upstream or downstream of the

meter to be tested. Insertion meters can only be used on pipes with a special connection for inserting the meter. The accuracy of the insertion meter should be checked regularly, and previous tests should have been conducted to determine the correct position of the meter in the pipe. However, if this is available, installing the insertion meter is simple.
Tests done by Johnson[1] have shown that insertion meters are capable of achieving high enough accuracies for meter verification in the field. However, it is important that these tests are done in strict accordance with manufacturer's specifications and by a qualified and experienced person.

- A ***portable test rig*** consists of a bank of calibrated flow meters installed on a trailer or portable rig. The water passing through the meter being tested is diverted through the test rig and the flow rates and volumes compared. The test rig is relatively easy to install and gives accurate results. Disadvantages are that the water tested is lost, and that a test rig is expensive to set up and maintain.

- A ***clamp-on ultrasonic meter*** is installed directly upstream or downstream of the meter to be tested. Flow and volumes are compared between the two meters. While clamp-on ultrasonic meters are easy to install on the outside of a pipe, they are sensitive to the water temperature, pipe wall thickness and condition, and the velocity profile. The errors of the ultrasonic meter may well be significantly larger than those of the meter being tested, making them unsuitable for meter verification in the field. However, they can be used to obtain a quick approximation of the flow rate through the meter.

To obtain a good estimate of the meter's error curve, it is necessary to test the meter at a number of different flow rates. The more flow rates are tested, the better the estimate of the error curve, but at least four points should be used. It is important to determine the starting flow of the meter. The meter should then be tested at its minimum and transitional flow rates, a point between these two flow rates, and another point close to the permanent flow rate. The accuracy of the meter near the permanent flow rate can be assumed to stay constant up to the maximum flow rate.

The relative error of the meter can then be plotted against the flow rate, and a curve fitted through these points as an estimate of the meter's accuracy curve.

5.4.2 Large Meters

All large meters need to be tested at regular intervals. The American Water Works Association (AWWA) recommends that meters between 25 and 100 mm are tested every five years, and meters of 100 mm and larger every year. Older meters and meters with the highest readings should be tested first as they are most likely to have deteriorated.

5.4.3 Domestic and Small Meters

AWWA recommends that domestic and small water meters are tested every 10 years. However, it doesn't make sense to try to test all domestic and small meters due to the large numbers of meters in the system and small volumes involved. The recommended approach to domestic and small meter testing is to first group the meters by factors such as meter model, size, age, volume measured and user type, and then select a number of meters in each group to test. It is not recommended to use results from a different municipality, since conditions and meter deterioration may differ significantly.

Once meters have been grouped, it is necessary to test a representative sample of the meters in a group to represent the accuracy of the meters in that group. Sophisticated statistical sampling methods are available, but as a general rule of thumb at least 30 meters should be tested. (Arregui[2] recommends a sample of at least 50 users per group to test.) More meters tested will result in a more reliable estimate of the meter accuracies, and thus is recommended if possible. It is very important that the meters to be tested in each group are selected randomly. Thus, to select all the meters from a single neighbourhood or street will skew the results and induce errors. A good way to select (say) 50 meters from a group is to first number the meters from 1 to N (where N is the number of meters in the group). Then use a spreadsheet to generate 50 random numbers between 1 an N, and select these meters for testing.

5.5 Analysis

A core part of a meter management programme consist of the analysis of meter data in the meter database in order to understand the performance of meters in the system, and to make certain strategic decisions and develop action plans.

Various types of analyses can be performed based on the needs of the municipality, such as identifying wrongly sized meters, developing models to predict the performance of different meter models and determine when meters should be replaced.

Decisions on meter replacement are probably the most important to make, since this has a direct impact on the income generated from water sales. Since meter performance varied between systems, it is not appropriate to use fixed replacement periods. However, an idea of the expected service life of meters can be gained from other areas. Smaller meters can last between 12 and 20 years, although service lives of less than 10 years have also been reported. Larger meters typically have lower service lives, with 75 mm and larger meters typically lasting between 5 and 10 years.

These typical periods can be used to obtain a quick estimate of the adequacy of a meter replacement programme: for instance, if the economic life of a meter is 10 years, and a municipality has 80 000 meters in service, it means that 8 000 meters should be replaced every year to stay up to date with the programme.

Different methods are available for analysing the financial value of replacing a water meter. One of these is the payback period method, in which the time required to recover the investment made in income is measured.

The financial costs and benefits of a water meter are discussed in Section 4.5.1. The cost of replacing the meter is made up of the meter price and installation cost. The 'income' generated by making this investment lies in the increase in income from the meter as a result of lower meter under-registration, and the associated increase in sewage charges (if linked to water consump-

As an example, if the economic life of a meter is 10 years, 10% of the meters in the system should be replaced every year to stay up to date with the replacement programme.

tion). Maintenance, operational and meter reading costs can safely be assumed to be the same for the new and old meter.

To calculate the increase in income as a result of the new water meter, it is necessary to know the accuracy curve of the meter (through measuring or assuming it), as well as the distribution of flow rates through the meter. The flow rate distribution should not be based on measurements from the existing meter, since these readings will exclude any under-registered water. It may be estimated from similar consumers, or by temporarily replacing the existing meter with a calibrated meter. When both the meter error curve and flow distribution through the meter are known, it is possible to calculate the total monthly volume of water under-registered by the existing meter.

The under-registration volume calculation is now repeated for a new meter using the manufacturer's error curve with the measured flow distribution. The difference between the old and new meter errors is the additional water that will be measured and billed every month if a new meter is installed. The value of the additional water can now be determined and compared to the cost of the meter replacement.

The analysis of meter economics is complicated by the fact that certain costs occur at the beginning of the meter's service life (cost of meter and installation), while others are distributed over the life of the meter (cost of apparent losses). Since the value of money changes over time due to inflation and interest, it is necessary to use a method that incorporates the time value of money. Various methods are available, but only the two most common ones are discussed here. They are the Payback Period and Net Present Value methods.

- ***Payback Period method***. In this method, the time required to recover the initial investment to purchase and install a meter is calculated from the income generated by the meter. When the meter replaces an existing meter, only the additional income (due to the lower apparent losses) is taken into consideration. Since only a short part of the meter's life is considered, the time value of money doesn't play a big role and may be omitted altogether. As a result, the Payback Period method is simple to implement in addition to its results being intuitive and easy to understand.

- ***Net Present Value (NPV) method***. In this method, the income and expenses that will be made throughout the life of the meter are estimated for the current value of money, i.e. how much will it cost in today's terms. The method can be used to check whether installing or replacing a meter makes economic sense (will the meter bring in more money than it will cost over its lifetime), and compare different meters in an equitable way (for instance, allowing a more expensive meter with better accuracy to be compared to a cheaper meter with worse accuracy to determine the most cost-effective meter over the long run). This method is not discussed in detail, but various books are available that give a full discussion of this method. In particular the book by Arregui and the 'Optimal meter selection system' paper by Johnson listed in Appendix C are recommended.

For domestic meters, users should be placed in groups based on the factors that will influence their demand patterns including type of service, income, gardening activities, water borne sewage, stand size and total water demand. Their consumption patterns should be measured with a high accuracy meter, such as a class C or D positive displacement meter. For large consumers, a suitable highly accurate meter should be selected – it is especially important that this meter should be sensitive in the lower flow range. The test meters should be capable of being logged with the lowest possible pulse value – for domestic users a pulse should preferably represent 1 l or less..

A good rule of thumb is that if the income or additional income resulting from a meter installation should recover the cost of the meter replacement in four years or less, the replacement represents good value for money and should be implemented.

Case study: Meter replacements in São Paulo, Brazil[3]

About a decade ago, the water company of São Paulo (SABESP) implemented a massive meter replacement scheme to reduce their apparent losses. They found that of the meters that needed to be replaced, 85% were over-, 4% under-, and only 11% correctly sized. Replacing these meters made substantial improvements to their income from meter sales as reflected in the fact that the average payback period for replacements was only 2 months.

It is useful to calculate the cost of meters based on different replacement periods and to use this as an input into the decision making process. In general terms, the longer a meter is left in the field before it is replaced, the cheaper it becomes in capital expenses terms. For example, replacing meters every 10 years will be cheaper than replacing the same meters every 5 years, considering only the direct costs of the meter and its installation. On the other hand, the longer a meter is in the field, the more it will deteriorate and the higher the levels of apparent losses will be. Thus a 5-year old meter will have lower levels of under-registration when the meter is 10 years

Example of a meter replacement analysis

A 200 mm diameter meter is used to measure the consumption of a factory that uses 30 000 m^3 per month. Replacing the meter at a cost of R20 000 is expected to improve the meter accuracy from -4% to -1% of the total consumption. Calculate the payback period if the meter is replaced for a water price of R4/kl.

The improvement in meter accuracy is 3% of the total consumption, or 1 200 l/month. Thus the increase in sales from the meter will be R4 800 per month, translating to a return period of just 4.2 months. This is an excellent investment, since the cost of replacing the meter will be recovered in less than five months, after which the increased income will be a net 'profit' for the municipality.

old. When these two costs are added, it is possible to determine the optimal meter replacement period, when the total of all the cost components is at a minimum. This type of analysis can be very useful when done with known accuracy behaviour of meters in a particular system.

It is recommended that domestic meters are checked and considered considered for replacement before the age of 10 years, and bulk meters before 5 years.

6 Meter Reading and Data Management

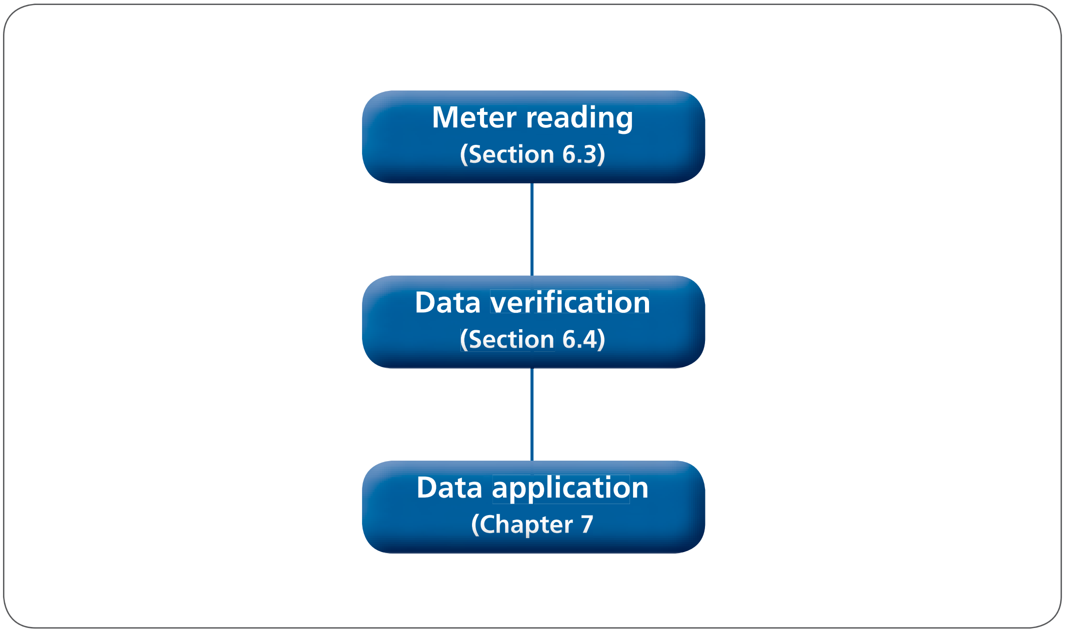


Figure 6-1 The meter data management process

6.1 Introduction

This chapter deals with the taking and handling of water meter readings to ensure that accurate consumption data is gathered. The data, in turn, is used for various purposes, such as billing, system management and future planning. The selection and implementation of an appropriate data management system for meter data is vital for the success of an integrated water metering strategy. In most cases this is done through a specialised software package.

The meter data process involves meter reading, verifying the accuracy of the readings and making it available various applications. These steps and the links between them are shown graphically in Figure 6-1.

Several factors have to be considered when deciding on a meter reading and billing system, such as what department takes responsibility for meter reading, whether any part of the system will be outsourced, and the type of system that will be used.

As water meter readings can be used for several purposes, the data may be transferred through one or more data management systems, each designed for its own specific purpose. Consider for example monthly readings of water consumption. The first process of capturing and processing will take place in the meter reading system. The data will then be transferred, ideally automatically, to a billing system. The main purpose of the billing system is to ensure that every consumer is billed for their month's consumption. However, meters that are not used for billing purposes should also be read and handled by the meter reading or meter management databases.

Given the correct tools, water supply managers can obtain a variety of useful information from the water meter readings, the scope of which goes beyond monthly consumption billing. These applications are covered in Chapter 7.

Like the meter management process covered in Chapter 5, a database sits at the core of a meter data management system. This database, called the meter reading database, may be combined with the meter management or treasury databases, or it may stand on its own with links to them.

6.2 Meter Reading Database

Although the calculations needed to produce meter reading information are theoretically simple, the volume of data that is involved makes it difficult to use basic software such as spreadsheets. Even in relatively small towns with less than 15 000 stands, it has been found that spreadsheets become prohibitively inefficient and clumsy. It is therefore common to use software specifically designed for the purpose.

The software used must have the functionality to make the information available to the user in a seamless structured data table and it must be possible to sort and query the data and provide the results of calculated statistics in suitably formatted reports. It must also be possible to separately view the data and a graphical display of water consumption for each user.

In many cases meter readings are handled by treasury databases that are geared to financial functions and billing. However, treasury databases often do not provide the functionality to assist other users of the data, such as water managers, to make use of it. For this reason it is advisable that treasury databases are designed with the needs of other users in mind, or another database is linked to the treasury database to make this data available.

Since direct access to treasury or billing system databases is seldom allowed, the link to the treasury database is normally done via a data file of predefined format. This would typically occur through the running of a custom developed routine in treasury system.

The data fields that should ideally be included in a meter reading database for consumers and water meters are given in Tables 6.1 and 6.2 respectively.

Table 6-1 Typical consumer data fields required in a meter reading database

Field	Item	Comments
1	Account number	A unique account number.
2	Stand ID	A unique identification number for the stand, often made up of the Town, Suburb, Stand, Portion and Sub portion.
3	Stand number	The registered number of the stand.
4	Stand portion	Portion a stand is divided into more than one portion.
5	Ward	Number of the ward the stand is situated in.
6	Area Code	A code indicating which area of the town the stand is situated.
7	Suburb	The name or a code for the suburb the stand is part of.
8	GIS Code	Location of the stand
9	Owner's name	The stand owner's full name and title.
10	Physical address	The full street address of the stand.
11	Postal address	The owner's postal address.
12	Phone numbers	Fields for office, work, fax and cell phone numbers.
13	Land use	A code indicating the registered land use of the property, for instance residential or industrial.
14	Zone	A code indicating the zoning of the stand.
15	Value of land	Value of the stand from the valuation roll.
16	Value of improvements	Value of the stand plus buildings.
17	Stand size	The area of the stand in standardised units.
18	Floor space	The total floor space of buildings on the stand.
19	Allowable floor space ratio	The ratio of floor space to stand size that is allowed for this area.
20	Occupied	A code indicating whether the stand is occupied or vacant.
21	Debtor	The details of the person or body responsible the accounts (if different from the owner). Full name, address and other contact details should be included.
22	Basic tariff	The tariff structure for the basic (fixed) part of the water bill. tariff structure used for the stand.
23	Consumption tariff	The consumption tariff structure (including block rates).

Table 6-2 Typical meter and reading data fields required in a meter reading database

Field	Item	Comments
1	Meter serial number	The serial number on the meter.
2	Meter count	The meter number if more than one meter serves the same stand. Typically, the first meter is indicated by 0, the second meter by 1, etc.
3	Number of units	The number housing units served by the meter.
4	Installation date	Date the meter was installed.
5	Number of digits	Number of digits on the meter dial. Only full m^3 digits are included. Typically 4 for small meters and 5 or 6 for larger meters.
6	Meter measurement unit	Should be m^3.
7	Meter size	Meter size in mm.
8	Meter route number	The meter reader route the meter forms part of. Sometimes referred to as the meter book number.
9	Meter location	Location of the meter on the stand.
10	Average Consumption	The average daily demand for the current month.
11	Meter reading data	Repeat for a given number of meter readings, for instance the last 25 readings.
11.1	Reading date	Date the reading was taken.
11.2	Meter reading	The reading on the meter.
11.3	Reading type	A code describing the type of reading that was done, for instance for instance a 'reading' or 'estimate'.

6.3 Meter Reading

6.3.1 Consumer Meters

It is important that water meters are read at regular intervals, preferably once a month. In some cases meters are read less frequently and the readings of the intermediate months are estimated. This practice saves money, but can also introduce significant errors that may create consumer relations problems when sudden large water bills are sent to correct wrong estimates.

Different systems are available for consumer meter reading, and a municipality should consider the costs, advantages and disadvantages of each system to select the most appropriate one. A combination of technologies is often the most effective solution. The main meter reading systems available are:

- ***Direct reading***. Meters are read directly from the indicator by a meter reader. Readings can be recorded using pen and paper, or on a handheld terminal that allows the readings to be transferred elec-

Reading water meters

Water meters are always read in the same direction as reading a book, i.e. from left to right. By law, all meters have to measure in m^3 (i.e. kilolitres), and must clearly distinguish between full m^3 values and fractions of a m^3. In some meters, such as Figure 2-6(a) this is done using contrasting colours; typically white numbers on a black background for full m^3 values and white numbers on a red background for fractions of a m^3. In other meters, such as Figure 2-6(b), rotating disks are used for full m^3 values, and dials for fractions of a m^3. Electronic indicators often use a decimal point or display the fraction values in a smaller font. It is common practice for meter readers to only read the full m^3 values.

Unfortunately some large meter models use rotating disks to measure **tens** of cubic meters, and indicate the right-most digit of the full m^3 value using a dial. The rotating disk indicators of these meters have "x10" written next to them. Such indicators can cause serious reading errors: if only the rotating disks are read and entered as cubic meters, the reading will be ten times smaller than the actual consumption, causing large losses of income for the municipality. In some cases, this problem is handled by the meter database by automatically multiplying the reading by a factor of 10. However, if in such cases the meter reader enters the full m^3 reading, this will again result in a consumption that is 10 times greater than the actual consumption. Meters that measure tens of m^3 should be avoided if possible. These meters should be identified and handled consistently. It is important that meter readers are properly trained to identify and avoid this type of problem.

Meter readers should be precise and not suffer from any reading impairments. Proper training of meter readers is very important. When reading, both the meter serial number and indicator reading should be taken to ensure the reading is allocated to the correct meter. It is also important that meter readers should be trained to identify and report problems with meters, such as signs of tampering, damage to meter boxes and leakage.

Meter readers should be provided with the correct tools, and properly trained on safety measures when reading meters. Injury can result from opening manhole covers without the proper tools and dangerous animals (such as snakes or bees) may potentially hide inside meter boxes.

tronically to the meter reading database. This is preferred, since entering the data manually creates an additional opportunity for errors to be introduced.

Handheld terminals can also ensure that all meters on the meter reader's route are read, and perform initial verification of the values entered. Units with built-in camera and GPS systems are now available. They should allow the meter reader to enter problems, such as damaged meters or meters that are impossible to access. Direct reading of meters does not require additional equipment to be installed in the meter, but has high labour costs. Meter readers often have problems accessing meters, and reading errors are common.

- ***Automatic remote reading***. Meter readings are recorded automatically by connecting a handheld device to a connection point on the meter. The meter reading is automatically transferred to the device. This allows for a high reading success rate and saves on labour costs since meter readers can read more meters in a day.

Exercise – Meter Reading

Take the readings on the meters below, including both full m³ values and fractions of a m³. The correct answers are given at the bottom of the box.

a b c

d e f

Answers: a) 1604.1672 m³, b) 177.179 m³, c) 134847.135 m³, d) 1073.19645 m³, e) 1189.7958 m³, f) 0.1465 m³

Figure 6-2 Meter readings

However, special and more expensive meters need to be installed.

- ***AMR (Automatic Meter Reading).*** AMR uses technology to transmit meter readings automatically to a central location using phone network or radio frequency (RF) technologies. In *telephone AMR systems*, meter readings are sent to a central station using a fixed or cellular phone connection. Telephone readings have a high success rate and saves on labour costs, since no meter readers are required. The main disadvantages are the costs of installing and maintaining the system. In *radio frequency AMR systems* the meter is connected to a transponder unit that transmits the meter reading via a radio frequency (RF) signal. The transponder is activated automatically by an outside

Case study: AMR pilot project in Cape Town[1]

The City of Cape Town implemented an AMR (Automatic Meter Reading) pilot project to test its benefits against those of manual meter reading. The project was implemented in Sunset Beach (an affluent township), the N2 Gateway housing complex (high density complex of two and three storey apartments) and the Epping industrial area.

First, a meter audit was done to identify the meters that were AMR compatible and update the meter database. This was followed by a selective meter replacement programme and the installation of an AMR system.

The meter audit proved to be very valuable, and various problems were identified:

- Rubble-filled meter chambers.
- Poorly constructed meter chambers.
- Defective shut-off valves at meters and zone boundaries.
- Meters not on the billing database.
- Wrong meter sizes and serial numbers in the meter database.
- Over-sized water meters, especially in the industrial area.

Regarding AMR, it was found that the meter pulse interface unit (PIU) has the greatest influence on the cost of an AMR system when compared with the cost of the meter. For example, a 15 mm domestic meter costs around R180, whilst the PIU could cost anything between R65 and R650 depending on the meter model. For meters larger than 40 mm the difference in cost of the meter and PIU was found to be less significant.

One of the biggest benefits of AMR proved to be the fact that all meters can be read at the same time, compared to meters read at different days and times with manual meter readings. This means that the extent and location of water losses in the system can be determined with great accuracy by comparing the readings of DMA and consumer readings for exactly the same time period. Significant losses were found in certain areas of the pilot study, which could then be addressed.

transmitter, which can be carried by a meter reader walking past the property, carried in a vehicle being driven past the property, or contained in a fixed area network. The latter option requires the installation of infrastructure that will collect the meter readings and transmit them to a central location via a network of receiving and transmitting stations. The fixed area network fully automates the meter reading process. The system saves on labour costs and has a high reading success rate. However, the cost of installing the meter units and communication infrastructure is high. Units that operate on battery power may require batteries to be replaced at regular intervals.In advanced AMR systems more intelligence is built into water meters and instructions may be sent to the meter from a control station, is called *AMI (Advanced Metering Infrastructure)*. The meter may be programmed to estimate on-site leakage, record the user's consumption pattern, or restrict supply if the user defaults on payments.

6.3.2 Bulk Meters

The reading of distribution, bulk transfer and even large consumer meters is often required on a continuous basis to inform system operators of the current levels of flow and potential problems in the system. This makes direct reading by meter readers unfeasible. The following systems are commonly used for reading and recording of bulk meter readings:

On-site data logging. A data logger is connected to the meter and the meter readings downloaded from the logger to a computer after a certain period. The main disadvantage of on-site logging is that the meter readings are not immediately available, but can only be accessed after they have been downloaded. However, data loggers are versatile and can easily be moved to a new location to investigate demand or flow patterns.

Telemetry data logging. Telemetry systems use the same approach as on-site logging, but data is transferred to a central station through a fixed or cellular phone system. The data transfer can be done automatically or on demand by a user.

Supervisory control and data acquisition (SCADA). SCADA is a common approach to communicate readings from water meters and other system components to a central location. SCADA systems provide automatic and manual control opportunities of pumps, valves, reservoirs and other equipment.

AMR systems as described for consumer meter reading are also suitable for distribution and bulk transfer meters.

6.4 Data Verification and Processing

Once the meter readings have been entered into the meter database, it is necessary to verify the data to identify and eliminate potential errors. Various errors may be included in the data, including:

- Errors in readings
- Errors in dates
- Missing readings
- Meter replacements and clock-overs
- Meter readings not taken on the same day of the month.

The meter reading may also indicate a problem with the meter itself, such as a meter that has stopped functioning. It is thus necessary for the metering database to interpret the data, identify errors and make corrections where possible. It is recommended that the water meter reading should be estimated for the same day (say the 25th) each month. Both the original meter readings and the estimated monthly consumptions should be stored in the system for future reference. The database can make estimates, handle certain errors automatically and raise queries for further investigation by the system operators. Some common errors that should be identified and handled by a meter reading database are given below:

- A stand exists on the system, but no or too few water meter readings are available to estimate its consumption.
- Inconsistent dates. The system could not determine the order in which the readings took place due to date inconsistencies.
- A meter clock-over that will cause a very large water reading one month to be followed by a very small reading the next. It is important to include information on the number of digits on the indicator to identify meter clock-overs.
- New or replacement meters that have been installed.
- Spikes or dips in consumption. Abnormally high or low consumption for a stand are often signs of errors in the meter readings.
- Missing readings. Where no readings are available for the last month, the system has to estimate consumption based on the consumption history for the stand.
- Long gaps in the meter reading. When a meter has not been read for a certain number of months (typically 3), consumption estimates become uncertain and an instruction should be given for a reading to be taken.

Reporting should be clear and concise with pre-determined standard reports readily available to the user. The functionality should also be available for the user to perform own queries and produce own reports.

7

Integrated Water Meter Management: Putting It All Together

7.1 Introduction

The aim of this chapter is to provide an introduction to integrated water meter management (IWMM) from a municipality's perspective. As discussed in Chapter 1, there are four main drivers for a comprehensive water metering programme: equity, water efficiency, economic benefits and system management. These drivers go well beyond the aims of specific departments, such as engineering or treasury, but connect with the broader aims of a municipality's mandate.

Various departments of a municipality are affected by or have an interest in water meters, but the main departments may be identified as the treasury, engineering and management. The treasury uses water meter readings for billing consumers. Engineering is responsible for installing, maintaining and managing water meters, but also needs water meter data for functions such as water demand management, non-revenue water management and network modelling. Management has to ensure that the correct systems and policies are in place, adequate funds are allocated to water meter management, and take strategic decisions based on water meter data.

It makes a lot of sense to coordinate and integrate the management of water meters and water meter data between these departments. This will not only ensure that the greatest benefits are gained from a water metering programme in the most cost-effective way, but also that policies and decisions are based on the latest data.

To discuss the integrated management of water meters in a municipality, the areas affected by water meters are discussed in four main categories:

- *Strategic planning,* covering policies and decisions on a strategic level, such as the metering strategy, staffing, water tariffs and strategic planning (Section 7.2).
- *Information management*, which deals with the handling of water meter data, billing and benefits that can be obtained by integrating consumption data with other systems (Section 7.3).
- *Asset management*, which deals with the management of water meters to ensure that the maximum benefit is obtained from them (Section 7.4).
- *Water management*, which deals with the way data from water meters can be used to manage water in the most efficient way, addressing issues such as water demand and non-revenue water management (Section 7.5).

In the final section of the chapter (Section 7.6), a questionnaire is provided to allow a municipality to assess how well it is doing on IWMM, and recommendations are made regarding the main steps to develop an efficient and integrated water meter management system.

7.2 Strategic Planning

An effective water meter management system requires strong overall leadership, which has to be driven from a management level to ensure that the systems and efforts of different departments are coordinated and in line with the larger strategic objectives of the municipality. A high-level water metering committee with representation from all affected departments should be set up for this purpose.

It is important to realise at this level that water meters are not the solution to all problems, but is simply a tool that is used in the municipal management process. Very often problems such as poor payment for services, vandalism and high on-site leakage rates are the symptoms of deeper socio-economic problems that have to be addressed by other means, although water meters may well play an important role.

Issues that should be dealt with at a strategic level include the following:

- Ensuring that sufficient staff members with the right qualifications and training are appointed to manage the various aspects of the IWMM process.
- Allocation of responsibilities for different aspects of water metering to different departments. One of the key issues to be decided is whether engineering or treasury should be tasked with meter reading. There is a very strong case for engineering to take on this role: engineering is responsible for managing the physical water meters, and thus can use meter readers more efficiently by training them to identify problems with meters that need to be addressed while reading the meters.
- Development of policies on water meters, including the types of meters to be installed, installation standards, procurement, meter management, data handling and quality assurance.
- Development of policies on the handling of water meter data, including the structure and interconnectedness of databases, what data records to keep, and what type

of analyses to perform regularly. Outsourcing of certain functions, such as meter reading, should also be discussed at this level.

- Development of strategies to handle problems or issues that need to be addressed (such as the impact of new legislation, e.g. the new Consumer Protection Act) and new technologies (e.g. smart metering and automatic meter reading systems).
- Design of water tariff structures, which do not only affect municipal income, but can also be used as part of the water demand management strategy.
- Development of systems for making data more accessible to different parties.
- Budget requirements for water meter management.

Two of these aspects, metering strategy and tariff setting, are discussed in more detail below.

7.2.1 Metering Strategy

It is important to realise that different to consumer metering strategies may be adopted, and that the correct strategy depends on local needs and conditions. A number of different metering strategies, or a mix of them, may be used by a municipality, including conventional metering, pre-paid metering, demand restriction and no metering.

7.2.1.1 Conventional Metering

The conventional metering strategy is to install water meters on all consumer connections and send monthly water bills based on the actual or projected consumption. The cost of providing a metered connection to new consumers is covered by a connection fee. When water meters are not read every month, the consumption for intermediate months is estimated based on factors such as historic consumption and seasonal patterns. The consumer is required to pay a deposit to ensure that any unpaid bills are covered.

A conventional metering system is convenient for the consumer, since nothing is required except to pay the bill once it arrives. However, the consumer is expected to pay a deposit, and cover the installation costs of new meters through a connection fee. Errors in the meter reading process can cause excessive bills and severe inconvenience to the consumer. A large but hidden leak occurring on the consumer's property can also be responsible for a very large bill.

The major disadvantage of a conventional metering system is the effort and cost required to manage the system. Meter readers have to be employed to read each meter every month (or at least every few months). Meter readers often have their own problems, such as getting access to water meters installed on consumers' properties. The water meter readings must then be entered into a computer system, checked for errors, and bills printed and mailed to consumers. Systems are required to handle errors that invariably occur when reading meters or transferring data. In addition, significant efforts are required to collect outstanding payments and disconnect users that do not pay their outstanding bills.

7.2.1.2 Pre-paid Metering

Prepaid meters are water meters with built-in processing units and a mechanism that can automatically close a valve to shut off a consumer's supply. Consumers purchase water in advance, and the amount purchased is transferred through a token or electronic signal to the meter (see Figure 7-1). Once the available credit on the meter has been used, the prepaid meter automatically shuts down the supply. In some cases the supply is shut down completely, while in others a small flow through the meter is maintained. OIML R49 requires prepaid meters to have checking facilities, such as protection against reverse flow through the meter.

Prepayment water metering provides solutions to some of the problems associated with conventional metering and revenue collection for both the utility and end-user. It was largely developed in South Africa during the late 1990s as a solution to low-income areas. However, this technology has greatly advanced and today it is often used as an alternative to conventional metering for all types of users.

To the municipality, the main advantage of prepaid water meters is that revenue is collected in advance, and the supply is automatically shut down when the available credit runs out. This means that meter readings, an extensive billing system and

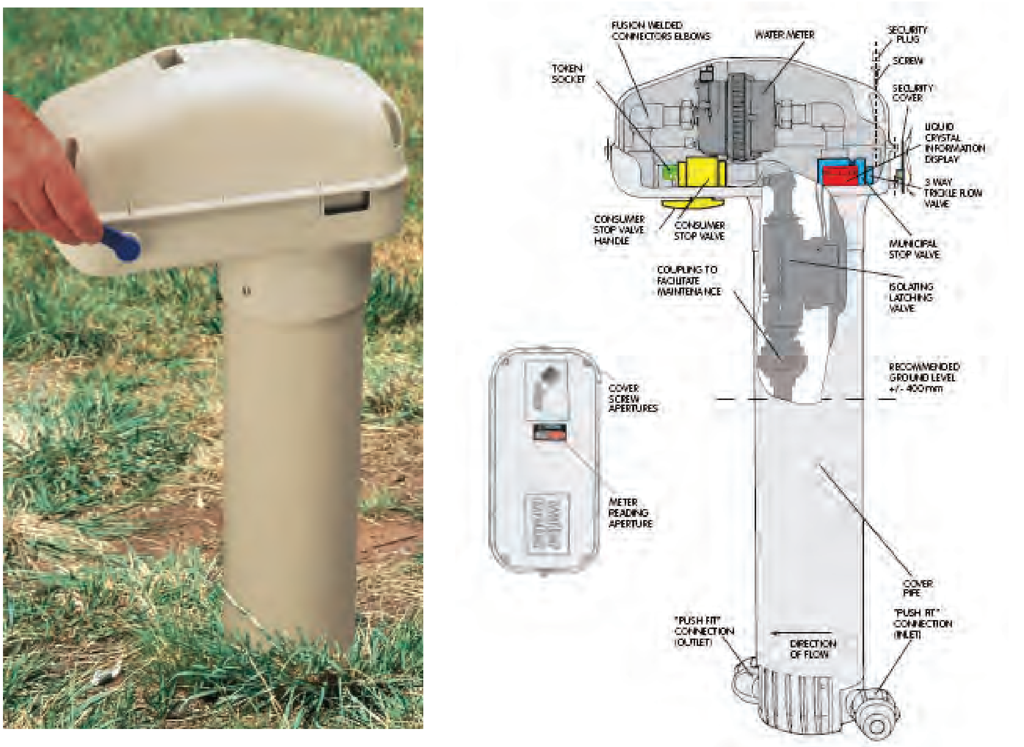


Figure 7-1 Domestic prepaid water meter (courtesy of Elster Kent)

debt collecting systems are not required, reducing the financial risk to the municipality and saving the cost of an extensive meter reading and data management scheme.

The built-in processor and shut-off valve make prepaid metering systems suitable for other and more advanced functions. They can, for instance, be used to automatically dispense the free basic allowance of water before requiring credit to operate. Alternatively the meter may revert to a small flow through the meter once credit runs out, instead of shutting down completely. Prepayment meters can also be programmed to allow users to provide some quantity of water past the point where the available credit has been depleted with a warning given to the consumer to recharge the meter credits.

Another benefit is that consumers cannot ignore their water use, but is constantly reminded of it by virtue of having to purchase credit in advance, and when checking the credit remaining on the meter. It also gives consumers control over their own consumption and encourages them to manage their consumption appropriately. This often means that consumers use water more sparingly, thus saving money while helping to conserve the available water resources.

Consumers benefit, since a good credit record is not needed in order to get a water connection. If a leak occurs on the consumer's property, the loss to the consumer is limited since the meter will automatically shut down once the available credit is depleted.

The greatest disadvantage of prepaid water meters is the increased cost of the meter due to the additional components, the need for secure housing with tamper protection and stringent requirements for the meter's electrical components. Municipal staff working with prepaid meters require more skills to install, maintain and operate prepaid meters than conventional meters. Prepaid meters are also more sophisticated and have more components that can fail and cause problems. Thus regular inspection and maintenance of these meters is more important than for conventional meters. Prepaid meters also need an electrical supply via the network or a battery. A further disadvantage is that consumers might be more inclined to tamper with or bypass the meter when their water is shut off, causing an increase in apparent losses.

Experience has shown that careful consideration should be given to policy around how prepayment systems will be implemented

Case study: Prepaid meters in Soweto[1]

More than 100 000 prepaid water meters have been installed in Soweto. Although the project met with organised resistance from the community, including legal action, the matter has been settled by the Constitutional Court's ruling that the use of prepayment meters is not unconstitutional. Prepaid meters have been very successful in reducing water demand attributable to wastage: on average for all installed meters, water demand has been reduced from more than 65 kl per formal residential property per month to less than 12 kl per property per month (on average for the project as a whole), representing a saving of more than 80% in total supply. The costs of installing pre-paid water meters were often recovered within four years.

(or retrofitted) in areas where either a flat rate system or conventional metering system is in place. A backlash from the community can be expected when the system is perceived as being forced onto consumers. It is recommended that meters be installed on demand from individual consumers and that steps are taken to make the system more attractive to consumers.

Due to the nature and layout of informal settlements, prepayment water meters are not considered to be a viable option, whether from a cost recovery, maintenance or community acceptance point of view. The cost of the prepaid meters in these areas can often not be recovered since users generally rely on the free basic allowance and do not purchase enough water through the pre-payment meter to recover the cost of the meter and installation. The same is true for very poor areas with poor service delivery and intermittent water supply.

Factors to consider when selecting a prepayment water metering system

- Application of the meter and need for metering
- Acceptance by political representation and the beneficiary community
- Robustness, performance and reliability
- Functionality, especially around tariff structures and the dispensing of free basic water
- Approvals provided by standards setting bodies such as SABS and JASWIC
- Cost
- Expected service life of the meters
- Experience in similar areas
- Managerial and technical capacity to operate and maintain the system once installed

In informal communities where water is supplied via communal standpipes, fitting a prepayment meter to the standpipe may be an attractive option and can significantly reduce wastage.

In middle to high-income areas, the installation of prepayment meters is likely to result in a drop in overall amounts of revenue collected. This is because consumers tend to become more aware of consumptive habits and patterns and tend towards more conservative usage. Thus prepayment meters may form an important part of a water demand management project.

It is very important that a prepayment water metering system should be managed well. Experience has shown that the success and acceptance of these systems are a function of how well the system is managed after installation. Dedicated management and technical staff may be necessary to ensure that the system operates efficiently. Attention should be given to the generation of (and attending to) exception reports by the purchased and installed system. This is a distinct advantage of prepayment over conventional systems and meters flagged by way of exception reports should be investigated for tampering, vandalism and meter failure. Given the opportunistic nature of consumers (and potentially also officials), neglecting to manage the system well could quickly corrupt the ideals and objectives sought in the implementation of any large scale project.

Because of the potential of vandalism to meters, experience has shown that when installing yard meters, they should preferably be located on the property and not in the road reserve. This approach obliges the owner to become the custodian of the meter, and in so doing reduces the risk of vandalism. Enforcement of the custodian principal is possible through correctly promulgated water supply by-laws.

7.2.1.3 Supply restriction

An effective way to control water consumption in areas where it is uneconomical to provide conventional or prepaid metering systems, is to restrict the flow to consumers. This gives consumers access to as much water as the system will allow them without having to worry about the cost of the water. The consumers get a free or cheap supply, but in return the volumes provided are limited and thus wastage and leakage are controlled. Consumer that can afford to upgrade to a better system may apply and get an upgraded connection, thus allowing the community to improve their quality of life as their resources grow. It is also a cost-effective system for municipalities, since no metering or billing system is required.

Flow restrictors are devices that restrict either the flow rate or volume of water received by a consumer. This category includes trickle feed systems in which the supply is restricted to a trickle collected by the user in a container such as a roof tank.

Electronic flow limiters are devices that require a direct connection with a flow meter and can dispense a predetermined volume of water (typically programmed by the operator to allow 200 litres per day). It uses electronics and thus requires a power supply or battery. The typical battery life of these systems is 3 to 5 years. These systems are more sophisticated than mechanical systems, and also significantly more expensive.

7.2.1.4 No metering on unrestricted connections

Systems without flow metering or restrictions exist in many areas. Users of these systems pay for their water through a fixed tariff, or may not pay at all. Since the cost to the user is not linked to the water consumption, there is no incentive to use water sparingly, or to fix leaks on their properties. The water consumption and leakage grows with time and the cost of the water supply through such a system to the municipality often becomes exorbitant. Thus it is important to ensure that all consumers in the system are managed through an appropriate metering or restriction system.

7.2.2 Water Tariff Design

A well functioning IWMM system is useful in determining a stepped tariff structure for water sales if the calculated income can be based on actual water consumption data. In this respect it is also important to be able to apply price elasticity to determine the effect on water consumption in the prediction of revenue from water sales with increased tariffs. This will vary according to land use categories. Sewer tariffs can also be applied according to the water consumption. In both cases the parameter required is the annual average daily water demand.

The information that is typically available from meter reading, billing or treasury systems includes readings for each water meter in the distribution system and is normally stored on a monthly basis along with land use and other stand related information. (See chapter 6).

A general problem is that billing or treasury systems are not designed to produce the meter information and reports required for the purposes referred to above. The data is also often not spatially referenced, which would allow links to cadastral database applications in GIS. It is therefore necessary to extract the information from the databases and use additional manipulation to perform the required statistical calculations.

Setting a rate structure to ensure full cost recovery and adequate revenues is essential for any universally metered system. In preparing a rate structure, there are two types of costs to consider: fixed and variable costs. There are also several types of rate structures available:

- Fixed rate. Users pay an equal amount for each unit of water consumed.
- Increasing block rate. Users pay an equal amount for each unit of water consumed up to a maximum, at which point a new higher unit rate is applied for each additional unit of water consumed. Several increasing blocks can be imposed.
- Seasonal pricing. In this variation of the fixed rate, users pay an equal amount for each unit of water consumed; however, the unit rate will vary based on the season. The rate is normally higher in the summer months to try and curb peak demands due to dry weather irrigation and recreational use.
- Fixed cost plus rate. The user is charged a minimum amount regardless of consumption to cover specific fixed costs for operating the system and then charged a rate per unit of water consumed based on one of the structures listed above. There are several variations to the rate structures listed above; however, they are the most common ones used. Each water utility should conduct a rate structure study to determine the most appropriate system to use.

7.3 Information Management

The quality and usefulness of an IWMM system depends largely on the quality and accessibility of water meter data and meter readings. In some cases all data related to water meters are held in the same database, but it is common for different databases to handle different aspects of the data. This is acceptable, as long as these databases are designed to interact and share information so that all users have access to the latest data.

Municipalities depend on water sales for a significant part of their income, and thus one of the most important functions of the information management system is to calculate and print accurate water bills.

Another very important task of the information management system is to make a wide range of data accessible to users in different departments needing it for different purposes. While this supports a lot of the functions discussed under other headings, the information management system can be used for various queries to identify problems and obtain a better understanding of the system. A user-friendly query builder is essential. Applications of the information management system can include the following:

- Estimation of water demand distribution for building accurate hydraulic models of water and sewer distribution systems.

- Identification of water meters for which values are estimated and not read.
- Making consumption data available to consumers on their water bills or a website. Information on the consumption of other users in the same category can also be given for comparative use.

Linking to information to a cadastral shape file allows spatial representation of the data. Having an aerial photograph and other spatial information available (e.g. street names, contours, hydraulic models, topography) further enhances the usefulness of the system. Once again, the underlying databases should be accessible so that the information can be queried and displayed.

7.4 Asset Management

Water meters are assets belonging to the municipality and should be managed according to good asset management practice. Asset management is in itself an integrated process of managing the acquisition, use, management and disposal (replacement) of assets with the goal of minimising the risks and costs associated with the asset over its life-cycle. Asset management falls outside the scope of this book and thus only a brief overview of some of the issues addressed by an asset management programme is listed. A downloadable report on asset management, which includes some water metering case studies, is given under the Recommended Reading section of Appendix C.

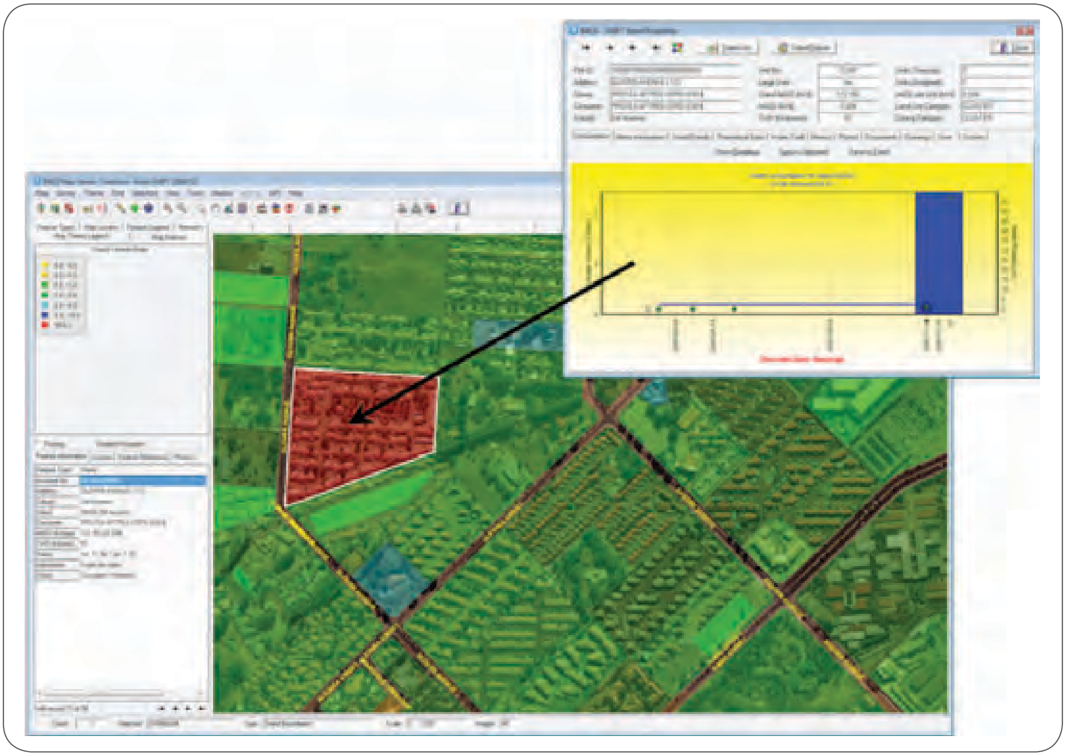


Figure 7-2 An example of a combined spacial representation of data (courtesy of GLS Consulting)

Some of the aspects of water meters included under asset management are:

- An asset register (database) that includes all meters in the system and their associated data.
- A meter audit, which entails that meters are found, read, inspected and checked against the meter database.
- A meter testing programme to collect information on the behaviour of different meter models for different consumer types.
- Prioritising meters for replacement to ensure the maximum return on investment.
- Identifying broken, tampered and inaccurate meters.
- Meter replacement programme.
- Monitoring performance of different meter models in the system and using this information when purchasing new meters.
- Ensuring that meters are correctly installed and maintained.

7.5 Water Management

Water management deals with the movement of water through the municipal system from sources to consumers and other uses. The application of meters to water management can be divided into three categories:

- The municipal water balance
- Water demand management
- Non-revenue water management.

7.5.1 Municipal Water Balance

The International Water Association (IWA) has been leading efforts to categorise water in the municipal system, and does this through the water balance grid shown in Figure 7-3.

The IWA water balance divides the *system input volume* into *authorised consumption* and *water losses*. *Authorised consumption* can be either *billed* or *unbilled*, with the billed portion representing the *revenue water*.

According to the IWA grid, *water losses* are made up of *real losses* (physical leaks from the system) and *apparent losses*. *Apparent losses*, in turn, are made up of *unauthorised consumption* (mainly illegal connections) and *meter inaccuracies*. These *meter inaccuracies* refer to meter under-registrations and make up a significant fraction of the losses in the system.

A comparison of the readings on bulk transfer, zone, DMA and consumer water meters can be used to estimate *real losses* in different parts of the network. Leak detection teams and pipe replacement programmes can then be focussed on the most problematic areas.

It should be clear that water meters are essential for estimating the size of virtually all of the IWA water balance blocks. Thus accurate water meters are not only critical for measuring what happens to water in the system, but also for ensuring that *apparent losses* are minimised.

<table>
<tr><td rowspan="9">System input volume</td><td rowspan="4">Authorised consumption</td><td rowspan="2">Billed authorised consumption</td><td>Billed metered consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed unmetered consumption</td></tr>
<tr><td rowspan="2">Unbilled authorised consumption</td><td>Unbilled metered consumption</td><td rowspan="7">Non-Revenue Water</td></tr>
<tr><td>Unbilled unmetered consumption</td></tr>
<tr><td rowspan="5">Water losses</td><td rowspan="2">Apparent losses</td><td>Unauthorised consumption</td></tr>
<tr><td>Metering inaccuracies</td></tr>
<tr><td rowspan="3">Real losses</td><td>Leakage on transmission and / or distribution mains</td></tr>
<tr><td>Leakage and overflows at storage tanks</td></tr>
<tr><td>Leakage on service connections up to point of consumer metering</td></tr>
</table>

Figure 7-3 The water balance grid developed by the International Water Association[2]

Detailed procedures for estimating the volume of water in each block, including the roles that water meters play in this process, have been developed and are available from the IWA. It is important that the water balance be estimated correctly using these procedures. In some municipalities the treasury estimates non-revenue water in their own way, which may lead to wrong estimates and a lack of understanding of the problem and how to address it.

7.5.2 Water Demand Management

Water resources are limited, and thus there is a limit to how much water can be supplied. One of the ways to make water resources go further is to convince consumers to use water more efficiently. This process is called water demand management.

Water meter data can be used in various ways to do water demand management, including the following:

- Consumers can be made aware of their consumption, how it varies with time and how it compares to other consumers in the same class. This can be done using graphs and tables printed on the municipal water bills.
- Consumption data can be analysed in different user categories to determine the distribution of consumptions in each category, and how the consumption varies with stand size and stand value.

The highest consumers in each category may be identified and targeted for water demand management initiatives.

- Consumers can be made aware of on-site losses and encouraged to have these repaired.

7.5.3 Non-revenue Water Management

Water meters can contribute in various ways to estimating and reducing the different components of *non-revenue* water.

The first component of *non-revenue* water is *unbilled authorised consumption*, which may include municipal parks and buildings, as well as water used for fire fighting. Ideally water meters should be installed at all consumption points in the system so that an accurate assessment of these consumptions can be made. Fire connections are not normally metered, but fire services do estimate the water used after each fire event and these values can be obtained from them. Once *unbilled authorised* consumers are metered, it is possible to evaluate their consumption patterns and identify and investigate consumers that use excessive quantities of water.

Apparent losses consist of two components: *unauthorised consumption* and *meter inaccuracies*. *Unauthorised consumption* may result from illegal connections or from meters that have been tampered with. One of the best ways to identify meter tampering (or meter problems) is to monitor consumption patterns and further investigate consumers that display significant reductions in consumption (see Figure 7-4). In a linked GIS database it is possible to highlight properties with no water consumption registered on the meter database as shown in Figure 7-5. The stands marked in red in Figure 7-5 are clearly occupied and thus should have consumption.

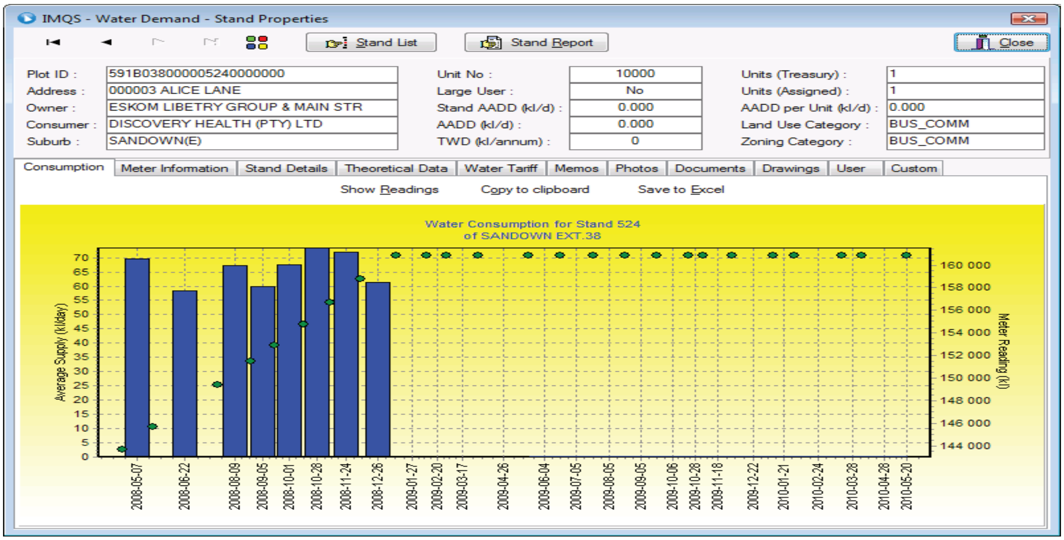


Figure 7-4 An example of meter readings suddenly stopping, indicating a stuck meter or possibly meter tampering (courtesy of GLS Consulting)

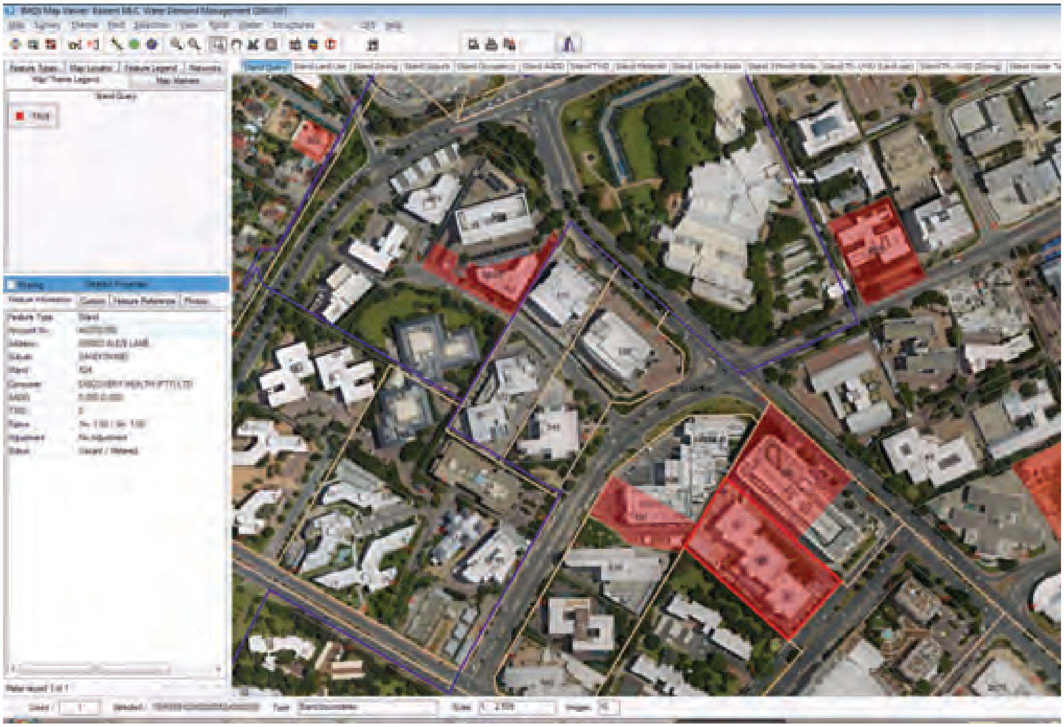


Figure 7-5 A GIS image of an area highlighting stands with no consumption on the metering database (courtesy of GLS Consulting)

Meter under-registration losses are controlled by ensuring that meters are replaced when they become too inaccurate. Meters accuracy tends to deteriorate fastest for low flow rates, which makes on-site losses a particular problem. These losses are common, and typically run continuously at low flow rates where meters are the least accurate. Convincing consumers to address on-site leaks will also reduce apparent losses in the system.

Another way in which apparent losses may be reduced is by checking meter sizes against measured consumption to identify and replace meters that are over-sized.

7.6 Implementing an Integrated Water Meter Management System

Many municipalities currently have a lack of proper water meter management, and suffer the consequences through lower levels of income from water sales. Often these municipalities also lack experienced and trained staff to manage such a process. Thus the purpose of this section is to give some guidance to a municipality regarding where they currently stand in terms of IWMM, and how to go about establishing an IWMM system. To evaluate a municipality's IWMM system, complete the questionnaire in the accompanying text box.

An IWMM strategy takes years to develop and implement. However, great improvements can be made with relatively little effort at the start of the process by focussing on the areas where the greatest benefits will be gained with least effort. A good rule of thumb is to start with the source and bulk transfer meters, and the largest consumer meters in the system. In most municipalities, a relatively small number of consumers use the most water in the system. For instance, more than 50% of the total revenue from water sales in the City of Atlanta in the US comes from less than 3% of their water meters[3].

This means that a significant improvement in income can often be made at small cost by checking these meters first, and taking steps to ensure that they operate accurately. Once the larger consumers have been dealt with, the location where the next highest potential benefits can be obtained is tackled next, and so on.

It is important to implement strategies that are written down and subjected to a quality assurance process so that new staff members don't have to reinvent the wheel. Adequate human and financial resources need to be assigned to the project. It is also important to set measurable objectives for the project so that progress can be monitored and management be convinced of the value of IWMM for the municipality. To assist municipalities, a list with recommended steps to establish an IWMM programme is provided in a separate text box.

Questionnaire: How does your municipality do on Integrated Water Meter Management?

Tick true answers for the questions below regarding water meter practices in your municipality. The scores and their evaluation are provided at the end of the questionnaire.

1. Which statements that are true for water sources (bulk supply points, boreholes, dam intakes, etc.) and bulk transfers (water sales to and purchases from other municipalities)?
   a. All points are metered. ☐
   b. Meters are correctly sized (verified in the last 5 years). ☐
   c. Meters have been sized and verified, calibrated and/or replaced in the last 5 years. ☐
   d. Meter readings are taken continuously. ☐
   e. (d) is false, but meter readings are taken at weekly intervals or more frequently. ☐
2. Which statements are true for bulk consumers (top 10 % or some similar measure)?
   a. They have been identified for special attention. ☐
   b. Meters are correctly sized (verified in the last 5 years). ☐
   c. Meters have been verified, calibrated or replaced in the last 5 years. ☐
   d. Meter readings are taken at least every month (i.e. no consumption estimates are done). ☐
3. Which statements are true regarding isolated zones (district metered areas)?
   a. Zones have no more than 2 500 consumers each. ☐
   b. (a) is false, but zones have no more than 6 000 consumers each. ☐
   c. (a) and (b) are false, but some isolated zones are present in the system. ☐
   d. All zones are metered. ☐
   e. Meters have been sized and verified, calibrated and/or replaced in the 5 five years. ☐
   f. Meter readings are taken at least monthly. ☐
4. Which of the following system management steps have been taken in the last year (refer to Figure 7-3 as required)?
   a. Zonal losses estimated using minimum night flow analysis. ☐
   b. Revenue water estimated and compared to system input volume. ☐
   c. Unbilled authorised consumption estimated. ☐
   d. Apparent losses estimated. ☐
   e. Real losses estimated. ☐
5. Which statements are true for general consumer metering (i.e. excluding bulk consumers)?
   a. All Industrial, commercial and institutional consumers are individually metered. ☐
   b. All formal residential consumers are individually metered. ☐
   c. (b) is false but formal residential consumers not individually metered are metered in groups of fewer than 12 consumers per meter. ☐
   d. Informal residential consumers are metered in groups of fewer than 20 consumers or stand pipes per meter. ☐
   e. All municipal services for example parks, hospitals, jails, municipal offices and public toilets are metered. ☐
6. Which of the following guidelines or policies do you have in place?
   a. Location of meters in the system, including consumer and system management meters. ☐
   b. Meter sizing and installation standards. ☐

Putting It All Together

c. Meter testing and replacement strategy.

d. Meter procurement standards.

7. Which of the following employees or structures are in place in such numbers that they can run an efficient metering management system?

a. A person in charge of all water metering matters.

b. Trained and/or experienced staff for meter selection.

c. Trained and/or experienced meter technicians responsible for installation and replacement.

d. Meter readers.

8. Which statements are true network management meters?

a. Meters are installed at all reservoir and tank outflows.

b. Meters in (a) are read at monthly intervals or more frequently.

c. Meters are installed at pump stations and major branches of bulk pipes.

d. Meters in (c) are read at monthly intervals or more frequently.

9. On average, how often are consumer meters read (only tick one answer)?

a. Once per month.

b. Once every two months.

c. Once every three months.

10. Is your meter reading data is easily accessible to and used for the following functions:

a. Consumer billing.

b. Water loss estimations.

c. Water demand management.

d. Hydraulic network modelling.

e. Long and medium term demand projections.

Calculate your score. Look up the points for each true answer below and add up all your points to obtain your system's score.

1a	1b	1c	1d	1e	2a	2b	2c	2d	3a	3b	3c	3d	3e	3f	4a	4b	4c	4d	4e	5a	5b	5c
5	5	5	5	3	4	4	4	4	3	2	1	3	3	3	3	2	2	1	2	2	2	1

5d	5e	6a	6b	6c	6d	7a	7b	7c	7d	8a	8b	8c	8d	9a	9b	9c	10a	10b	10c	10d	10e	
1	1	2	2	2	2	2	2	2	2	2	2	1	1	4	2	1	2	2	2	2	2	

Evaluation

80 points and above: Your municipality is doing very well. Keep up the good work!

60 to 80 points: A good effort, but you are not getting the most of your metering system. Significant effort is required to get your metering system up to standard.

40 to 60 points: Some things are in place, but major work is required to get your system up to standard.

Below 40 points: Your municipality is not performing well at all, and a substantial effort will be required to build a proper metering system.

Main steps in developing an integrated water meter management system

1. Identify all sources of water into your system and bulk transfers to other municipalities. Ensure that each source or bulk transfer has a meter that is correctly sized, in good condition and regularly read (preferably continuously, but at least weekly).
2. Identify bulk consumers (top 10 %) in the system. Ensure that each bulk consumer has a meter that is correctly sized, in good condition and regularly read (at least monthly).
3. Identify zones in the distribution system – the smaller the zones are, the better. Ensure that each zone has a meter that is correctly sized, in good condition and regularly read (preferably continuously, but at least weekly).
4. Log the zonal meters to determine the minimum night flow (and thus the leakage) in each zone.
5. Estimate current revenue water based on water sales to consumers.
6. Do a preliminary water balance according to the IWA grid (Figure 7-3) and identify the most critical areas for intervention. This will typically lead to a leak detection and repair programme focussed on the zones with the highest leakage rates. A more comprehensive non-revenue control strategy should be developed from this initial effort.
7. Perform an initial review of consumer water meters in the system using the meter database or records and limited, targeted field investigations. Develop a strategy for the evaluation of consumer water meters, focussing initially on more affluent areas where consumption and payment levels are likely to be higher. Consumers without meters should be identified and prioritised for meter installation. It is important that all consumers are metered, although it may be necessary to initially meter stand pipes or indigent consumers in groups. A comprehensive meter audit, testing and replacement programme should develop from this initiative based on a metering strategy adopted by the municipality.

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GLOSSARY

APPENDIX A

Actual volume (V_a). The total volume of water passing through the water meter, irrespective of how long this takes.

AMR. *Automatic Meter Reading.*

Apparent losses. Water that seems like, but are not really water losses to a municipality. The main contributors to apparent losses are water meter under-registration, unauthorized consumption (water theft) and accounting errors.

Automatic Meter Reading (AMR). AMR uses technology to transmit meter readings automatically to a central location using phone network or radio frequency (RF) technologies.

Automatic remote reading. Meter readings are recorded automatically by connecting a handheld device to a connection point on the meter.

Bulk transfer connection. A connection through which water is transferred between two municipalities or from a bulk supplier to a municipality.

Calculator. See *counter*.

Check valve. See non-return valve.

Classes. See *meter classes*.

Combination meter. A type of meter that consists of two individual meters that operate as a single unit. A control valve directs flow through one of the two meters or both to provide a wide flow range.

Consumer connection. A water connection to a consumer. A distinction is made between *small* and *large connections.*

Control element. The dial or pointer on the indicator with the smallest value scale, i.e. the dial or pointer that indicates the smallest quantities of water.

Conventional meter classes. Meter classes A, B, C and D that has been in common use for decades. It is gradually being replaced by the *new meter classes* in many countries.

Corrosion. Any chemical reaction through which a material is degraded.

Counter. The part of a water meter that keeps track of the volume of water that has passed through the meter. It is also called the calculator.

Dezincification. Leaching of zinc from brass material through a chemical reaction with the water passing through the device.

Direct meter reading. Meters are read directly from the indicator by a meter reader.

Direct transducer. A transducer that uses a direct mechanical link (typically a spindle) between the *sensor* and *counter*. Also see *magnetic transducer.*

Distribution meter. A *network management meter* that is not a district *metered area*.

District area meter. A *network management meter* used to measure consumption of a *district metered area*.

District Metered Area (DMA). An isolated area of a distribution system with one or more metered inputs.

DMA. *District metered area*.

Doppler ultrasonic water meter. An *ultrasonic meter* that estimates the velocity of flow through the meter from the change in the frequency of a sound wave when it bounces back from moving particles in the fluid.

Dry dial. The counter and indicator of dry dial meters are contained in a dry, sealed chamber. Also see *wet dial.*

DZR. *Dezincification* resistant.

Electromagnetic meter. An inferential water meter that uses electromagnetic principles to measure the average velocity of the water passing through it.

Error. The difference between the *indicated volume* and the *actual volume*. Thus the *error* will be positive for an over-registering meter and negative for an under-registering meter.

Error curve. A graphical presentation of the relative error of the meter over its flow range.

Flow meter. See *water meter.*

Flow range. The range of *flow rates* in which the meter is required to operate within the *maximum permissible error*, thus between the *minimum* and *overload flow rates*.

Flow rate. A volume of water divided by the time taken for this volume to pass a point such as a flow meter.

Helical vane impeller. An impeller with vanes that are shaped in a helical or spiral fashion, similar to the propeller of a motorboat. See figure 2-3.

ICI. Industrial, commercial and institutional**.** Typically used to describe a category of consumers.

Impeller. A type of propeller that is rotated by the water moving through the meter. Single jet and multijet meters use radial impellers, while Woltmann meters uses helical vane impellers. See figure 2-3.

Indicated volume, V_i. The volume of water indicated by the meter. For a perfect meter, this will be equal to the *actual volume*. However, most meters will indicate slightly more or less.

Indicator. The part of a water meter that communicates the water meter readings to a meter reader. The indicator can be an analogue or digital device. Examples include dials and electronic displays.

Inferential meter. A flow meter with a *sensor* that measures the velocity of the water passing through it, and then converts the velocity into a volume. It is also called a velocity meter.

Insertion meter. A water meter that consists of a probe that is inserted through a special connection into a pipe to measure the flow velocity at a particular point (or sometimes a number of points).

Intrinsic error. The meter error determined under controlled conditions in a highly accurate testing laboratory accredited for this purpose.

IP68. The symbol used to indicate that the watertighness of a *dry dial* has been tested to standard IEC 605296. It is important to note how long the dial was subjected to the IP68 test.

ISO. International Organization for Standardization.

IWA. International Water Association.

IWA water balance. A standard water balance to account for water consumption and losses in a municipal water distribution system. See fig 7-3.

IWMM. Integrated water meter management.

Large meter connections. Consumer connections with water meters larger than 25 mm.

Legal metrology. The branch of *metrology* that deals with the legal requirements of measurements and measuring instruments in order to protect consumers and ensure fair trade.

Limiting conditions. Extreme conditions, including flow rate, temperature, pressure, humidity and electromagnetic interference, which a water meter is required to withstand without damage or permanent deterioration in its performance.

Lower zone. The area of a meter's *error curve* between the *minimum* and *transitional flow rates*. See Figures 2-8 and 2-9.

Magflow meter. See *electromagnetic meter*.

Magnetic meter. See *electromagnetic meter*.

Magnetic transducer. A transducer that uses a magnetic link between the *sensor* and *counter*. Magnetic transducers are typically used on *dry dial* meters. Also see *direct transducer.*

Maximum permissible error (MPE). The largest allowable absolute value of the *relative error*, i.e. the largest allowable *relative error* when the sign of the error is ignored. The *MPE* is larger for the *lower flow zone* than for the *upper flow zone*.

Mechanical meters. Meters that operate on a mechanical principle, such as moving a piston or turning an impeller.

Meter class. A system that classifies meters according to the accuracy performance. Conventionally a meter has been classified as class A, B, C or D, with class D the most stringent. In the new meter classes being introduced in many countries, these classes are replaced with a different classification system.

Meter error. See *error*.

Metering conditions. The conditions under which a meter operates, such as the flow rate, temperature, pressure, humidity and electromagnetic interference.

Metrology. The study measurement accuracy, including how to determine the accuracy of a given measurement device and what sort of accuracy is required when measuring different things. Also see *legal metrology*

MID. The Measurement Instruments Directive that requires water meters in the European Union to conform to certain minimum standards.

Minimum flow rate, q_{min} or Q_1. The lowest flow rate at which the water meter is required to operate within the *maximum permissible error*.

MPE. *Maximum permissible error.*

Multijet meter. A flow meter with a radial-vaned impeller rotated by a multiple jets of water from different directions. See figure 3-6.

Network management meter. A water meter used to measure the movement of water in the distribution system. A distinction is made between distribution and district area meters.

New meter classes. A new meter class system that has been adopted by a number of countries throughout the world, replacing the *conventional meter classes*.

Non-return valve. A valve that only allows flow in one direction through it.

OIML. International Organization of Legal Metrology.

Overload flow rate, (q_s or Q_4). The highest flow rate at which the meter should be able to operate (within its required accuracy) for a short period without permanent damage to its accuracy.

Permanent flow rate (q_p or Q_3). The flow rate for which the meter is designed. The meter should be able to operate continuously at this flow rate for its design life without exceeding the *maximum permissible error*.

Positive displacement meter. See *volumetric meter*.

Pressure loss. The pressure difference over the ends of a horizontal meter, at a given flow rate.

q_{min}. *Minimum flow rate* in the conventional meter class system.

q_p. *Permanent flow rate* in the conventional meter class system.

q_s. *Overload flow rate* in the conventional meter class system.

q_{start}. *Starting flow rate.*

GLOSSARY

q_t. *Transitional flow rate* in the conventional meter class system.

Q_1. *Minimum flow rate* in the new meter class system.

Q_2. *Transitional flow rate* in the new meter class system.

Q_3. *Permanent flow rate* in the new meter class system.

Q_4. *Overload flow rate* in the new meter class system.

Radial vane impeller. An impeller with straight vanes radiating out from the centre. See figure 2-3.

***Rated operating conditions* (*ROC*).** The range of conditions under which the water meter is required to operate within its maximum permissible error.

Reference conditions. The specified conditions under which the performance of a meter is tested in a laboratory.

Relative error. The *error* divided by the *actual volume*. The *relative error* will be positive for an over-registering meter and negative for an under-registering meter.

ROC. Rated operating conditions.

Rotary piston meter. A *positive displacement meter* with a rotating piston.

SABS. South African Bureau of Standards.

SANAS. South African National Accreditation System.

SANS. South African National Standard.

SCADA. *Supervisory control and data acquisition*.

Sensor. The part of a water meter that detects the flow passing through the meter, such as a piston or an impeller. Meters are classified according to the operating principles of their sensors.

Single jet meter. A flow meter with a radial-vaned impeller rotated by a single jet of water. See figure 3-4.

Small meter connections. Consumer connections with water meters of 25 mm or smaller.

***Starting flow rate* or q_{start}**: The lowest flow rate at which the meter is able to register a flow passing through it.

GLOSSARY

Strainer. A sieve that stops solid particles moving with the water from reaching and damaging a water meter.

Supervisory control and data acquisition (SCADA). A system for the transmission of information and instructions between a central control station and facilities in the field, e.g. reservoirs, pump stations and treatment plants.

Transducer. The part of a water meter that transmits the signal detected by the *sensor* to the *counter* of the meter.

Transit time ultrasonic water meter. An *ultrasonic meter* that estimates the average flow velocity from the time it takes an ultrasound wave to travel through the fluid.

Transitional flow rate, q_t or Q_2. A flow rate between the *minimum flow rate* and p*ermanent flow rate* at which the *maximum permissible error* of the meter changes, dividing the *flow rate range* into an *upper zone* and a *lower zone*.

Ultrasonic meter. An inferential water meter that uses the speed of ultrasound waves through the water to measure the average velocity of the water passing through it.

Upper zone. The part of a meter's *error curve* between the *transitional and overload flow rates*. See Figures 2-8 and 2-9.

Velocity meter. See *inferential meter*.

Verification officer. A person who is specially qualified and registered with *SANAS* to verify the accuracy of water meters.

Verification scale interval. The lowest value scale on the control element, i.e. the smallest volume of water that can be read from the indicator.

Volumetric meter. A flow meter with a sensor that measures the volume of water passing through it directly by counting off 'packets' of water. It is also called a positive displacement meter.

Water meter. A device that measures the volume of water that passes through it. Some documents distinguish between 'water meters' and 'flow meters', but in this document these two terms are used to refer to a generic water meter.

Wet dial. The counter and indicator of wet dial meters are surrounded by a fluid. The fluid can consist of water from the network or a special liquid in a sealed chamber. Also see *dry dial.*

Woltmann meter. A flow meter with a helical-vaned impeller rotated by the water moving over it. Horizontal (WP) and vertical (WS) Woltmann meters are available. See figures 3-8 and 3-9 respectively.

Working pressure. The average pressure that a water meter operates under.

WP meter. *A* horizontal *Woltmann meter.*

WRC. Water Research Commission.

WS meter. *A* Vertical *Woltmann meter.*

Organisations and Products

APPENDIX B

Metrology Organisations

- International Organization of Legal Metrology (OIML), http://www.oiml.org
- Bureau International des Poids et Mesures (BIPM), http://www.bipm.org
- Intra-Africa Metrology System, http://www.afrimets.org
- Southern African Development Community Cooperation in Measurement Traceability (SADC-MET), http://www.sadcmet.org
- National Metrology Institute of South Africa (NMISA), http://www.nmisa.org

Standards Organisations

- International Organization for Standardization (ISO), http://www.iso.ch/iso/home.htm
- European Committee for Standardization (CEN), http://www.cen.eu
- American National Standards Institute (ANSI), http://www.ansi.org
- African Organization for Standardization (AOS), http://www.arso-oran.org
- Southern African Development Community Cooperation in Standardization (SADCSTAN), http://www.sadcstan.co.za
- South African Bureau of Standards (SABS), https://www.sabs.co.za

Other Organisations

- International Water Association (IWA), http://www.iwahq.org
- American Water Works Association (AWWA), http://www.awwa.org
- African Water Association (AWA), http://www.afwa-hq.org/en
- Water Institute of Southern Africa (WISA), http://www.wisa.org.za
- South African Water Research Commission (WRC), http://www.wrc.org.za

Water Meter Suppliers

The following companies are the manufacturers or primary suppliers of water meters certified to SABS 1529:

- Aqua-Loc, www.aqualoc.co.za, ph. (011) 474 1240
- Elster Kent, www.elster.com, ph. (011) 470 4900
- Itron, www.itron.com, ph. (021) 928 1700
- Sensus, www.sensus.com, ph. (011) 466 1680

The following companies are suppliers of electromagnetic and ultrasonic water meters

- ABB, www.abb.co.za, ph. (021) 506 7700
- Krohne, www.krohne.com/South_Africa.1782.0.html, ph. (011)314 1319
- Siemens, www.siemens.co.za, ph. (021) 935 8000

Meter management software

The following products specifically deal with aspects of water meter management:

- Swift, http://www.gls.co.za/software/products/swift.html, ph.(021) 880 0388
- Meterman, www.wms.co.za, ph. 083 377 2635

Meter sizing and selection software

- Elster Kent
- Itron
- Sensus

Appendix C

Recommended Reading

Water Meter Management

1. *Establishing a metering plan to account for water use and loss,* by the Federation of Canadian Municipalities and National Research Council, 2003, Downloadable from http://gmf.fcm.ca/files/Infraguide/Potable_Water.

2. *Integrated water meter management,* by F. Arregui, E Cabrera Jr., and R. Cobacho, 2006, IWA Publishing, London

3. *AWWA Manual M6: water meters – selection, installation, testing and maintenance,* 1999, American Water Works Association.

4. *Meter management: best practices for water utilities*, by D.L. Schlenger, 1997, Journal of Water Engineering and Management, March, 33–37.

5. *Flow measurement handbook, industrial design, operating principles, performance, and applications,* by R.C. Baker, 2000, Cambridge University Press, Cambridge.

6. *A compendium of best practices in asset management, by J.N.* Bhagwan, 2009, Global Water Research Coalition, Downloadable from http://www.wrc.org.za/ SiteCollectionDocuments/News%20documents/2009-02-23%20GWRC%20final-Jay.pdf

Water Meter Selection, Testing and Replacement

1. *Optimal meter selection system* by E.H. Johnson, 2001, published in Water SA Volume 27, No. 4, Downloadable from www.wrc.org.za.

2. *Evaluating residential meter performance*, by P.T. Bowen, J.F. Harp, J.E. Hendricks and M. Shoeleh, 1991, American Water Works Association Research Foundation AWWARF. Denver, CO.

3. *In-situ calibration of large water meters* by E.H. Johnson, 1999, published in Water SA Volume 25, No. 2. Downloadable from www.wrc.org.za.

4. *Determining the economical optimum life of residential water meters,* by H. Allender, 1996, Journal of Water Engineering and Management, September; 20-24.

5. *Implementing a large-meter replacement program*, by M.J. van der Linden, 1998, published in Journal AWWA, August, pp 50-56.

6. *Economic analysis for replacing residential meters*, M.D. Yee, 1999, published in Journal AWWA, July, pp 72-77.

7. *Domestic water meters: influence of various fittings and installation configurations on accuracy of 15 mm water meters*, by P. Chipindu and C.J. Wantenaar, Water Research Commission Report No.948/1/00, Downloadable from www.wrc.org.za.

Water Billing and Accounts

1. *Guidelines on domestic water accounts – towards a consistent approach in South Africa*, by S. Slabbert, 2010, WRC Report no TT 457/10, Downloadable from www.wrc.org.za.

2. *Towards standards for municipal invoices in South Africa*, by S. Slabbert, 2010, WRC Report no TT 458/10, Downloadable from www.wrc.org.za.

Water Meter Standards

1. SANS 1529-1: *Water meters for cold potable water Part 1: Metrological characteristics of mechanical water meters of nominal bore not exceeding 100 mm*, South African Bureau of Standards, Pretoria

2. SANS 1529-4: *Water meters for cold potable water Part 4: Mechanical meters of nominal bore exceeding 100 mm but not exceeding 800 mm*, South African Bureau of Standards, Pretoria

3. *OIML R 49-1, Water meters intended for the metering of cold potable water and hot water. Part 1: Metrological and technical requirements*, International Organization of Legal Metrology, Paris. Downloadable from www.oiml.org.

INTRODUCTION TO

INTEGRATED WATER METER MANAGEMENT

EDITION 1

About the author

Dr JE (Kobus) van Zyl holds Bachelor and Master's degrees in Civil Engineering, and a Diploma in Scientific Computing from the Rand Afrikaans University (now University of Johannesburg). He obtained a PhD in Civil Engineering at the University of Exeter in 2001.

He is a registered Professional Engineer, a member of the South African Society of Civil Engineering, American Society of Civil Engineers and the International Water Association, and a Fellow of the Water Institute of Southern Africa. He was Chair of the Department of Civil Engineering Science at the University of Johannesburg (2005-2007), and held the Rand Water Chair in Water Utilisation at the same institution. In 2008 Dr van Zyl chaired the 10^{th} Water Distribution System Analysis (WDSA) Conference, held in the Kruger National Park. This is one of the two leading international conference series on water distribution systems, and the first WDSA conference held outside the USA.

He has twice been awarded the Best Paper prize in the Journal of the South African Society for Civil Engineering, and is an Associate Editor of the Journal of Water Resources Planning and Management.

Dr van Zyl's research focuses on water distribution systems, and his current interests include hydraulic modelling, stochastic analysis, water losses, metering, and water demand management.

Dr Van Zyl currently holds an associate professorship at the Civil Engineering Department of the University of Cape Town.

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