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UNIVERSITY OF CAPE TOWN

Apparent water loss due to consumer meter inaccuracies in selected areas of South Africa

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Faculty: Department of Civil Engineering

Course: CIV5000Z Masters Dissertation: Civil Engineering

Due Date: 28 September 2012 (Revised Copy of Dissertation)

Apparent water loss due to consumer meter inaccuracies in selected areas of South Africa 2012

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Acknowledgments

I would firstly like to thank my Supervisor, Prof Kobus van Zyl, for giving me the opportunity and privilege to study for a Master's degree, secondly the Water Research Commission of South Africa (WRC) for funding this research and the following people who was involved in one way or another with making this research possible:

- Kerry Fair (GLS Consulting) – For providing the City of Cape Town meter database
- Simon Scruton & Brendan Magill (eThekweni Municipality)– For providing the eThekweni meter replacement database and bulk meter reports from eThekweni and Pietermaritzburg
- Melvin Engelbrecht (City of Cape Town)- provided bulk meter audit reports of a pilot study in Parow Industria
- Trevor Westman – Provided the Tshwane meter audit report
- Nazeem Marlie (City of Cape Town) gave guidance and support for the flow logging and on-site leakage work.
- Randall Davids (iKapa Reticulation and Flow cc) - performed the installations of and carrying out of the flow logging field work.
- Beau Smith and Thando Maphaqa (UCT final year students) – helped with the PR work required for getting consumers to give permission to access and log their water meters.
- Malunga Masaobi, Karl Bester and Seamus Levin (UCT final year students) – carried out the on-site leakage study in Cape Town. Special thanks go to Malunga for carrying out this work in Bloemfontein as well.
- Mary-Anne du Preez (Water Control Engineer from JOAT), Robison de Melo (Project Engineer from JOAT) and Conrad Huygen (Principal Consultant from Business Connection) - for the list of meters younger than five years in the Bloemfontein on-site leakage study
- Sharon Yaniv (ARI Valves) – provided a few papers about Unmeasured Flow Reducers (UFRs) and was available to answer questions about the product
- Rehaaz Narker (Itron) – provided the Bloemfontein case study on UFRs
- Edgar Johnson for reviewing this thesis and giving comments, including providing a few papers.

Abstract

Apparent losses form an important component of the International Water Association's water balance. While apparent losses look like real losses to a municipality, this is not actually the case. The main components of apparent losses are water meter under-registration and unauthorised consumption.

Water utilities in South Africa and internationally are becoming increasingly aware of the importance of good meter management practices based on the vast amount of literature published and work done by municipalities in recent years. Water meters are known to increasingly under-register as they age and register consumption. They register consumption the least accurate at low flowrates and their accuracy in this range deteriorates the fastest.

This study investigates the extent of the apparent loss problem in selected areas of South Africa due to meter inaccuracy in a number of different ways, including an inspection of new residential consumer meters, interrogation of a metering database, flow logging of domestic consumers with and without an Unmeasured Flow Reducer (UFR) installed and a compilation of reports on bulk consumer meters.

It was found that 16 % of 402 properties investigated in the City of Cape Town had an on-site leakage and their median flowrate was 10 litres/ hour. In Bloemfontein, it was found that 28 % of the 167 properties investigated had an on-site leakage with a median flowrate of 20 l/h.

An investigation into the performance of 15 mm positive displacement meters based on eThekweni's water meter database showed that the under-registration from these meters increase by 0.36 %-points per year and 0.9 %-points per 1000 kL registered.

Flow logging of domestic consumers with and without UFRs, showed that there was no genuine improvement in meter accuracy with meters that had UFRs installed in-line with it. However, there were only 8 properties (3 of which having a UFR installed) in the study that were investigated and no statistical conclusive conclusions could be made.

Bulk meter audits in Ekurhuleni and Tshwane showed apparent losses of 18 % and 19 % respectively.

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1 Introduction

1.1 Background

Water is a limited natural resource that plays a vital role in sustaining human life and driving economic development. It is abstracted from natural water bodies, where it is then treated for potable use and distributed to domestic, institutional, commercial and industrial consumers.

The increasing demand for water in South Africa and internationally to meet both human and economic needs, coupled with aging and inefficient distribution systems, has necessitated the need for better asset management practices to reduce water losses. The International Water Association (IWA) has done pioneering work in the field of best practices to reduce and classify water losses. They developed a water balance, which classifies water entering a distribution system into authorized consumption and water losses. Water losses are further classified into both real and apparent losses. Real losses are a physical loss of water and include all water losses that occur upstream of the consumer meter. Apparent losses are non-physical water losses, in that it is water that reaches the consumer, but is not recorded by the water utility and appears as a physical loss. Apparent losses are classified as metering inaccuracies and unauthorized consumption.

Water utilities in South Africa and internationally are becoming increasingly aware of the importance of good meter management practices based on the vast amount of literature published and work done by municipalities in recent years. Water meters are known to increasingly under-register as they age and register consumption. They register consumption the least accurate at low flowrates and their accuracy in this range deteriorates the fastest (Davis, 2005).

A research project performed by the Water Research Commission in Johannesburg was performed to investigate the level of on-site leakage on residential properties (Lugoma et al., 2012). It was found that 67 % of 128 households had on-site leaks with an average leakage rate of 16.5 l/ property/ h. The study showed that significant number of on-site leakages occur on residential properties at low flowrates, indicating a large contribution to apparent losses.

The purpose of this study is to investigate the extent of the apparent loss problem in selected areas of South Africa due to meter inaccuracies in a number of different ways.

1.2 Objectives

The objectives of this study are as follows:

- Perform an international literature review on apparent losses due to meter inaccuracy.
- Measure on-site leakages on residential properties in selected suburbs in the City of Cape Town and Bloemfontein and estimate apparent losses due to this.
- Estimate the meter error versus age and registered volume relationship by analyzing the eThekweni municipality's meter replacement database
- Test water meters in the field to obtain both consumption patterns and meter error of brand new meters installed in the field in selected suburbs in the City of Cape Town
- Test the impact of Unmeasured Flow Reducers (UFRs) on reducing apparent losses in the City of Cape Town
- Review reports on bulk water meter audits performed by municipalities

1.3 Methodology

The following is an overview of the methodology used for investigations performed in the field and analysis of the meter database:

- On-site leakage investigation. Only new meters in the field were considered in the study. Upon reasonable notice, the consumer was asked to stop all consumption and their meter was read over defined time intervals to determine the existence of an on-site leakage and its flowrate.
- Meter database analysis. The eThekweni Meter Replacement Database was used to estimate meter error versus age and registered volume by comparing consumption one year before and after a meter is replaced. Thousands of meters per age and registered volume group are analyzed to achieve a representative sample of meter under-registration in the field.
- Consumer flow logging with and without UFR. An accurate master meter was installed in-line with the consumers meter and equipped with a data logger. The consumption pattern is then logged for a minimum of one week with a 1 litre per

pulse output. The consumption of the master meter is corrected by weighting the meter's error curve estimated in a laboratory to the logged consumption pattern. The master meters installed with and without a UFR is compared for error and consumption patterns.

- Review of reports on bulk meter audits. A number of reports from municipalities and conference papers were compiled to find trends.

1.4 Structure of thesis

This thesis is composed of four different studies which are related in part, and as a result each study is given its own chapter where their detailed introduction, methodology, results, discussion and conclusion are presented. The final Chapter 7 concludes the main findings of each study in the thesis. The following is the layout of this thesis:

- Chapter 1: Introduction.
- Chapter 2: Literature Review
- Chapter 3: On-site leakage field study of domestic consumers
- Chapter 4: Meter database analysis to estimate meter error
- Chapter 5: Flow logging of domestic consumer meters and UFRs
- Chapter 6: Review of bulk consumer meter audits
- Chapter 7: Conclusion

2 Literature Review

2.1 Introduction

Since the 1990s the International Water Association (IWA) has been at work developing a standardized water audit methodology and water loss performance indicators (Thornton et al., 2008). The IWA Water Balance was developed to be used as an accounting approach that records and displays how treated water entering the system is distributed. It is an important starting point for any Non-Revenue Water reduction strategy, which requires the following questions to be answered (Farley & Liemberger, 2005):

- *“How much water is being lost?”*
- *Where is it being lost from?*
- *Why is it being lost?*
- *What strategies can be introduced to reduce losses and improve performance?*
- *How can the strategy be maintained and the achievements sustained?”*

One of the important aspects of the water balance is the need to have clear and precise definitions for each category. Figure 2.1 describes how the IWA have categorized the water balance.

System Input Volume	Authorised Consumption	Billed Authorized Consumption	Billed Metered Consumption (including water exported)	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non- Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorized Consumption	
			Metering Inaccuracies	
		Real Losses	Leakage on Transmission and/ or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
		Leakage on Service Connections up to point of Customer metering		

Figure 2.1: The Standard IWA Water Balance (Lambert & Hirner, 2000)

The following defines some of the relevant categories of the water balance (Lambert & Hirner, 2000):

- System input. Is defined as the total volume of water entering a distribution system.
- Authorized Consumption. Is all water that is consumed by registered customers whether this consumption is metered or not.
- Water Losses. Is defined as the System Input Volume minus Authorized Consumption. Water Losses are composed of Real and Apparent Losses.
- Real Losses. The physical loss of water from a pressurized distribution network up to the point of the customers' meter.
- Apparent Losses. The non-physical loss of water that reaches the consumer but is not recorded by the water utility. This includes meter under-registration, unauthorized consumption and accounting errors from the billing or metering reading process.
- Non-Revenue Water. It is the sum of Authorized Unbilled Consumption and Water Losses. It is water that the water utility does not receive any income for.

A considerable amount of work and focus has been placed on Real Losses and still much needs to be done in understanding Apparent Losses, its extent in water utilities and finding practical ways of minimising it cost effectively. The IWA Task Force on Apparent Loss is currently doing work in this regard (Johnson & Vermersch, 2011).

2.2 Financial impacts of apparent losses

Apparent loss is not a physical loss of water; therefore it does not have the operating problems that are associated with real losses in terms of technical and environmental issues. The loss of water from apparent losses is a financial problem of the utility. Apparent losses also distort water consumption data that is important for planning and management.

Apparent losses are normally valued at the retail rate charged to customers thereby making its financial impact much greater than that of real losses which are valued at variable production costs (Thornton et al., 2008). Depending on the utility, wastewater charges may be billed from the volume of water consumed by the consumer, thereby increasing the financial impact of apparent losses. The unit retail cost of water can be as much as 10 to 40 times that of the production cost for delivery and treatment (Thornton et al., 2008).

It has been reported in water utilities in Switzerland and the United States that although apparent losses only make up for a small amount of water loss in volumetric terms, they are more costly than real losses by a large margin.

In Geneva, Switzerland, apparent losses only accounted for 26 % of Non-Revenue Water (NRW) in terms of volume of water in 2004, yet accounted for 69 % of NRW in terms of financial loss to the utility (Guibentif et al., 2007).

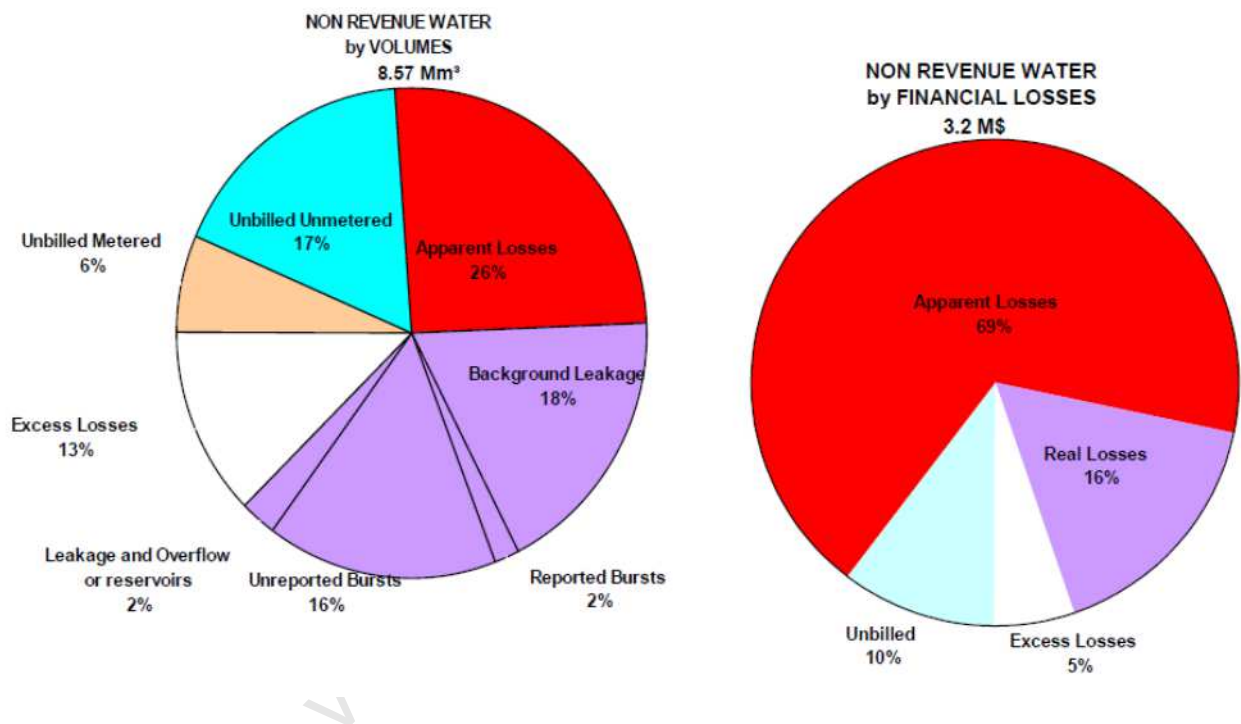


Figure 2.2: Water losses estimated in Geneva, Switzerland, in 2004 and comparing contribution of volumetric and financial impacts (Guibentif et al., 2007)

In Philadelphia, United States, apparent losses cost the city \$ 30.8 million compared to \$ 5.1 million in real losses, but only represented a third of the volume of real losses in the 2006 water audit (Thornton et al., 2008).

In Tampa Bay, United States, apparent losses accounted for 37 % of water loss volume, but cost the utility 68 % of the total cost of water losses in the 2005 fiscal year (Pickard et al., 2008). Customer metering accounted for 48 % of the total cost of water losses with unauthorized consumption and data handling errors accounting for 12 % and 8 % respectively.

Thornton et al. (2008) states that in water serviced areas that are stricken by droughts and water shortages should also value their real losses at the retail rate, as it is seen as a new source of water that can be consumed.

2.3 Reducing apparent losses

It would be ideal to remove all apparent losses from a water distribution network, however as one attempts to achieve this, so does the task become more costly. As one tries to achieve zero apparent loss the marginal costs begin to exceed the marginal benefit. Therefore, just as is done with real losses, it is understood that there will always be apparent losses and one should seek to achieve the economic level where the marginal cost of apparent loss reduction initiatives is equal to the marginal benefit of potential revenue gain from decreased apparent losses (Figure 2.3).

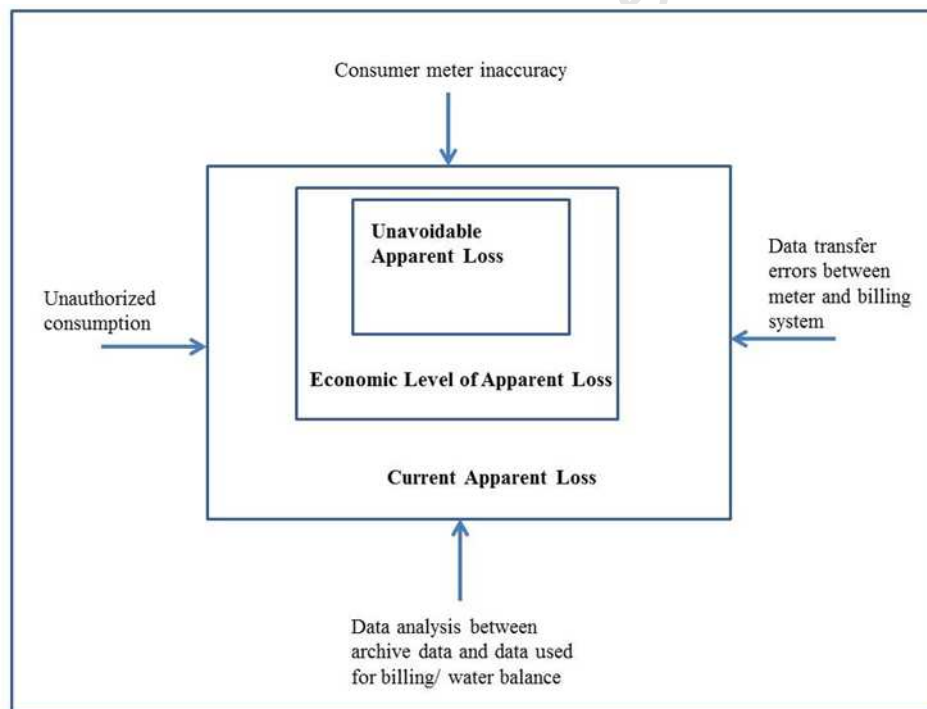


Figure 2.3: The apparent water loss control methodology (Rizzo et al., 2004)

Apparent loss reduction interventions may have other unintended consequences due to the multi-dimensionality of apparent losses. Rizzo et al. (2007) states that the four components of apparent losses ‘can act and interact interchangeably’. This means that a water meter may be over-registering and decreasing apparent losses, but its effects may be reduced due to

unauthorized consumption. Another case may be that the meter reader may overstate the actual reading of a meter, but the effects of this error could be not realised in the total apparent loss quantity, due to under-estimating of the actual consumed volume during estimations in the billing system for that year.

Rizzo et al. (2007) point out that apparent losses are also '*dynamic in nature*' and that removing water meters that are over say 5 years old does reduce meter under-registration, but one must keep in mind that the other remaining meters would have aged as well. Also, increasing discipline of meters readers will not only improve meter readings but may also reduce unauthorized consumption, as the meter connection will be inspected better for an illegal connection or tampering.

Rizzo et al. (2007) state that an '*Integrated Apparent Loss Strategy*' is required to deal with these complexities of the multi-dimensionality and dynamics of reducing apparent losses. Adopting an Integrated Apparent Loss Strategy is essentially a move to change and managing that change effectively i.e. Change Management. Pocas Martins (2009) tackles the issues surrounding successful Change Management in a water company with the goal of reducing water losses.

When presented with the problem of apparent losses, it makes sense that utilities focus on those activities that give the greatest return for the least amount of effort and cost. A good example of this is replacing the meters of large consumers first that are 'old' or 'over-sized' to ensure a quick return on investment. The income generated from a large meter replacement programme could then be used to finance the implementation of a more comprehensive meter replacement programme for smaller consumers and other apparent loss reduction projects.

The following diagram (Figure 2.4) developed by Rizzo et al. (2007) presents the actions and approaches that define an Integrated Apparent Loss Strategy.

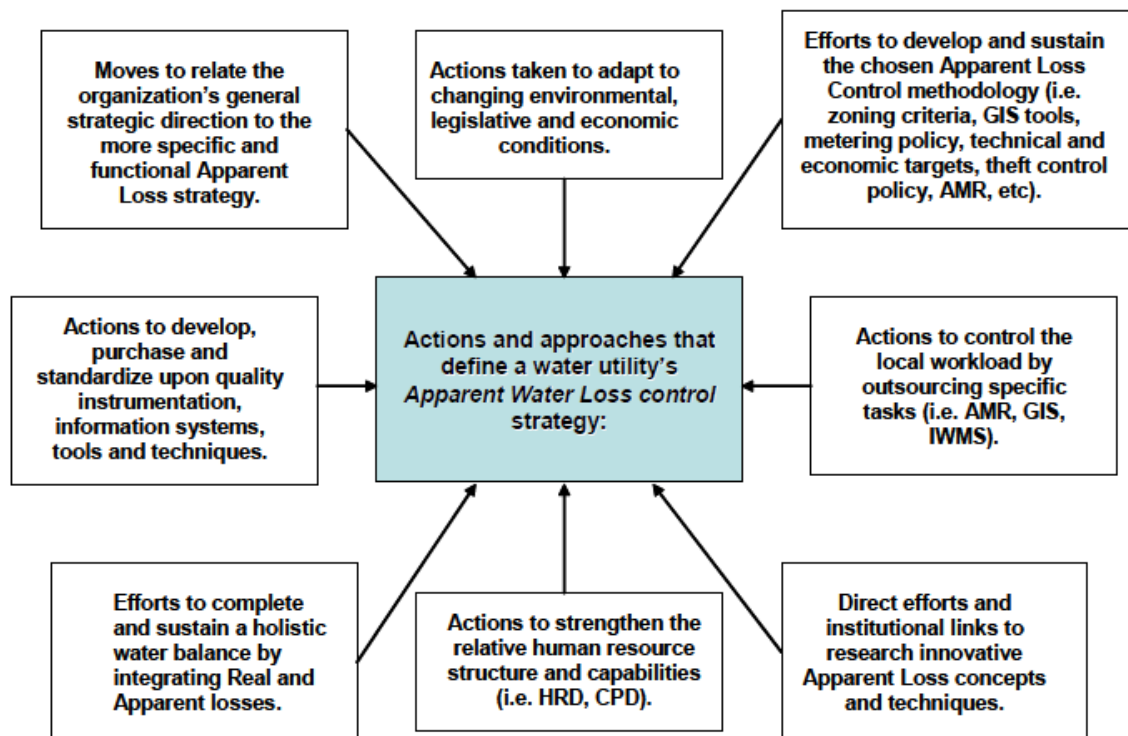


Figure 2.4: An integrated apparent water loss strategy (Rizzo et al., 2007)

2.4 Performance Indicators

Performance indicators are necessary to compare the performance of one utility to another, how the same utility is performing from year to year and for setting performance targets.

The IWA Task Force's Apparent Loss Team recommends that the performance indicator for apparent losses should not be represented by a percentage of the water supplied, but rather calculated in the same way as that done for Real Losses and the Infrastructure Leakage Index (ILI) (Rizzo et al., 2007). The Task Force proposes that a value of 5 % of water sales should be used as the Unavoidable Annual Apparent Loss (UAAL) for the moment until further investigation, and should be calculated as follows (Rizzo et al., 2007):

$$\text{Apparent Loss Index (ALI)} = \frac{\text{Current Annual Apparent Loss (CAAL)}}{\text{Unavoidable Annual Apparent Loss (UAAL)}}$$

Thornton et al. (2008) state that a UAAL of 5 % may be high for developed countries where they have good customer meter management, buildings do not have roof tanks and low

unauthorized consumption due to good policies and safeguards. However, Thornton et al. (2008) also state that 5 % is reasonable for developing countries.

2.5 Current practices for quantifying apparent losses

The level of apparent losses for many water utilities is relatively unknown due to either a lack of data or no standard methodology to measure apparent losses (Mutikanga et al., 2010). Therefore many water utilities use default values or rules of thumb to quantify the level of apparent losses (Mutikanga et al., 2010).

Default values have been used in Australia, New Zealand, USA and Canada to estimate apparent losses (Seago & McKenzie, 2007). Table 2.1 shows the suggested default values that these countries use.

Table 2.1: Suggested apparent loss default values for developed countries (Seago & McKenzie, 2007)

Unauthorized Consumption	Domestic Meter Under-registration	Non-domestic Meter Under-registration
0.1 % of Total System Input	2 % of metered consumption	2 % of metered consumption

In South Africa, a study was done by (Seago et al., 2004) whereby they a table was developed to give a water utility suggested values of meter under-registration, illegal connections and data transfer errors (Table 2.2). The motivation of the paper was to shift away from the 20 % lump sum value of total water losses used in the past to calculate apparent losses in the *BENCHLEAK model* (software that estimates real losses). Only meter age and water quality were considered in the study as indicators of meter under-registration to simplify the table. Each municipality in their study was asked to provide information with regard to their meter accuracy and age, illegal connections and data transfer errors. The values for meter under-registration were estimated based on the fact that Europe has a compulsory meter replacement programme every 5 years and the domestic meters used in South Africa are very similar to those used in Europe, according to Seago et al. (2004).

Table 2.2: Suggested default values as percentages of water losses for distribution systems in South Africa (Seago et al., 2004)

Illegal Connections		Meter age and accuracy			Data transfer	
			Good water quality	Poor water quality		
Very high	10 %	Poor > 10 years	8 %	10 %	Poor	8 %
High	8 %	Average 5-10 years	4 %	8 %	Average	5 %
Average	6 %					
Low	4 %	Good < 5 years	2 %	4 %	Good	2 %
Very low	2 %					

Mutikanga et al. (2010) developed a similar table as Seago et al. (2004) for Kampala City in Uganda, which can be used as default values for developing countries. The difference lays mainly in the method, as Mutikanga et al. (2010) sought to measure the actual metering errors, obtain actual illegal consumption data and did a meter reading and billing system audit. Table 2.3 shows the results of the study.

Table 2.3: Default values proposed for developing countries (Mutikanga et al., 2010)

Unauthorized Consumption	Meter age and error				Meter reading, data handling and billing errors	
			With household storage tanks	Direct supply		
City (> 100 000 service connections)	10 %	Poor (> 10 years)	- 28 %	- 10 %	Poor ^a	10 %
Municipality (50 000-100 000 service connections)	3 %	Average (5-10 years)	- 20 %	- 8 %	Average ^b	6 %
Medium towns (5000-50 000 service connections)	2 %	Good (< 5 years)	-15 %	- 5 %	Good ^c	2 %
Small towns (< 5000 service connections)	0.5 %					

^a No management controls in place, employees are poorly remunerated and inefficient billing system
^b Management controls in place, fairly remunerated employees and good billing system
^c Well functioning utility with good customer billing system
 Percentages represent percentages of water sales

2.6 Factors affecting consumer meter error

2.6.1 Introduction

Consumer water meters serve the purpose of recording the volume of water that is consumed by a consumer. Like any measuring instrument a water meter is not 100 % accurate. Therefore, water meters may under-register or over-register the total volume of water passing through it.

The most common water meter is the mechanical type, which has a sensor element that is rotated as water passes the meter chamber. The sensor element has a rotational inertia and friction that the flow of water needs to overcome so that it can rotate and register the water passing through it. This property of the meters sensor element means that the meter tends toward under-registration at low flows and over-registration at high flows.

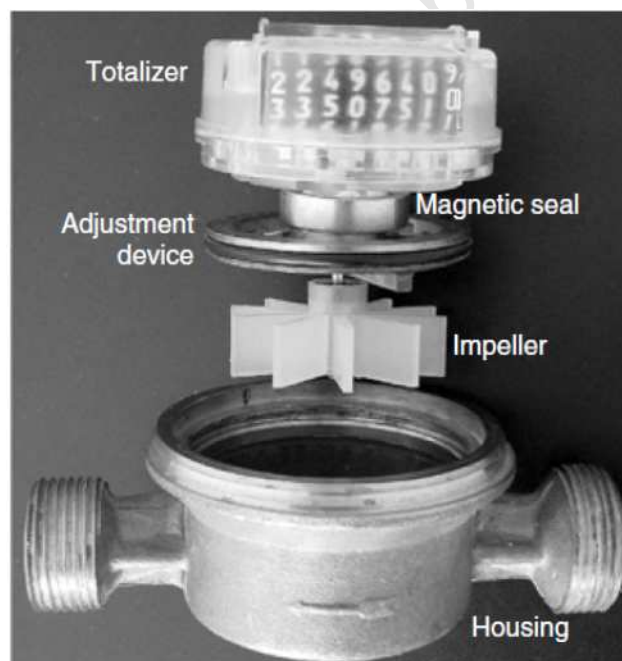


Figure 2.5: Components of a single-jet meter (Arregui et al., 2006 b)

The accuracy of a water meter population is dependent on a number of factors related to the consumer meter, the consumer's consumption behaviour and the distribution system (Table 2.4).

Table 2.4: Factors affecting meter accuracy and layout of this section

Consumer meter	Consumer consumption behaviour	Distribution system
1.3.2 Error curve	1.3.7 Consumption pattern	1.3.9 Water quality
1.3.3 Type	1.3.8 Seasonal water demand	1.3.10 Spinning
1.3.4 Size		1.3.11 Network pressure
1.3.5 Installation		1.3.12 Environment
1.3.6 Age		

Consumer meter under-registration is said to be the main cause for apparent losses in a distribution system by the American Water Works Association (AWWA) (2009).

2.6.2 Error curve

The South African Bureau of Standards (SABS) have published the SANS 1529 specification that groups the accuracy of meters into four different meter accuracy classes. There are several internationally published standards that each has their own class types and definitions for each class. These standards are the OIML R49, ISO 4064, EN 14154 publications.

Water meters do not measure different flowrates at the same accuracy across the measuring range. Therefore, there are certain flowrates that characterize the measuring range and accuracy of the meter. These flowrates are termed as the starting flowrate (q_{start}), the minimum flowrate (q_{min}), the transitional flowrate (q_t), the permanent flowrate (q_p) and the overload flowrate (q_s).

Mechanical meters have a sensor that requires a certain amount of momentum created by the flow of water passing through the meter chamber to rotate the sensor. The minimum flowrate required to just get the sensor moving and registering flow is defined as the starting flowrate (q_{start}). In other words, any consumption flowrates below the starting flowrate is not registered at all by the meter.

The meter error curve is defined by the three flowrates in the SANS 1529 document: the minimum flowrate (q_{min}), the permanent flowrate (q_p) and the overload flowrate (q_s). The minimum flowrate is the flowrate where the meter must have a maximum permissible error below 5 % up to the transitional flowrate. The transitional flowrate is the flowrate where the meter error changes from below 5 % to below 2 % error in the laboratory. For all flowrates between the transitional and overload flowrate the meter must have an error of below 2 %.

The permanent flowrate is the design flowrate of the meter, where the meter can measure consumption without any appreciable deterioration than what is expected under normal operating conditions. The permanent flowrate is also sometimes termed in literature as the nominal flowrate. The overload flowrate (q_s) is the flowrate whereby the meter can only operate for a few seconds without seriously damaging the meter. The overload flowrate is double the magnitude of the permanent flowrate.

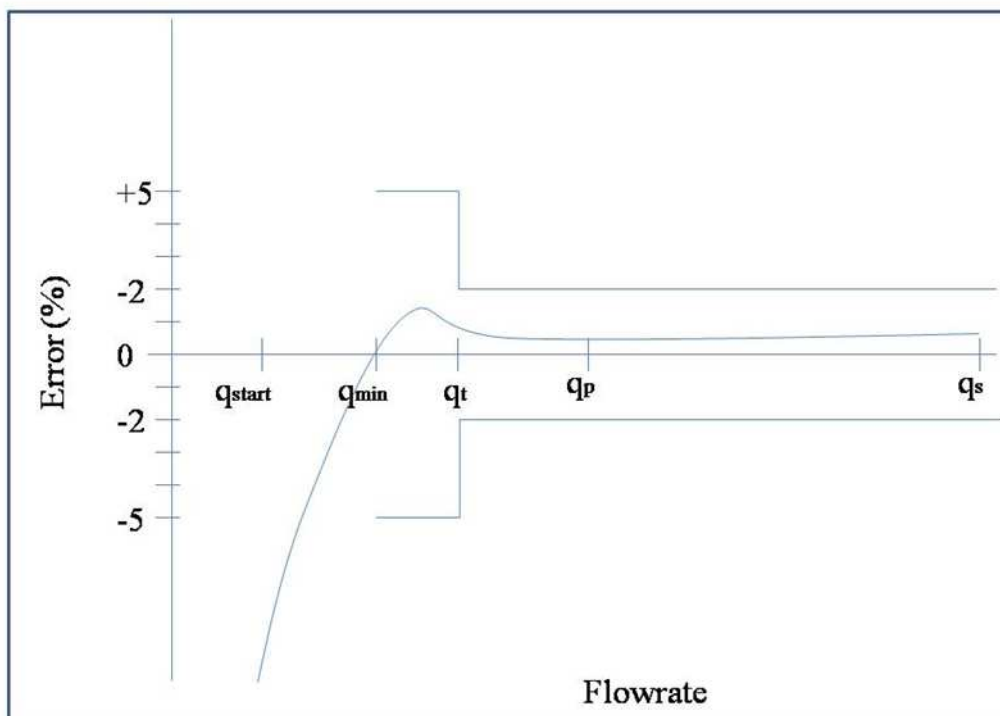


Figure 2.6: Typical meter error curve for a new multi-jet meter, showing defined flowrates

The SANS 1529 document divides the ability of meters to measure flow accurately into groups called classes. These classes are defined by the minimum and transitional flowrates, which are expressed in terms of the permanent flowrate of the meter.

Table 2.5: Meter classes defined for permanent flowrates up to 10 m³/h (SANS 1529-1, 2006)

Meter class	Minimum flowrate (q_{min})	Transitional flowrate (q_t)
A (least accurate)	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 (most accurate)	0.0075 q_p	0.0115 q_p

Table 2.6: Meter classes defined for flowrates exceeding 10 m³/h (SANS 1529-1, 2006)

Meter Class	Minimum flowrate (q_p)	Transitional flowrate (q_t)
A (least accurate)	0.08 q_p	0.3 q_p
B	0.03 q_p	0.2 q_p
C (most accurate)	0.006 q_p	0.015 q_p

The meter classes represent the ability of the meter to measure accurately in the lower flowrates. Therefore a Class D meter will measure more accurately at lower flowrates than a Class C, B and A meter. Class D meters are the most accurate meters and Class A is the least accurate. According to SANS 1529-1, Class A meters are illegal to use for custody transfer.

2.6.3 Type

There are many different types of water meters, but can be categorised into two groups that either measure consumption through the meter inferentially or volumetrically. Water meters are named according to the type of sensor inside the meter chamber. The sensor is the device that picks up the flow of water passing through the meter.

Inferential water meters are also known as velocity meters. They infer the volume of water passing through the meter by the velocity of the water passing through the meter. Some common examples of inferential meters which are mechanically driven are single-jet, multi-jet and Woltmann meters. Inferential meters that are not mechanically driven either are electromagnetic meters which use Faradays law to infer volumes or are Ultrasonic meters that use the Doppler Effect or the Single-Transit Time Effect to infer volumes from water flow velocities. Ultrasonic and Electromagnetic meters are rather expensive and are commonly used as SIV (System Input Volume) custody transfer meters where minimum measurement errors are required.

Volumetric meters are also known as positive displacement meters. The volume of water passing through the meter is measured by each fixed volume of water per rotation of the sensor. The rotary piston and nutating disc meters are positive displacement meters.

Compound meters are two meters put together in one unit. The objective is to have a large meter that can measure high flowrates and a smaller meter that can measure low flowrates at the required accuracy.

Every meter type has different characteristics and is selected based on site conditions and application.

2.6.4 Size

Typically a meter is least accurate at low flowrates and is more accurate at medium to high flowrates. Therefore, the performance of a particular size meter to measure consumption is dependent on the flowrate demand pattern of the consumer. Water meters that are too large will operate mainly below the meter's transitional flowrate and will under-register a large portion of the water passing through it compared to a correctly sized meter. Meters that are too small will operate mostly above the meters permanent flowrate, thereby achieving better accuracy in measuring flows, but will deteriorate faster (Arregui et al., 2011). High pressure loss caused by meter under-sizing is also a concern.

In Sao Paulo, Brazil, a massive bulk meter change out programme was implemented in 1997 as these meters were experiencing a progressive decay in their performance (Wilson, 2003). In the initial pilot study, 354 bulk meters were selected to be replaced or refurbished and if necessary resized. It was found that 248 (about 70%) of those meters were in fact oversized and only six were undersized. The payback period for the investment was at an average of 2 months, with 83 of those meters having a payback of just one month. By January 2002 a total of 16 809 meters were replaced, with 85 % of them being oversized and only 4 % being undersized.

In the United States, City of Anderson, a meter change-out programme was initiated. Meters were investigated for their applicability of some of the meter types installed and their sizing (Hannah, 2008). The results of the meter replacement programme yielded a 45.5 % increase

in billed consumption for apartment complexes and a 43.4 % increase at schools, motels and retail stores.

Water meters are often sized as the same diameter of the pipe it is installed at, resulting in over sizing (Wilson, 2003). Wilson (2003) claims that over-sizing of water meters, in general, is the major contributor to apparent losses.

2.6.5 Installation

Most water meters are designed to operate in specific orientations such as vertical, horizontal or an incline position. In general, single-jet and multiple jet meters are only designed for horizontal positions, whereas positive displacement meters can operate in virtually any position. When a meter is placed in an incorrect orientation, a higher meter error can be expected. Arregui et al. (2011) states that as a general rule that meters installed in incorrect positions under-register higher at low flowrates below the meters transitional flowrate and maintain their accuracy above the transitional flowrate. However, the mechanical parts of the meter will degrade faster as the impellor bearings are not operating efficiently due to the increase in friction of the moving parts caused by the incorrect orientation (Arregui et al., 2011).

The velocity profile distortions caused by disturbances upstream of the meter affect the measuring accuracy of the meter (also referred to as jetting), but once again the degree of impact on accuracy is dependent on the type of meter. Positive displacement meters are relatively insensitive to velocity profile distortions, but velocity meters are affected to varying degrees for different meter types.

When the pipe upstream of a meter passes through two perpendicular planes, a swirl velocity profile develops which may cause more severe meter inaccuracy (Arregui et al., 2011).

Manufacturers typically specify the length of straight pipe required upstream and downstream of the meter to mitigate the effect of velocity profile distortions upstream of the meter.

2.6.6 Age

Water meters as they age lose their metrological performance and in general tend to under-register consumption. Therefore, the longer a meter stays in operation the higher the potential meter under-registration and consequent financial loss.

Provided the correct size and type of meter was selected and correctly installed according to manufacturer specifications, the deterioration of the meter's performance should be related purely on the design life of the meter. The age of the meter is either defined as the length of time in operation or accumulated consumption volume registered on the meter dial.

In Arizona, United States, it was found in the initial stages of a residential meter replacement programme that the variance of cumulated volume of 10 year old meters ranged from a total of 300 000 to 3 000 000 gallons (1 136 to 11 355 kl) (Davis, 2005). In the Arizona case, it was determined that an accumulated consumption volume based meter replacement programme was more suitable. Using accumulated consumption as the indicator for meter replacement prevents meters from being replaced too early or too late, as might be the case in some instances when using time as an indication of age.

The meter replacement roll-out included testing of 1 297 positive displacement meters that were all 10 years old to determine the deterioration of meters with increasing cumulative consumption (Davis, 2005). This was done to determine the optimal replacement period of meters as a function of cumulative volume. Meters were tested at low (0.25 gpm or 57 l/h), medium (2 gpm or 454 l/h), fast (15 gpm or 3 407 l/h) flowrates. Figure 2.7 describes the results of the meter testing done. It was observed that data was more scattered for low flowrates and the decrease in accuracy for medium flowrates were the least.

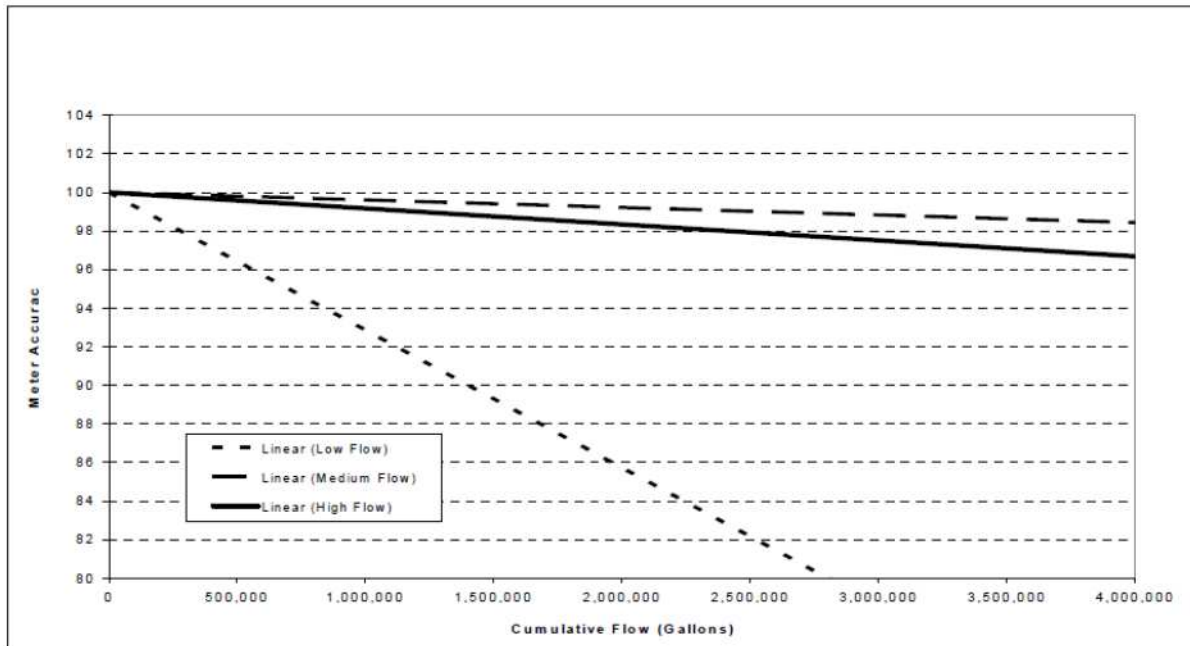


Figure 2.7: Meter accuracy versus cumulative flow for 10 year old meters, tested at low, medium and high flowrates (Davis, 2005)

Arregui et al. (2003) shows a similar trend in Davis’s (2005) study, that meters degrade the fastest at low flowrates as they age over time. Arregui et al. (2003) tested 238 Class B single-jet meters with permanent flowrates of 1.5 m³/ h of two different manufacturers in a laboratory. The meters were tested at the 30 l/ h, 120 l/ h, 750 l/ h and 1500 l/ h and their starting flowrates.

Arregui et al. (2011) performed fatigue tests on four Class C single-jet meters in the laboratory, to determine how the meter error curve is affected with usage. A volume of water was passed through each meter at an intermittent flowrate of 2 250 l/ h for periods of 15 seconds, until a total volume of 1500 m³ was registered. The error curve was then estimated at 0, 600, 1000 and 1500 m³/h. It was found in the study that the errors at medium and high flowrates were practically unchanged and only the low flowrates were generally affected negatively.

2.6.7 Consumption pattern

The daily consumption pattern of the consumer is the main factor that affects the meters ability to register consumption accurately. To achieve the greatest economic performance of

the meter, it is important that the greatest proportion of the consumer's consumption flowrates is between the minimum and permanent flowrates of the meter, and never exceeds the meter's overload flowrate.

There are a number of technical papers available that give information on standard domestic consumption profiles, see Arregui et al. (2006 b).

For example, Arregui et al. (2006 a) logged the consumption profiles of three different types of consumers in South America and Spain (Figure 2.8). The following defines the consumer types shown in Figure 2.8.

- Type 1. Apartment blocks with a direct supply from the network or pump. A total of 389 households were logged for approximately one week.
- Type 2. Apartment blocks supplied from an elevated tank at the top of the building, with the meter installed upstream of the tank. A total of 58 households were logged for a period of one week.
- Type 3. Single houses with a garden. The summer consumption of 34 households was logged for a period of four weeks.

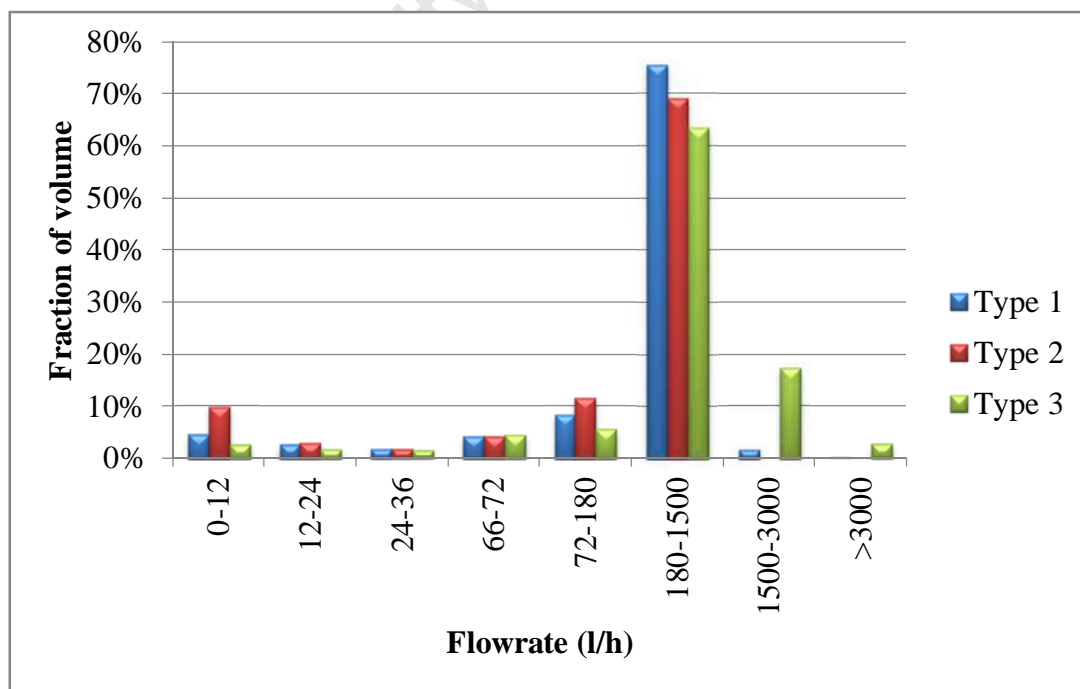


Figure 2.8: Typical consumption flowrates for different household types in Spain and South America (Arregui et al., 2006 a)

In Kampala City, Uganda, many residential customers have storage tanks installed on their premises due to an unreliable water supply (Mutikanga et al., 2010). As part of a study performed by Mutikanga et al. (2010) the accuracy of water meters at these households were tested and at households without storage tanks were tested. Water meters younger than 5 years with storage tanks under-registered by 15 % compared to 5 % with meters that have a direct supply (Table 2.3).

2.6.8 Seasonal water demand

Seasonal water use in areas that are only occupied in summer vacations also exhibit a problem for meter accuracy (Arregui et al., 2006 a). This could be due to lime-scale build-up and biological growth accumulating inside the meter when it is stagnant, which may affect its moving parts.

Davis (2005) logged the consumption patterns of residential consumers in Arizona (United States) over a week during the four different seasons. It was found that there was relatively little change in the percentage of time of low consumption flowrates between the seasons. The medium and high flowrates were the most sensitive to seasonal variation. This study shows how the meter accuracy for the same meter can change over the seasons. In Table 2.7, a summary of the data is shown with the number of samples used.

Table 2.7: Seasonal variation in consumption patterns (Davis, 2005)

Seasons	Percentage of consumption			Number of meter logged
	Low Flow	Medium Flow	Fast Flow	
	0 – 57 l/h	57 – 454 l/h	454 – 3407 l/h	
Spring	13.9 %	19.0 %	67.1 %	27
Summer	10.5 %	16.0 %	73.4 %	48
Autumn	11.5 %	25.3 %	63.3 %	30
Winter	7.8 %	33.6 %	58.6 %	27
Annual Weighted Average	10.87 %	22.31 %	66.81 %	132

2.6.9 Water quality

The quality of the water in the form of suspended solids and depositions also has an impact on the accuracy of the meter. Meter types have different sensing elements and therefore deal with poor water quality differently. Mechanical velocity meters tend to over-register more

due to lime-scale build-up on the impellor at medium to high flowrates and under-register greater at low flowrates (Arregui et al., 2011). Positive displacement meters run the risk of being blocked by either chemical build-up or a small stone passing the strainer.

In Kampala City, Uganda, about 76 % of meters in the distribution system are of the volumetric type and was found to be unsuitable due to poor water quality (Mutikanga et al., 2010). As a result of poor repair practices in the distribution system, many new volumetric meters would be blocked, and the evidence of this showed in the meter workshop during servicing where suspended solids were found in meter strainers. Mutikanga et al. (2010) concluded that velocity type meters should be installed in the system in future, as this type of meter has greater resistance to poor water quality.

Referring back to Table 2.2, it appears that water quality has a great impact on a meter's accuracy. However, Seago et al. (2004) do not explicitly motivate their reasons or give any real scientific basis for the results. This large impact of water quality on a meter's accuracy is expected for positive displacement meters but not really for velocity meters. One must keep in mind that the values to determine meter accuracy in Table 2.2 were for South African conditions which have an average mix of different meter types. They are default values for when no better information is available.

2.6.10 Spinning

Spinning is the rapid oscillation of the meters sensing element, which occurs when air pockets pass a meter, as a result of a poorly designed distribution network (Rizzo et al., 2004).

Air also enters the distribution system during repairs and installations of pipes. This occurs as the pipe is drained, filled with air and after repairs or installation is complete, water fills the pipe under pressure with the air being retained and passed through the consumer meter.

All mechanical water meters are sensitive to spinning.

2.6.11 Network pressure

It is well known that pipe carrying water under high pressure has a greater probability to leak than a pipe under low pressure. The magnitude of a flowrate of a leaking pipe is dependent on

the static pressure in that pipe. Therefore distribution systems with different network pressures will exhibit different on-site leakage characteristics on consumer properties, which in turn affect the consumer consumption patterns.

The network pressure also affects the maximum flowrate a consumer can experience when opening their tap at full bore. Therefore the maximum flowrate a consumer can use for consumption is limited to the network pressure.

2.6.12 Environment

Environmental factors such as high temperatures and exposure to sunlight may deform or weaken plastic components of the meter and freezing temperatures may increase the operating pressures inside the meter (Arregui et al., 2006 a).

2.7 Estimating consumer meter error

2.7.1 Introduction

The objective of testing is to quantify the level of consumer meter under-registration in a supply area. The two parameters of interest are the error curve of the water meter and the consumption pattern of the consumer. Once these parameters are known the level of meter under-registration can be calculated.

The common method of determining the level of meter under-registration is to physically test the meter either in the field or in a laboratory and then determine the customer's consumption flowrate profile. There have been a number of different methods used for testing meter error and flowrate profiles due to either local conditions or financial reasons.

Industrial, Commercial and Institutional (ICI) consumers have a heterogeneous water demand and therefore each customer stand needs to be tested individually, whereas for residential consumers at the local level the water demand pattern is more homogenous and depending on the population size, representative samples can be used (Arregui et al., 2006 a). The testing methodology of ICI consumers is the same as that for residential consumers except that they need to be tested individually.

There have been alternative testing methodologies presented in the literature other than the traditional testing of meter error curves in the field or laboratory and logging consumption profiles:

- A zone water balance can be performed to measure meter under-registration (Fantozzi et al., 2008; Rizzo et al., 2007). This is done by removing or quantifying all real losses, on-site leakages and other apparent loss components. For example, real losses can be removed physically or the Minimum Night Flow (subtracting on-site leakage and night consumption) at the zone inflow meter can be measured (Rizzo et al., 2007). This method is more accurate using Automatic Meter Reading (AMR) technology, to reduce the time delay between measuring the zone inflow meter and consumer meters.
- A new meter can be installed in series with the old meter for a sample of customers and the difference registered volume of the new meter and old meter can be calculated (Arregui et al., 2006 b).
- Billing records can be analyzed, whereby the consumption records of old meters that have been replaced can be compared with the newer meters to obtain the level of meter under-registration for the old meter (Arregui et al., 2006 b). The comparison period should cover a period of a year so that seasonal changes and changes in water demand patterns can be taken into account.

The following will discuss the issues and literature related to estimating meter accuracy curves, customer consumption patterns and the weighted meter error.

2.7.2 Meter error curves

The accuracy of a water meter is dependent on the flowrate passing it (Arregui et al., 2006 b). Therefore, to obtain this curve the meter needs to be tested for error at a number of selected flowrates to draw the error curve.

To reduce variability in meter error test results, the population of meters are stratified according to characteristics that affect metering performance into homogenous groups (Arregui et al., 2006 a).

Arregui et al. (2007) states that there are a number of variables that may affect the accuracy of a meter related to the meter characteristics and the consumer characteristics, which in turn

will determine the makeup of the homogenous groups. These meter characteristics include the technology, model, brand, age etc. The consumer characteristics include water consumption patterns, water quality, number of pipe repairs in the network, weather conditions etc. To achieve the most accurate tests results all these variables would need to be considered. However, the numbers of meters that need to be removed from the field become too large and costly. A trade-off between the level of accuracy desired and the number of variables considered needs to be done to achieve the most optimal set of data. Therefore, only those variables that are considered to have the most influence on the metrological performance of the meter should be considered.

The following meter characteristics that affect meter performance have been used to some extent to separate meters into homogenous groups in various case studies. In Switzerland Guibentif et al. (2007) categorized meters by age, annual volumes, diameters, manufacturers and type of customer amongst others, in Italy Fantozzi (2009) removed meters from four water utilities and divided meters according to brand, mark, age, consumption and water quality, in Spain Arregui et al. (2007) tested meters of different models and ages and in Uganda Mutikanga et al. (2010) categorized meters according to age groups only, as only positive displacement meters were tested.

After the meters have been ordered into homogeneous groups and samples have been selected from the field using a random sampling technique, the meters need to be tested to construct the meter accuracy curve for each meter. To construct the meter accuracy curve, the meter needs to be tested at a number of flowrates. Obviously the more flowrates the meter is tested at, the more accurate the constructed curve would be to the actual accuracy curve of the meter. However, the more flowrates the meters are tested at, the more time consuming and costly the test. Arregui et al (2006 a) argues that the AWWA method of measuring the accuracy at slow, medium and high flowrates is not accurate enough for the purpose of testing for meter under-registration.

Arregui et al (2006 a) recommends that the meters starting flowrate should be found and the meter be tested at the minimum flowrate, another flowrate between the minimum and transitional values, the transitional flowrate and the overload flowrate. In Italy, Fantozzi et al. (2009) used a similar method of that described by Arregui et al. (2006 a). The meters were tested at q_p , $0.3*q_p$, q_{trans} , q_{min} and the starting flowrate q_{start} . Mutikanga et al. (2010) also

agree that the standard ISO 4064 three flowrates (q_{\min} , q_t and q_s) are inadequate to obtain a defined meter error curve. They performed their tests at 11 different flowrates that as closely as possible resemble the customer consumption profiles.

Water meters can be tested in the laboratory or in the field to estimate its error curve. In the laboratory or in the field, meters are tested by comparing the actual volume of water passing the meter and the registered volume at a specific selected flowrate. The flowrate used for testing is usually measured by a calibrated master meter. The tests vary in how the actual volume of water passing the meter is measured. In the laboratory, the actual volume can be determined by using a calibrated master meter, calibrated volumetric tank or a calibrated weighing scale (Arregui et al., 2006 b). In the field, the actual volume and test flowrate is usually measured by a calibrated master meter. Ross-Jordan (2006) suggests that the actual volume and flowrate can be measured by filling a 25 litre bucket and using a stopwatch. The method presented by Ross-Jordan (2006) is not very accurate, but is useful if the previous more accurate methods are not possible.

Many different methods have been used to draw the meter error curve. Measuring meter error is subjective and depends on the level of accuracy in data required and budget.

2.7.3 Consumption patterns

The consumer's consumption pattern influences the ability of the water meter to accurately measure the volume of water passing through it. The consumption pattern of the consumer can be determined by either using standard consumption profiles from literature or from tests carried out in the field (Fantozzi, 2009; Arregui et al., 2006 a).

It must be noted that using standard consumption profiles from literature is subject to error, and should only be used as a reference when no better information is available (Arregui et al., 2006 a). It is advised by Arregui et al. (2006 a) to rather measure the consumption profiles of consumers in the field. It is also stated by Arregui et al. (2006 a) that the local consumer characteristics need to be defined and not blindly use the stratification defined in literature. Characteristics such as monthly volume of consumers can be used to stratify households (Arregui et al., 2006 a).

When measuring the consumption patterns of domestic consumers, the following needs to be done (Arregui et al., 2006 a).

- The population of consumer's needs to be stratified according to variables that have the most influence on the measuring error of the meter. Specifically, variables that affect consumption at low and high flows need to be identified. Households must be selected randomly and depending on the homogeneity of the samples, a sample size of say 50 for each category is usually sufficient to achieve results within a reasonable uncertainty.
- The correct instrumentation needs to be used. Calibrated water meters need to be installed with sufficient accuracy to measure low flows such as leakages. The calibrated meter also needs to have a pulse emitter with a minimum resolution of 0.1 l/pulse. Data loggers with sufficient memory capacity are required. Data loggers are devices which are capable of recording and storing information obtained from the meter regarding the consumer's consumption flowrates during the day.
- It is recommended that the minimum time period that flow consumption needs to be recorded, is one week, to pick up the full range of the consumption flowrates used.

In the Ugandan case study, Mutikanga et al. (2010) logged the consumption flowrates of 90 consumers in Kampala City. A similar methodology was used as that described by Arregui et al. (2006 a). Class D positive displacement meters with sufficient sensitivity to detect low flows were used, the meters were equipped with pulse emitters (0.1 l/ pulse) and data loggers were used to record the consumption flowrates for a week.

There is uncertainty associated to the estimation of the consumption patterns which are caused by different factors like (Arregui et al., 2007):

- Erroneous stratification of the population. The objective of stratifying consumers is to create homogenous groups which have similar consumption characteristics to decrease variability in results. However, if users are stratified improperly a heterogeneous group can be created where consumers have different consumption characteristics, and a large variability in results can be expected.
- Incorrect selection of the sample. In some cases, the sample selected for a defined stratum can be incorrect. This could be due to an improperly updated commercial

database where user characteristics are inaccurate or the consumer itself could have changed its consumption characteristics without notifying the utility.

- Variability in the water consumption. Water consumption with regard to quantity and flowrate intensity change not only throughout the day, but also throughout the week and seasons. Therefore, when measuring the water consumption pattern, at least a week or two of data logging needs to be performed to minimize uncertainty.
- Distortions caused by the measuring and data logging equipment. When analyzing data stored from a data logger, the consumption pattern stored in the data logger is not 100 % representative of the actual consumption pattern. This is due to the non-linear error curve of the calibrated meter and due to the data processing of the data logger. The resolution of the pulse emitter also has bearing on the uncertainty of the data obtained.

2.7.4 Average Weighted Error

The average weighted error is the percentage of water that is not registered by the consumer meter. The average weighted error of a water meter in operation is affected by two parameters: the error curve of the meter and the consumption pattern of the consumer. The calculation of the average weighted error is performed by multiplying the percentage error of the meter and the percentage of consumption at each defined flow interval, then adding all the percentage errors of each flow interval. Table 2.8 is a sample calculation of the average weighted error (Arregui et al., 2006 a).

Table 2.8: Calculation of average weighted meter error for a meter (Arregui et al., 2006 a)

Flowrates (l/h)	Consumption Profile (%)	Meter error (%)	Registered Volume (%)
0-12	4.7	-100	0.00
12-22	2.3	-100	0.00
22-24	0.5	-68	0.16
24-36	1.9	-52	0.91
36-72	4.3	-11	3.83
72-180	8.5	0	8.50
180-1500	75.7	-0.8	75.09
1500-3000	1.9	-0.8	1.88
> 3000	0.2	-0.8	0.2
Total registered volume (%)			90.6
Weighted meter error (%)			-9.4

2.8 On-site leakage

On-site leakages are defined as the leakage occurring on the downstream of the consumer meter. The flowrate and occurrence of on-site leakages are a function of the condition of the consumers plumbing system and the network pressure. These leakages can occur from pipes, plumbing fittings, toilets, geysers, taps and other household appliances.

On-site leakages constitute both an apparent loss and demand management problem. However, high flowrate leakages with respect to the meter accuracy curve do not represent a problem in terms of apparent losses i.e. the meter measures most of the leakage in its higher accuracy range. It is the low flowrate leakages that represent a problem for apparent losses, as most of the flow is not registered by the meter.

The importance of understanding the situation and reducing on-site losses has resulted in a number of studies being performed. In Johannesburg, a study was done to investigate the level of on-site leakage on residential properties, which is relatively unknown in South Africa (Lugoma et al., 2012). On-site leakages were measured by manually reading the consumer meter when there was no consumption during the day time at 5 min intervals. To ensure that there was no consumption during the manual reading process, the consumer was notified about a week before the visit and if home asked to stop all consumption. A second visit was made to verify the leakage. It was found that 67 % of 128 households had on-site leaks with an average leakage rate of 16.5 l/ property/ h. The study was unable to point out what the causes of the existing on-site leakage were.

In Johandeo located in Sebokeng (southern Gauteng- Emfuleni Local Municipality), during a community awareness intervention programme, 80 % of 2 100 households were found to have on-site leakages during household visits which involved inspection of internal plumbing fixtures (Wegelin et al., 2009 b).

It was found in the '*Water Leak Repair Program in Poor Areas in the City of Cape Town*' that 62 % of 8 000 properties had leaks by inspecting internal plumbing fixtures and fixing them, with 77 % of these leaks from toilet cisterns (Frame et al., 2009). The project reduced monthly household consumption from 19 to 11.5kl.

In Australia, a pilot study was performed in a selected District Metered Area (DMA) in Queensland to measure household leakages in residential properties using Automatic Meter Reading (AMR) technology (Britton et al., 2011). Using the AMR drive-by technology, 2 % of 2 359 households were identified to have leaks. Several leaks were identified in these households of which 46 % of the total leaks was due to leaking toilets. Dual flush toilets with a cistern size of 9/4.5 litres were found to have leakage flowrates of between 13.33 to 34.56 litres per hour. Single toilets with a cistern size of 11-15 litres were found to have leakage flowrates of between 12.2 to 38.89 litres per hour. Britton et al. (2011) discovered that the cause of the majority of leaking toilets were as a result of the failure of the 'top valve' in the cylindrical control unit inside the cistern. Leaks from pipes and taps were the other main leak types after the toilet.

Finally, in the Drakenstein Municipality as part of their leak repair programme, repaired the leaks of over 1 413 households in the Saron area (Drakensberg Municipality, 2009). It was found that 83.4 % of the properties had on-site leakages, with 30.9 % of properties having cistern leaks and 64.2 % having leaks on their pipes.

2.9 Unmeasured Flow Reducer

ARI Flow Control Accessories, which is a company based in Israel, has developed a device called the Unmeasured Flow Reducer (UFR) to reduce apparent losses due to meter under-registration. The UFR is a flowrate control device that prevents low flowrates from passing through the meter. It is technically a differential non-return valve, which requires a certain pressure difference across the device to allow water to flow through it (Yaniv, 2009). On a property with no on-site leakage, when there is no consumption the UFR is closed and there is no flow through the meter. As the consumer starts consuming water, the UFR remains closed until the pressure difference reaches 0.4 bar, which opens the UFR and a batch flowrate is sent through the meter at a flowrate which the meter can measure accurately. Once the UFR is open, only a 0.1 bar pressure difference is required to keep it open. In the case of an on-site leakage or consumption at a low flowrate, after the batch flowrate has been released by the UFR, the pressure equalises and the UFR closes again and the process is repeated. Figure 2.9 illustrates this graphically.

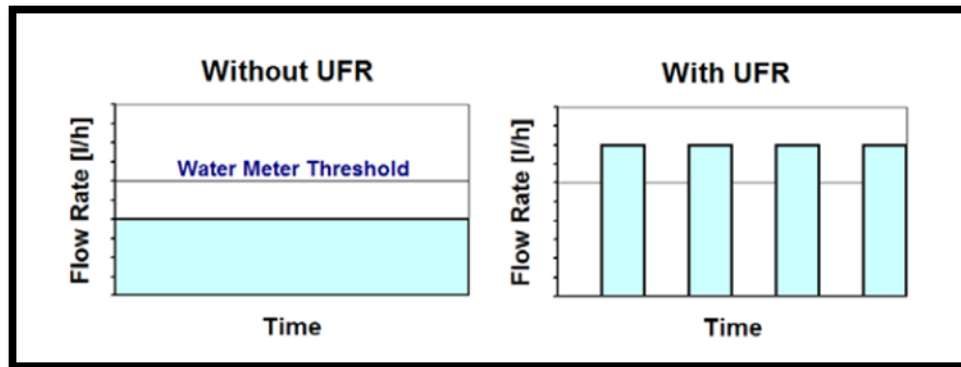


Figure 2.9: Comparison of flowrate curves for a meter with and without a UFR installed (Yaniv, 2009)

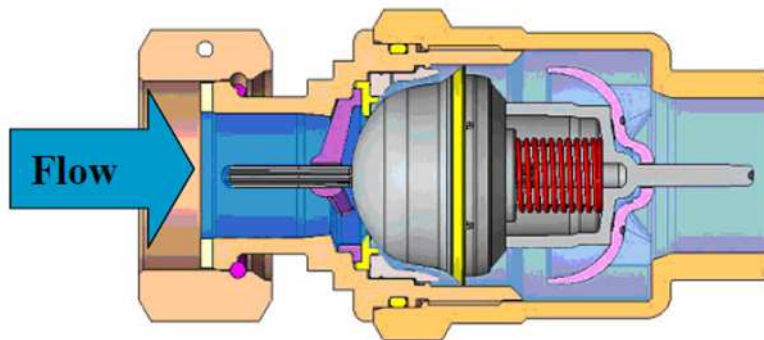


Figure 2.10: Illustration of the UFRs internal components when it is closed (Yaniv, 2009)

The following studies described are mostly from conference papers and not peer-reviewed journals and the degree of involvement of the supplier in these studies are not clear.

A number of studies have been performed to determine the effectiveness of the UFR (Figure 2.10) in reducing meter under-registration internationally and one being done in South Africa

Recently, in 2007, UFRs were tested in the Mangaung Local Municipality on 50 households in Batho near the Bloemfontein CBD (Webster, 2011). The tests were carried out by installing UFRs on each of the properties and reading the registered volume on the meter for six minutes between the middle of the interval of two batches when there is no consumption by the owner. The recorded consumption is then converted to an hourly flowrate, which

represents the flowrate of the on-site leakage. It was found that the UFRs were allowing the meter to register an additional 70 litres/ day per meter.

In Udine, Italy, a sample of 33 meters from the Acegas APS utility was removed from the field to be tested in the Maddalena Meter testing laboratory, with and without a UFR (Fantozzi, 2009). The meters were 20 mm Class C turbine meters with ages ranging from 1 to 7 years. It was found that meters with the UFR installed registered 94 %, 31.8 % and 14.4 % more water passing the meter at below the starting flowrate, at the starting flowrate and at the minimum flowrate respectively.

Another study was performed in Italy in Palermo City to determine the effectiveness of UFR's three different ways (Fantozzi et al., 2011). The first method was to compare the registration of meters with and without a UFR on two households which have a storage tank installed. The UFR reduced the meter error from -45 % to -7 % for the one household and -12 % to -1 % for the other. The first method indicated that there is an improvement in the meters accuracy and motivated the second method. The second method involved testing the UFRs in the laboratory using typical consumption patterns (Figure 2.11) measured in the area and comparing meters removed from the field (with and without the UFR installed) on the test bench.

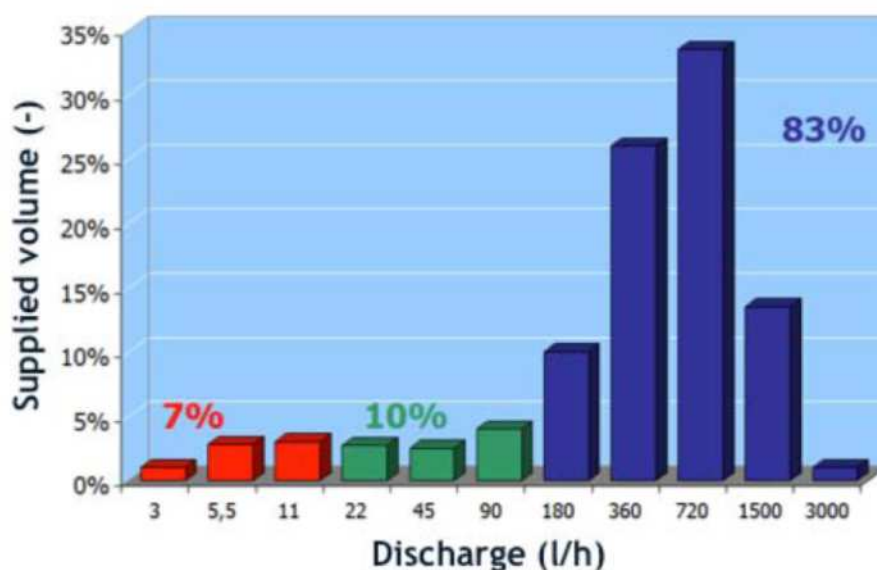


Figure 2.11: Water consumption pattern used for laboratory testing of meters with and without a UFR installed (Fantozzi et al., 2011)

Table 2.10 illustrates the results obtained from the laboratory testing, which shows clear improvement in the meters accuracy to measure consumption.

Table 2.10: Results of meter testing in the laboratory in Italy (Fantozzi et al., 2011)

Meter age* (years)	No. of meters tested	Average starting flowrate (l/h)	Error without UFR (%)	Error with UFR (%)
0-5	22	5.69	-2.60	-0.38
5-10	24	6.69	-5.80	-0.78
10-15	26	12.31	-9.30	-1.37
15-20	24	11.48	-7.90	-1.24
20-25	22	16.43	-11.30	-4.87
25-30	18	9.92	-6.80	-1.49
30-35	16	16.48	-11.80	-5.10
35-40	14	18.74	-13.20	-7.27
40-45	10	33.40	-16.80	-11.52

* Meters younger than 10 years are Class B and the rest are Class C

The third method was a zonal water balance of a Small District Metered Area (SDMA) and the accuracy of the meters without a UFR and with a UFR installed was compared. The SDMA consisted of 52 consumers having 33 Class C meters less than 11 years old, 17 Class B meters and 2 Class A meters which are older than 11 years. All the meters are of the turbine type and most of the consumers have storage tanks on their properties. The meter under-registration was 28.06 % and 18.91 % without and with the UFR installed respectively.

In Cyprus, a similar zonal water balance was performed on a hydraulically encapsulated zone of 69 consumers (Charalambous et al., 2007). All the consumers have a storage tank installed with a positive displacement meter to measure consumption. A total of 43 and 26 of the meters are Class D and Class C respectively. With a total 26, 7, 16, and 20 were 1-3, 4-7, 8-11 and greater than 11 years old respectively. A meter under-registration of 6.79 % and 2.12 % without and with the UFR respectively were estimated. Additionally, the study concluded that UFR's do not induce pressure surges into a distribution network, by measuring the pressures at an appropriate fire hydrant location before and after the UFRs were installed.

In Malta, a zonal water balance was performed on a small hydraulically encapsulated zone with an average meter age of 5 years old (Rizzo et al., 2007). The zone had 26 consumers with Class D positive displacement meters with a 1 m³/h permanent flowrate (Yaniv, 2009). The UFR's were installed with a bypass valve so that the meters registration could be

compared for a total of three tests with and without the UFR. A decrease of 5.5 % to 6 % of meter under-registration was estimated.

In two separate District Metered Areas (DMAs) in Jerusalem, Israel, the meter under-registrations were estimated using a zonal water balance before and after UFR's were installed (Davidesko, 2007). The DMAs all have Class B multi-jet meters with a permanent flowrate of $2.5 \text{ m}^3/\text{h}$. It was estimated that the DMA with 120 consumers had an under-registration of 16 % and 6.1 % without and with a UFR installed respectively. The other DMA with 360 consumers had an under-registration of 26 % and 18.8 % without and with a UFR installed respectively.

It is clear from the number of studies done both in South Africa and internationally that UFRs are very effective in reducing apparent losses substantially.

University of Cape Town

3 On-site leakage field study of domestic consumers

3.1 Introduction

On-site leakages are defined as leakages that occur on the downstream side of the consumer's water meter. Therefore these leakages are not real losses, but billable consumption from the consumer. On-site leakages therefore contribute to additional consumer water demand and can contribute to apparent losses. It is important to quantify the level of on-site leakages in terms of both occurrence and flowrate, to identify the extent of the problem and if it is economical to put measures in place to reduce it or try to measure them better through improved metering.

It is mainly the low flowrate leakages that present an apparent loss problem, as they occur below the transitional flowrate of the meter. It is a legal requirement stipulated in the *SANS1529-1: Water Meters for Cold Potable Water* standard that meters taken out of the field and tested in a laboratory must have a relative error of less than 8 % on the lower accuracy band of the meter error curve, therefore meters in the field can be expected to have at most that amount of relative error in legal terms. However, consumer meters in South Africa are usually left in the field well past their design lives and can be exposed to poor field conditions, therefore even greater relative errors can be expected. As a meter ages and is exposed to poor field conditions, so does its accuracy decrease, particularly below the transitional flowrate (Davis, 2005).

In the Johannesburg area, a study was performed to investigate the level of on-site leakage on domestic and non-domestic consumer properties, which is relatively unknown in South Africa (Lugoma et al., 2012). It was found that 67 % of the 128 households investigated had on-site leaks with a mean indicated leakage flowrate of 16.5 l/ h and a median of 5.7 l/ h. The study was unable to point out what the causes of the existing on-site leakage were. It was this study that motivated the need to investigate on-site leakages on domestic residential properties in the City of Cape Town and Bloemfontein municipal supply areas.

This study is an extension of the work performed in the Johannesburg study and uses a similar methodology. Only consumer meters less than 3 years old are considered in this

study, as these meters are most likely to still have a good accuracy at the lower flowrates to be able to register on-site leakage.

The objective of this study, like in the Johannesburg study, is to interrogate meters of new domestic consumers (< 3 years old) which still have good accuracy by:

- Collecting meter information in the field such as the meter types, classes, sizes and the condition of the meter installation.
- Reading water meters manually over defined time intervals during periods of no consumption by the user to measure on-site leakage.

The occurrence of on-site leakages, their corresponding flowrates and an accuracy assessment of the new meters in the City of Cape Town and Bloemfontein municipal supply area will be reported on.

3.2 Meter database

The consumer meter database for the City of Cape Town was collected from GLS Consulting Engineers from the Swift archive at their offices and the meter database for Bloemfontein was collected from JOAT consulting and sales at their offices.

The meter databases had no meter information category to identify the type, size, class and manufacturer of the meters in the field. This made it important that this information was collected from the field to assess the accuracy of the meter models found.

The databases only had meters of younger than 10 years old with the following information given as shown and described in Table 3.1.

Table 3.1: Data fields found in database, with definitions extracted from (van Zyl & Geusteyn, 2006)

Field name	Description
Serial_No	Meter serial number
Stand_ID	Stand's ID consisting of Town, Suburb, Stand, Portion and Sub portion. The format is defined according to the treasury system
Unit_No	Additional Stand ID number to make record unique
GIS_Code	GIS Code (as supplied by the treasury)
Town	Town
Suburb	Suburb
Suburb_Category	The user specified suburb category to which the suburb code is mapped
Stand_No	Stand number
Address	Address
Stand_Owner	Stand owner
Consumer	Consumer
Water_Tariff	Water consumption tariff code
Land_Category	The land use category determined from the land use, water tariff, availability code and tax tariff code
Zone_Category	The zoning category determined from the zoning code and the land use category
Stand_Area	Area of the stand
Measurement_Unit	Water meter measurement unit
Meter_Installation	Date when meter was installed
Units	Calculated Number of living units on the stand
Adjust	Adjustment code indicating anomalies in the readings

3.3 Methodology

3.3.1 Introduction

An identical procedure was followed as in Lugoma et al. (2012) study in determining on-site leakages by inspecting new water meters in the Johannesburg area.

A team of three final year undergraduate thesis students were used in this study to interrogate new water meters in the City of Cape Town and another for Bloemfontein.

3.3.2 Selection of study area

The City of Cape Town and Bloemfontein were the municipalities under investigation and a total of 15 and 6 suburbs respectively were selected.

A total of 405 new meters in the City of Cape Town (Table 3.2) and 166 new meters in Bloemfontein (Table 3.3) were investigated from the 01 July to the 22 October 2011 and 13 December 2011 to 11 January 2012 respectively.

Table 3.2: List of suburbs investigated in Cape Town

No.	Suburb	Number of samples	Period of investigation
1	Camps Bay	27	27/09/11 – 29/09/11
2	Claremont	29	16/07/11 – 31/09/11
3	Green Point	22	27/09/11 – 29/09/11
4	Lakeside	27	20/09/11 – 21/09/11
5	Langa	27	08/09/11 – 26/09/11
6	Mandela Park	29	13/09/11 – 27/09/11
7	Mowbray	26	01/07/11 – 14/10/11
8	Newlands	29	22/09/11 – 22/10/11
9	Observatory	27	13/07/11 – 20/09/11
10	Pinelands	29	14/09/11 – 16/09/11
11	Rosebank	17	04/07/11 – 15/09/11
12	Salt River	30	11/07/11 – 30/09/11
13	Thornton	30	21/09/11 – 22/09/11
14	Tokai	30	14/09/11 – 19/09/11
15	Woodstock	26	07/07/11 – 16/09/11
Sum		405	01/07/11 – 22/10/11

Table 3.3: List of suburbs investigated in Bloemfontein

No.	Suburb	Number of samples	Period of investigation
1	Botshabelo G	30	13/12/11-14/12/11
2	Mandela View	25	16/12/11-17/12/11
3	Vista Park	30	20/12/11-21/12/11
4	Brandwag	25	28/12/11-29/12/11
5	Freedom Square	26	03/01/12-05/01/12
6	Motlatla	30	10/01/12-11/01/12
Sum		166	13/12/11-11/01/12

3.3.3 Procedure for inspecting consumer meter

The following describes the procedure used in interrogating the new meters selected from the database:

1. Select properties
 - a. Only new domestic residential consumer's that are younger than three years old were selected from the database and listed.

- b. From the list of properties, the consumers were selected based on two factors. The first factor required that the properties to be selected were of reasonable walking distance from each other, but not all in the same street. The second factor required that the meter on the consumer's property can be found and is accessible.
 - c. Each property selected in the study was given a Reference ID to remove confidential data of the consumer in the analysis part of the study.
2. Notify the consumer
 - a. The consumer is made aware of the study by placing a letter in their mailbox about a week before the scheduled visit.
 - b. On the day of the visit, the consumer's door bell is rung, and if home, is requested to stop all water consumption.
 3. Collect field meter information
 - a. The meter is located and identifiable meter information is recorded. This meter information includes the manufacturer's name, the meter's permanent flowrate and the accuracy class of the meter, which are recorded on a field sheet (Appendix B). Additionally a photo of the meter is taken to help identify the meter.
 - b. The condition of the meter installation is also recorded and any other useful information found on the consumer's property.
 4. Read the meter's dial
 - a. The initial reading of the meter is recorded on the field sheet to the lowest fraction of a cubic metre and the stop watch is started simultaneously.
 - b. After each five minute interval, the reading on the meter dial is recorded in the field sheet for a total of three intervals.
 - c. If after ten minutes, there is no registered consumption on the meter's dial, it is assumed that there is no measurable on-site leakage on that property and further readings are discontinued.
 5. Confirm if there is an on-site leakage from the first visit.
 - a. If there was a registered volume found on the first visit, a second visit at a different time was made to confirm the presence of a probable on-site leakage.
 - b. The same meter reading procedure used in the first visit is repeated.

3.3.4 Water meter manufacturer catalogues

With the aid of the pictures of the meters taken and identifiable meter information in the field, the meters could be identified within the relevant manufacturer catalogues (Table 3.4). These catalogues contain additional information about the meters starting, minimum and transitional flowrates which are important to describe the accuracy of the meters in the field. All the meters in Table 3.4 have a lowest indicated volume of 0.1 litres.

Table 3.4: Meter information obtained from manufacturer catalogues

Manufacturer	Type	Size (mm)	Class	Q_p (m ³ /h)	Q_{trans} (l/h)	Q_{min} (l/h)	Q_{start} (l/h)
1	Positive displacement	15	C	1.5	22.5	15	5.7
1	Positive displacement	20	C	2.5	37.5	25	9.5
1	Positive displacement	25	C	3.5	52.5	35	13.2
1	Multi-jet	15	C	1.5	22.5	15	6
1	Multi-jet	20	C	2.5	37.5	25	6
1	Multi-jet	25	C	3.5	52.5	35	10
2	Multi-jet	15	B	1.5	120	30	12*
2	Multi-jet	20	C	2.5	37.5	25	10*
3	Multi-jet	15	B	1.5	120	30	10
3	Multi-jet	15	C	1.5	22.5	15	7
3	Multi-jet	20	B	2.5	200	50	18
3	Multi-jet	20	C	2.5	37.5	25	12
4	Multi-jet	15	B	1.5	120	30	12*
4	Multi-jet	20	B	2.5	200	50	20*

* There was no Q_{start} available in the manufacturer's catalogue, therefore a Q_{start} of 40% of the Q_{min} was assumed.

3.3.5 Calculating and verifying on-site leakages and their flowrates

The flowrate of the leakage found on a consumer's property were calculated by:

- Subtracting the final registered volume reading from the initial registered volume reading for each five minute interval.
- The leakage volume of each interval is then converted to an hourly flowrate in litres.
- The flowrate of the leakage is then taken as the mean of the six intervals.

Water meter samples that had no measureable on-site leakage after the second visit were deemed not to have any measurable on-site leakage, despite the first visits results.

Where the data indicated consumption occurred during the meter reading process in the field, it was purged from the data set. Table 3.5 lists these data.

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Table 3.5: Data purged from investigation

Ref. ID	Q ₁ (l/h)	Q ₂ (l/h)	Q ₃ (l/h)	Q ₄ (l/h)	Q ₅ (l/h)	Q ₆ (l/h)	Reason
To4	0.7	0.8	0.7	0	0.4	0	Owner consumed water despite being asked kindly no to during the visit. Based on team members observation.
Wo27	68.4	117.6	116.4	30	34.8	33.6	Owner consumed water despite being asked kindly not to, during the visit. Based on team members observation.
Lg33	33.6	9.6	9.6	33.6	34.8	33.6	Owner consumed water despite being asked kindly no to during the visit. Based on team members observation
CI2	2.4	6	2.4	2.4	2.4	2.4	Only Q ₂ is purged. Very likely consumption based on the flowrates read on other data points.
Gp1	1330.3	0.4	0.2	0.4	0.2	0.4	Only Q ₁ is purged. Concern of washing machine being on at the start of meter reading process and validated by comparing Q ₁ to the other flowrates read.
FS26	33.6	8.4	8.4	9.6	9.6	9.6	Only Q ₁ is purged. Very likely consumption based on the flowrates read on other data points.
BG10	80.4	97.2	75.6	55.2	56.4	57.6	The first three data points are purged. Very likely consumption based on the flowrates read on second visit.
BW23	26.4	105.6	26.4	26.4	26.4	25.2	Only Q ₂ is purged. Very likely consumption based on the flowrates read on other data points.
BG29	72.0	25.2	22.8	15.6	16.8	16.8	Only Q ₁ is purged. Very likely consumption based on the flowrates read on other data points.
BW19	68.4	69.6	69.6	70.8	69.6	129.6	It was found that a water feature was running consistently throughout the reading process. Therefore all the data on this property was purged.

3.3.6 Correcting for meter error

The volume of water registered on a meter’s dial is not the actual volume of water passing through the meter. Due to the error curve of the meter, the meter can under-register or over-register consumption, depending on the flowrate of water passing through the meter. The registered consumption visible on the meter’s dial is defined as the indicated volume (Q_i). The aim here is to correct for the meters error by drawing the meter’s error curve and adjusting the indicated flowrates measured in the field to obtain the actual flowrate (Q_a) passing the meter.

The actual error curves of the meters investigated in the field are unknown and therefore a conservative guess is required. The permanent, transitional, minimum and starting flowrates of the different meter models were found in manufacturer catalogues and their corresponding relative errors were conservatively guessed. The transitional flowrate was assumed to be +2% and the minimum flowrate to be 0 %. A 2nd order polynomial was drawn through the transitional and minimum flowrate, such that it never exceeds +2%, to find the relative error at the starting flowrate and draw the error curve. Equation 3.1 describes the 2nd order polynomial:

$$Relative\ error\ (\%) = \frac{Q_i - Q_a}{Q_a} = a(\ln Q_a)^2 + b(\ln Q_a) + c \dots\dots\dots (3.1)$$

Figure 3.1 is an example of typical error curves drawn using the above methodology.

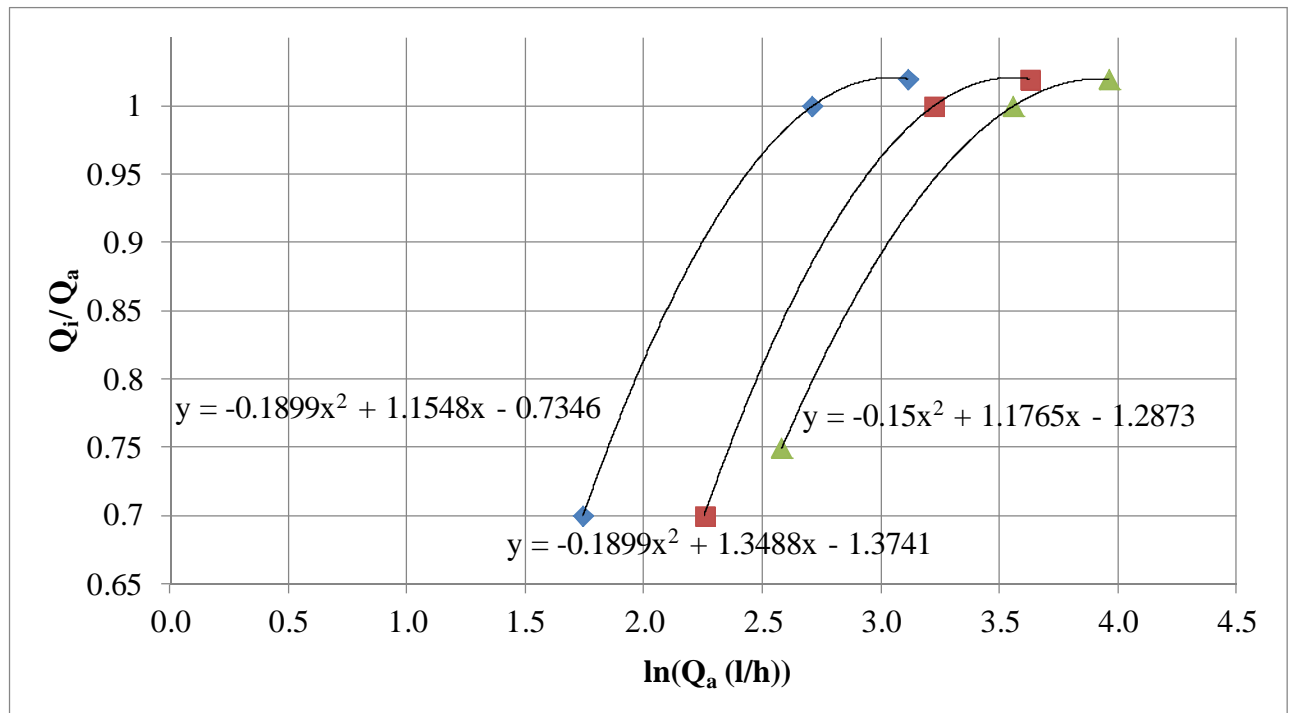


Figure 3.1: Meter error curves of class C positive displacement meters of 15, 20, 25mm sizes from left to right. These meters are from Manufacturer 1.

The next step is to develop an expression that can convert the indicated flowrate on the meter dial to an actual flowrate passing through the meter by using the conservatively guessed meter error curve. A 3rd order polynomial was used to do this:

$$Q_a = aQ_i^3 + bQ_i^2 + cQ_i + d, \quad (Q_{start} \leq Q_i \leq Q_t) \dots\dots\dots (3.2)$$

Equation 3.2 is only valid between the starting and transitional indicated flowrates read on the meter dial. Therefore it has the following boundary conditions:

- Measured flowrates less than the Indicated Q_{start} are equal to the Actual Q_{start} .
- Measured flowrates greater than the Actual Q_t have zero relative error.

Figure 3.2 is an example of typical indicated flowrate conversion curve for a meter.

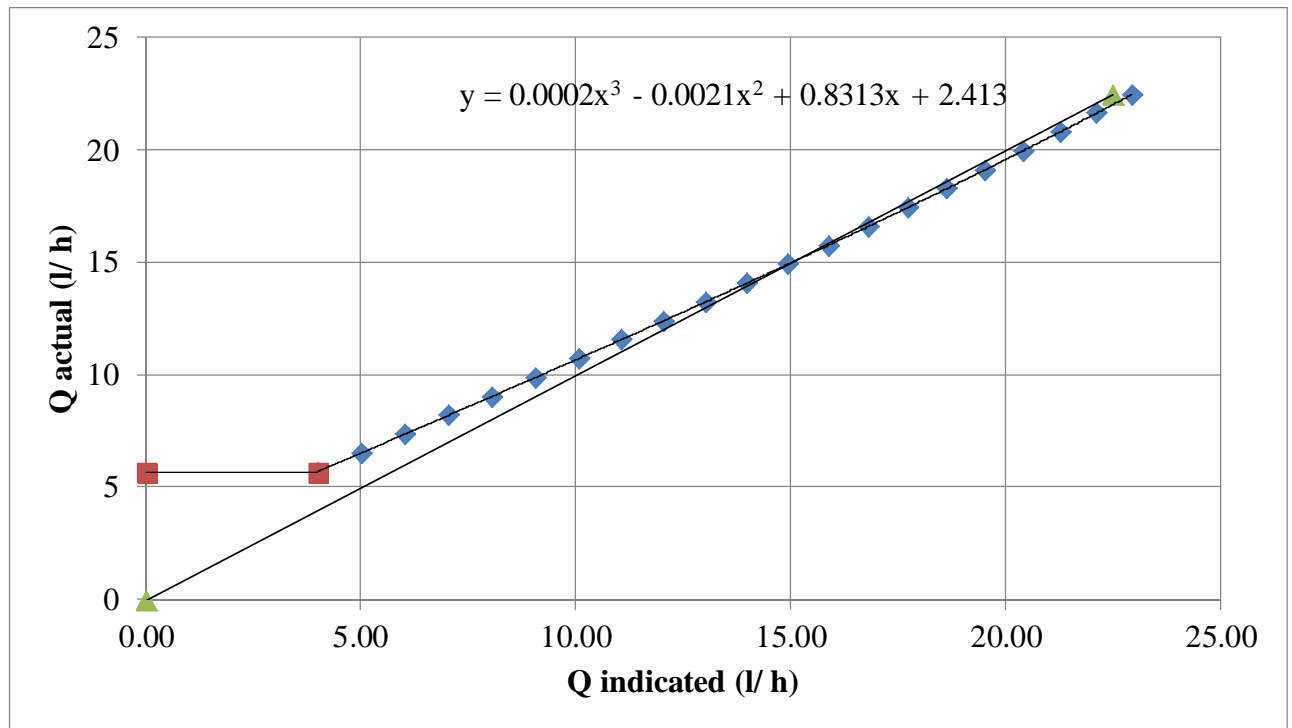


Figure 3.2: Indicated flowrate conversion curve, for a 15mm Class C positive displacement meter

Table 3.6 describes the coefficients calculated using the above methodology to convert indicated flowrates to actual flowrates.

Table 3.6: Coefficients a, b, c and d estimated for Equation 3.2

Meter information					Coefficient			
Manufacturer	Type	Size (mm)	Class	Q _p (m ³ /h)	a	b	c	d
1	Positive displacement	15	C	1.5	2.00E-04	-0.0021	0.8313	2.413
1	Positive displacement	20	C	2.5	6.00E-05	-0.0013	0.8314	4.0219
1	Positive displacement	25	C	3.5	3.00E-05	-0.0008	0.8614	4.7482
1	Multi-jet	15	C	1.5	2.00E-04	-0.0017	0.8429	2.2345
1	Multi-jet	20	C	2.5	8.00E-05	-0.0026	0.8665	3.7278
1	Multi-jet	25	C	3.5	3.00E-05	-0.0014	0.869	4.872
2	Multi-jet	15	B	1.5	9.00E-07	-1.00E-04	0.9751	0.8156
2	Multi-jet	20	C	2.5	5.00E-05	-1.00E-03	0.8431	3.7243
3	Multi-jet	15	B	1.5	1.00E-06	-2.00E-04	0.9771	0.7724
3	Multi-jet	15	C	1.5	2.00E-04	-0.0013	0.8251	2.3956
3	Multi-jet	20	B	2.5	3.00E-07	-9.00E-05	0.9811	1.136
3	Multi-jet	20	C	2.5	4.00E-05	-5.00E-04	0.8587	3.262
4	Multi-jet	15	B	1.5	9.00E-07	-1.00E-04	0.9751	0.8156
4	Multi-jet	20	B	2.5	3.00E-07	-7.00E-05	0.9753	1.3579

3.4 Results and discussion

3.4.1 Introduction

This section discusses the results and analysis by:

- Assessing the accuracy of the meters investigated in the study with regard to information collected from the field. This information includes factors that affect the accuracy of a meter which could impact the results regarding to the number of leaks being picked up by the meters investigated.
- Reporting on the occurrence of leakages for the whole population and comparing separate suburbs.
- Reporting on the measured leakage flowrates found on properties and comparing between suburbs.
- Reporting on the actual leakage flowrates from correcting the measured leakage flowrates. The results of this study from Cape Town and Bloemfontein are compared with the City of Johannesburg.

3.4.2 Assessment of meters investigated in Cape Town

Although the meters investigated are younger than 3 years old and should still have good accuracy, it is also important to assess the registered volumes and meter models encountered in the investigation which also have an impact on meter accuracy.

3.4.2.1 Age-Volume analysis of meter samples

Figures 3.3 and 3.4 graphically describe the proportion of meter ages and registered volumes respectively of the meters encountered in the investigation.

Figure 3.3 illustrates that a total of 90 % of the meters were less than 2 years old.

In Figure 3.4, it was found that 79 % of the meters had a registered volume of less than 1000 kL, which indicates that a significant portion of the new meters still have a very good accuracy.

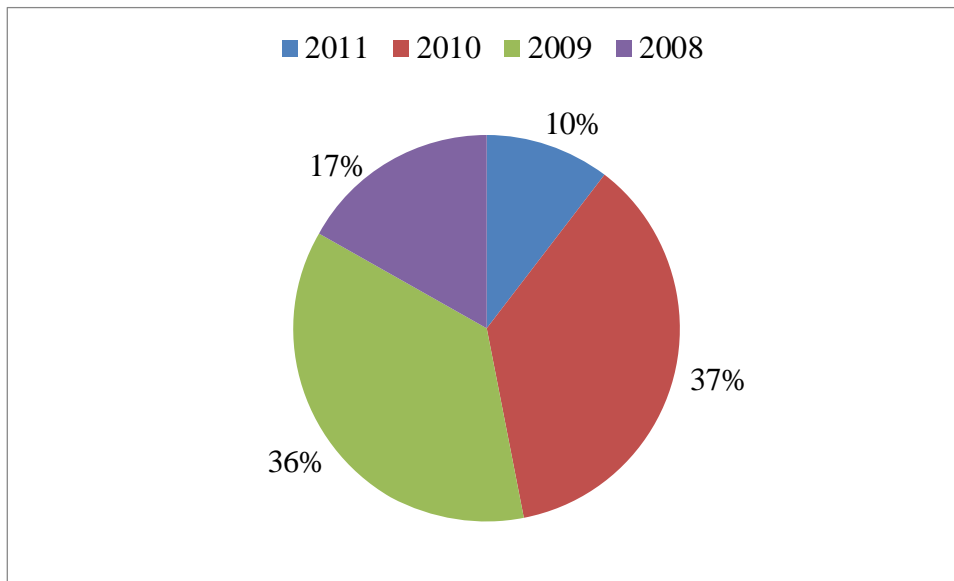


Figure 3.3: Proportion of meter ages of the 405 meter's investigated

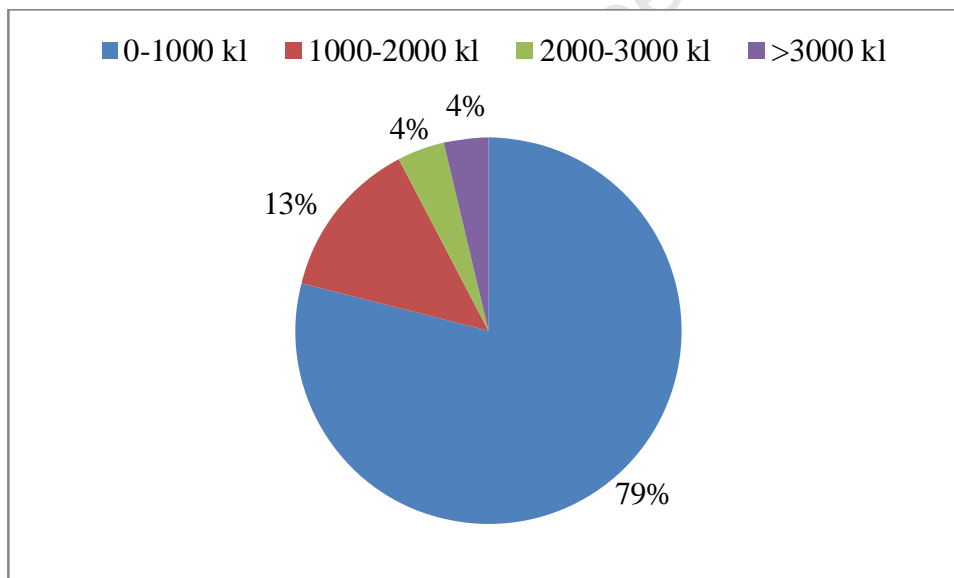


Figure 3.4: Proportion of registered volumes of the 405 meter's investigated

3.4.2.2 Meter model analysis

The meter model refers to the manufacturer, type, permanent flowrate and class of the meter and the proportions of each encountered in the field are illustrated graphically in Figure 3.5, 3.6, 3.7 and 3.8. Missing information for each is described as unknown.

Figure 3.5 illustrates that Manufacturer 1 accounted for 79 % of the meters and Manufacturer 2 accounting for 14 %.

Figure 3.6 illustrates that 58 % of the meters encountered were Multi-jet meters and 41 % of meters being of the Positive Displacement type.

Figure 3.7 illustrates that 39 % of meters had a nominal bore diameter of 15 mm and 37 % were 20 mm, with only 3 % being 25 mm.

Figure 3.8 illustrates that 92 % of the meters were Class C and only 5 % being Class B.

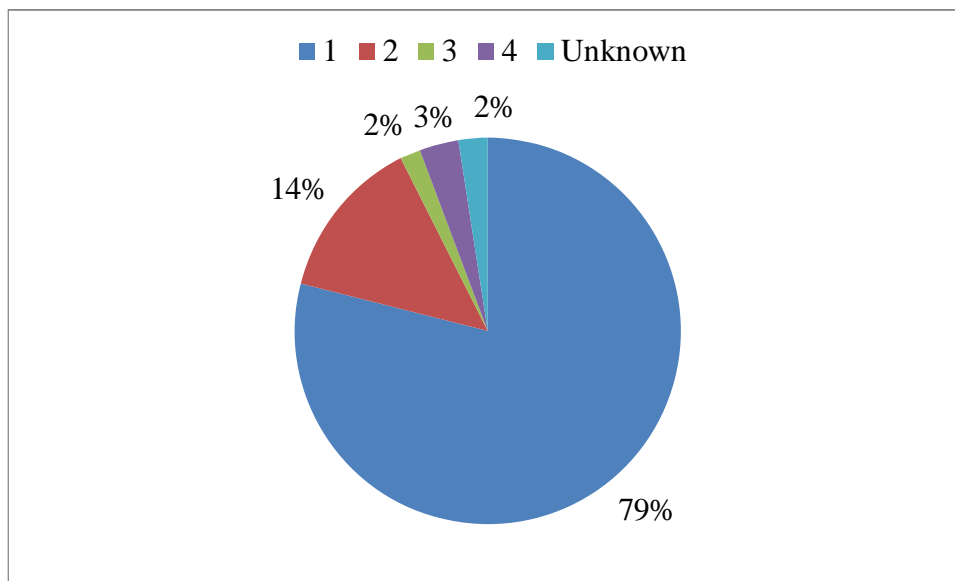


Figure 3.5: Proportion of manufacturer's encountered in the field

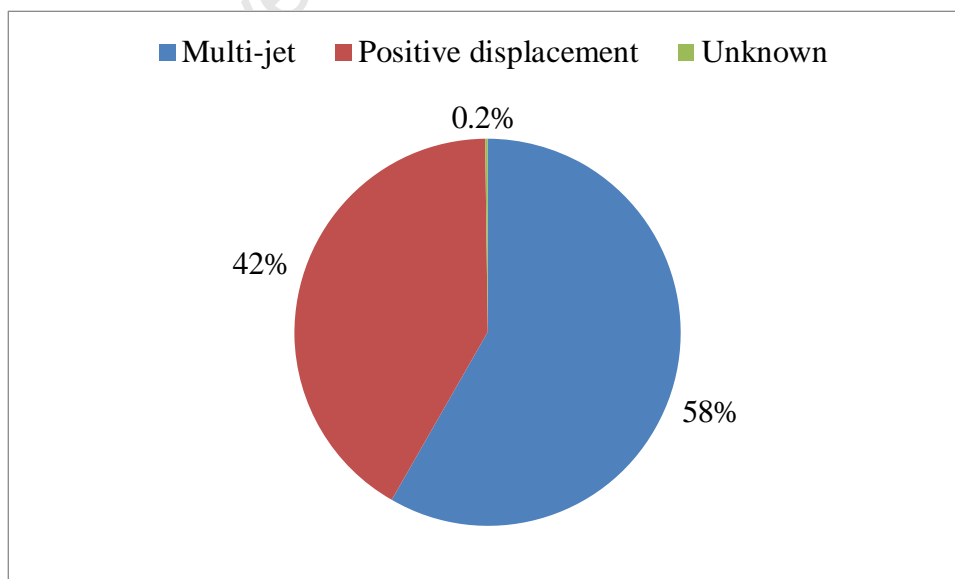


Figure 3.6: Proportion of meter types encountered in the field

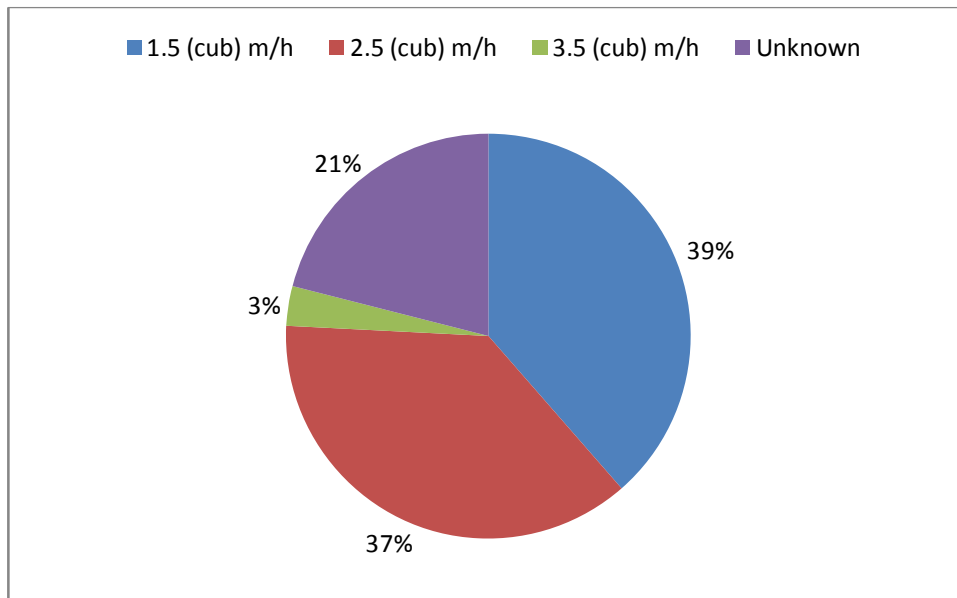


Figure 3.7: Proportion of meter permanent flowrates encountered in the field

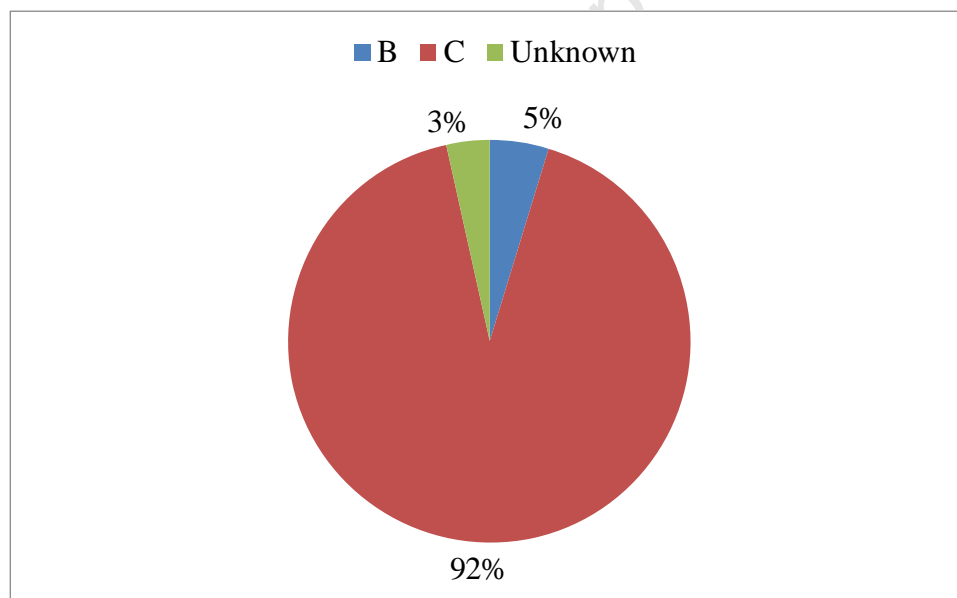


Figure 3.8: Proportion of meter classes encountered in the field

3.4.3 Assessment of meters investigated in Bloemfontein

3.4.3.1 Age-Volume analysis of meter samples

A total of 88 % of the meters had a registered volume of less than 1000 kl, 8 % between 1000 and 2000 kl, 2 % between 2000 and 3000 kl and 1 % greater than 3000 kl.

A total 33 % of the meters were installed in 2011, 30 % in 2010, 14 % in 2009 and 23 % in 2008.

3.4.3.2 Meter model analysis

All the meters found in Bloemfontein were from Manufacturer 1. All the meters had a permanent flowrate of $1.5 \text{ m}^3/\text{h}$ and all of them being of the positive displacement type with the exception of one multi-jet meter. A total of 25 % of the meters were Class B and the remainder Class C.

3.4.4 Occurrence of on-site leakages

A total of 405 properties were investigated in the City of Cape Town for measurable on-site leakage, with three properties being purged from the data set due to consumer's not stopping consumption as kindly asked to, during the visit. A total of 16 % of the 402 properties were found to have confirmed measurable on-site leakages, with Langa having the highest occurrence of 42 % and Mowbray the lowest of 4 %.

In Bloemfontein, a total of 167 properties were investigated for measurable on-site leakage. One property was completely purged from the data set as it had a water feature running consistently throughout the measuring process. From the 166 properties, it was found that 28 % of them had a confirmed leak. Freedom Square had the highest occurrence of on-site leakages of 62 % with Motlatla and Vist Park having the lowest of 3 %.

Table 3.7 and Figure 3.9 present the results from the investigation numerically and graphically respectively for City of Cape Town. Table 3.8 and Figure 3.10 show the results for Bloemfontein.

Table 3.7: Percentage occurrence of on-site leakages found between suburbs in City of Cape Town

Suburb	Number of properties	Number of leaks	% Leaks
Langa	26	11	42
Salt River	30	10	33
Woodstock	25	6	24
Rosebank	17	3	18
Newlands	29	5	17
Pinelands	29	5	17
Mandela Park	29	5	17
Observatory	27	4	15
Claremont	29	4	14
Thornton	30	4	13
Lakeside	27	3	11
Camps Bay	27	2	7
Tokai	29	2	7
Green Point	22	1	5
Mowbray	26	1	4
Sum	402	66	16

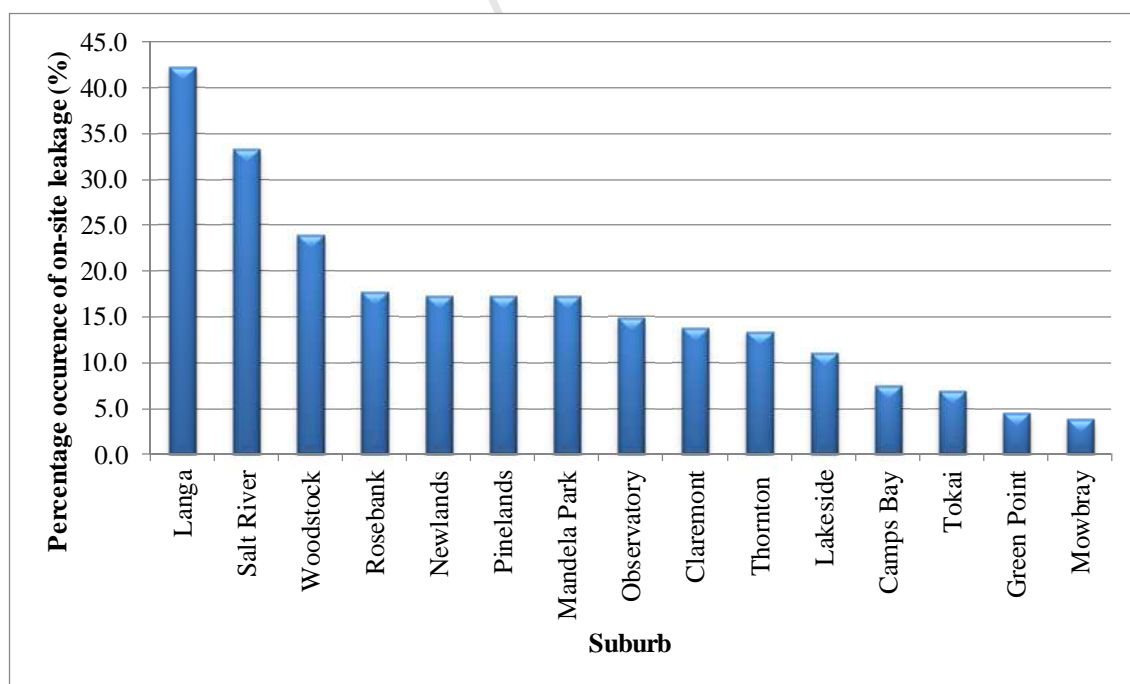


Figure 3.9: Percentage occurrence of on-site leakage between suburbs in City of Cape Town

Table 3.8: Percentage occurrence of on-site leakages found between suburbs in Bloemfontein

Suburb	Number of properties	Number of leaks	% Leaks
Botshabelo G	30	14	47
Mandela View	25	3	12
Vista Park	30	1	3
Brandwag	25	12	48
Freedom Square	26	16	62
Motlatla	30	1	3
Sum	166	47	28

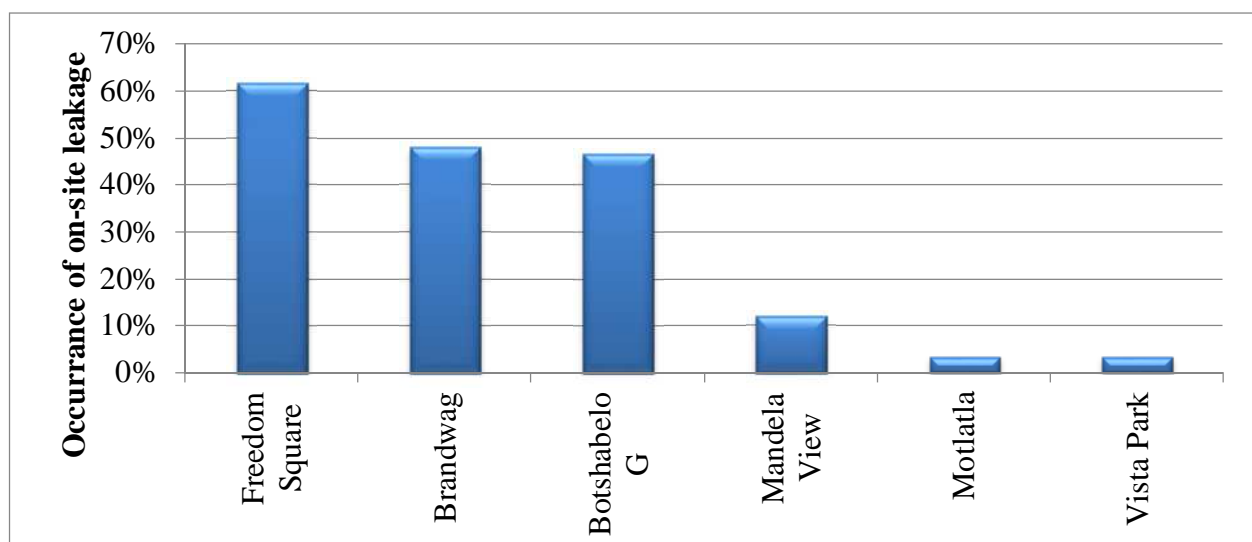


Figure 3.10: Percentage occurrence of on-site leakage between suburbs in City of Cape Town

3.4.5 Leakage Flowrates found on properties with confirmed on-site leakage

In Table 3.9, the 69 properties with leaks in City of Cape Town had a mean flowrate of 18.4 l/h and a median of 5.4 l/h. The highest leakage found in the City of Cape Town was 449.2 l/h and the lowest being 0.1 l/h. The 47 properties with leaks in Bloemfontein had a mean flowrate of 38 l/h and a median of 20.2 l/h, which is considerably higher than that found in Cape Town. The highest leakage found in Bloemfontein was 410.8 l/h with a minimum of 1.2 l/h.

In Figure 3.11, the highest occurrence of leakage flowrates is between 0 to 5 l/h with a general decrease of occurrence as leaks become larger. Bloemfontein has a high frequency of large on-site leakages of almost 20% of them being more than 50 l/h.

Figure 3.12 illustrates that almost 90 % of the measured leakage flowrates occurred below 20 l/h in Cape Town compared to 50 % in Bloemfontein.

In Table 3.9, Langa has the highest mean flowrate at 65.5 l/h and Brandwag the second highest at 57.9 l/h. Mean flowrates less than 1.5 l/h were found in Thornton, Lakeside, Camps Bay, Tokai, Green Point and Vista Park.

Table 3.9: Descriptive statistics of on-site leakage data

Statistic	City of Cape Town (l/h)	Bloemfontein (l/h)
Mean	18.4	38.0
Standard Error	7.1	9.9
Median	5.4	20.2
Mode	1.2	4
Standard Deviation	58.7	67.6
Minimum	0.1	1.2
Maximum	449.2	410.8
Count	69	47

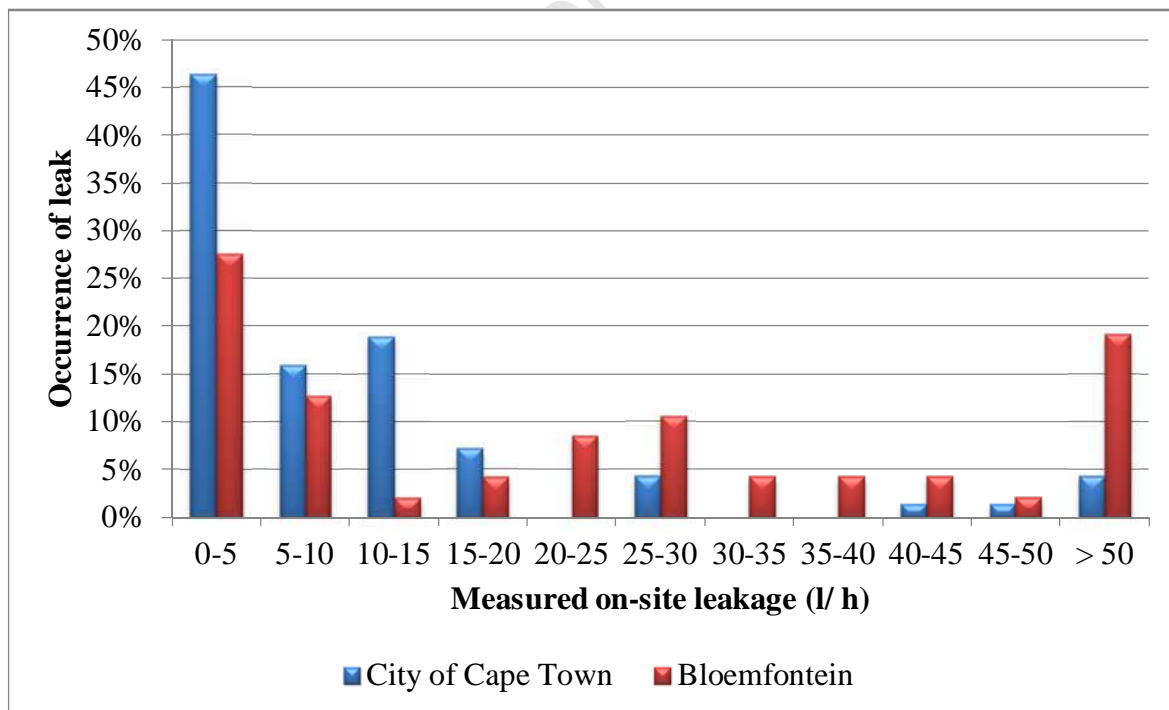


Figure 3.11: Histogram of on-site leakage flowrates measured on properties with leaks

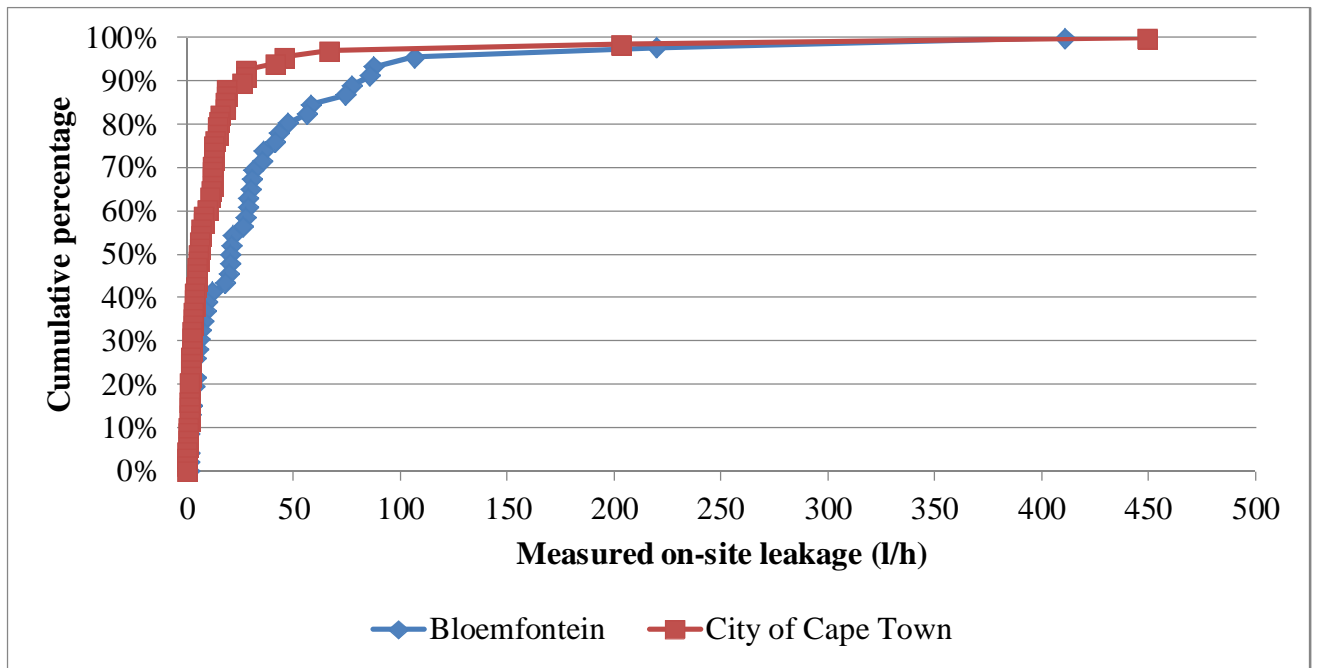


Figure 3.12: Cumulative frequency distribution of measured on-site leakages found on properties with leaks

University of Cape

Table 3.9: Comparison of mean flowrates measured between suburbs in Cape Town and Bloemfontein

City	Suburb	Number of leaks	Mean flowrate (l/h)
Cape Town	Green Point	1	0.3
Cape Town	Tokai	2	0.5
Cape Town	Lakeside	3	0.7
Cape Town	Thornton	4	1.1
Cape Town	Camps Bay	2	1.2
Bloemfontein	Vista Park	1	1.4
Cape Town	Pinelands	5	2.4
Bloemfontein	Mandela View	3	2.5
Cape Town	Mowbray	1	5.4
Cape Town	Claremont	4	6.8
Cape Town	Rosebank	3	7.2
Cape Town	Observatory	4	9.3
Cape Town	Woodstock	6	10.1
Cape Town	Newlands	5	11.3
Cape Town	Salt River	10	17.1
Cape Town	Mandela Park	5	26.1
Bloemfontein	Botshabelo G	14	26.6
Bloemfontein	Motlatla	1	29.8
Bloemfontein	Freedom Square	16	42.6
Bloemfontein	Brandwag	12	57.9
Cape Town	Langa	11	65.5

3.4.6 Correcting leakage flowrates for meter error

In Table 3.10, the mean corrected leakage flowrate for meter error in Cape Town is 21.2 l/h and the median is 10 l/h, compared to 18.4 l/h and 5.4 l/h respectively for the uncorrected leakage flowrates. In Bloemfontein the corrected mean leakage is 39.1 l/h and median of 20.0 l/h, compared to 38.0 l/h and 20.2 l/h. Very little change from the measured and actual leakage for properties in Bloemfontein is due to the majority of leakages being above or near the transitional flowrate of the meter.

In Figure 3.13, the highest occurrence of leakage flowrates is between 5 to 10 l/h (which is the starting flowrate of the meter) with a general decrease of occurrence as leaks become larger.

Figure 3.14 illustrates that almost 90 % of the leakage flowrates measured in Cape Town is below 20 l/h and 50 % for Bloemfontein. This result suggests that the assumed error curve used to correct for meter error, is in fact very conservative. In the Johannesburg study (Lugoma et al, 2012) it was found that 80 % of leakages occurred below 20 l/h.

Table 3.10: Descriptive statistics of on-site leakage data corrected for meter error

Statistic	Cape Town (l/h)	Bloemfontein (l/h)	Johannesburg (l/h)
Mean	21.2	39.1	23.4
Standard Error	7.0	9.8	5.9
Median	10.0	20.0	8.6
Mode	5.7	5.7	5.7
Standard Deviation	58.0	67.1	54.9
Minimum	5.7	5.7	5.7
Maximum	449.2	410.8	411.4
No. of properties with leaks	69	47	86

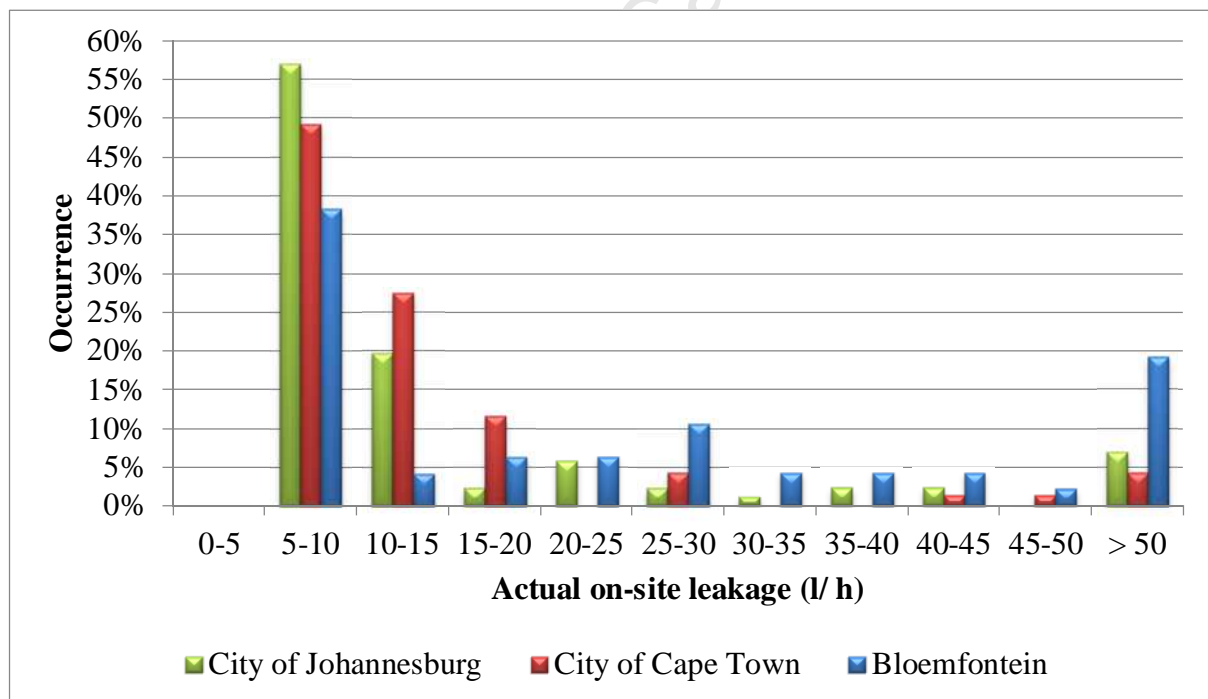


Figure 3.13: Histogram of on-site leakage flowrates measured on properties with leaks corrected for meter error

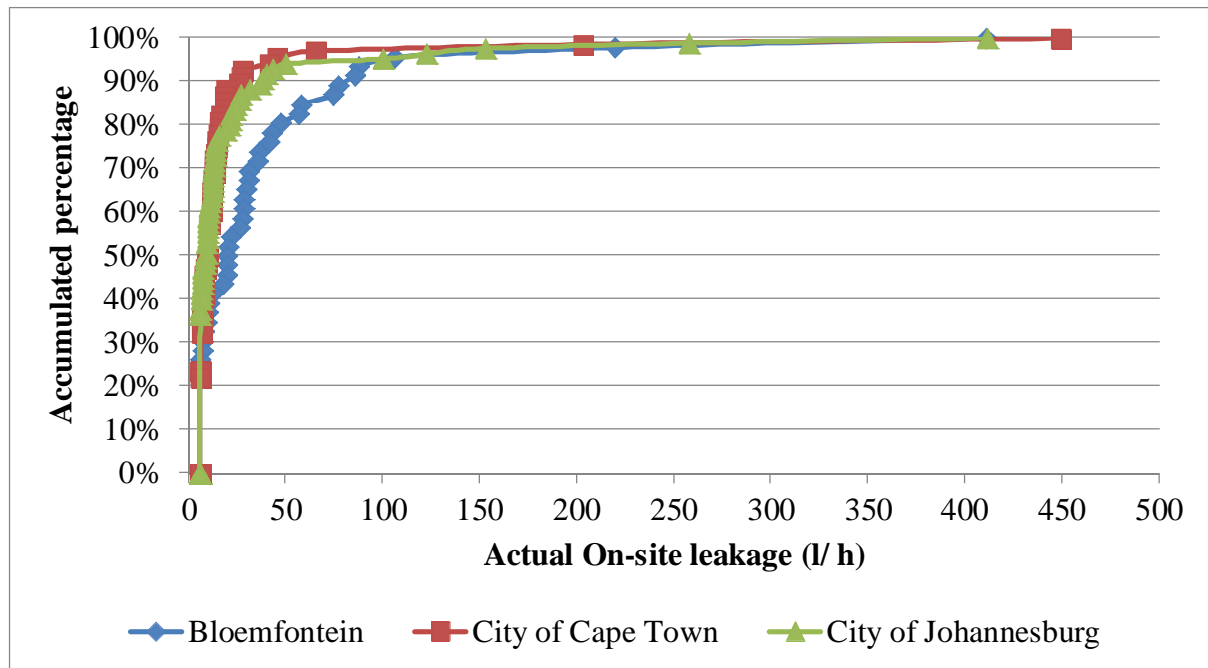


Figure 3.14: Cumulative frequency distribution of measurable on-site leakages found on properties with leaks corrected for meter error

3.4.7 Contribution of on-site leakage to apparent loss

By adding the metered and actual volume of consumption of each leaking property, the apparent loss due to on-site leakage can be calculated.

A total of 13.1 % of on-site leakage is unmetered for new meters in Cape Town, also considering that the estimation of the error curve was very conservative. In Bloemfontein 2.7 % of consumption was unmetered, which is a result of 50 % of leaks being greater than 20 l/h.

A median actual on-site leakage of 10 l/h in Cape Town was estimated (Table 3.10), which translates to a total on-site leakage volume of 7 200 litres per month, for properties that have a leak. This means that 943 litres of water lost through on-site leakage per month is unmetered by new meters. Although Bloemfontein has a median actual on-site leakage which is double of that found in Cape Town for properties with a leak, only 389 litres per month is lost through unmetered on-site leakage from new meters.

3.5 Conclusion

It was found in this study that only 16 % of domestic properties in the City of Cape Town have a measurable on-site leakage compared to 28 % in Bloemfontein and 67 % in the City of Johannesburg (Lugoma et al., 2012).

The mean and median flowrates found in the City of Cape Town were 21.2 l/h and 10 l/h respectively. The on-site leakage flowrates found in Cape Town compared well with that found in the Johannesburg study, which had mean and median flowrate of 23.4 and 8.6 l/h respectively. The cumulative frequency diagrams of leakage flowrates found in each study also compared very well, which further validates the reliability of each study. In both studies, the majority of leakages (80 and 90 %) were less than 20 l/h.

Bloemfontein however deviated from the other two studies. There was a high frequency of large leaks found with only 50 % of them occurring below 20 l/h.

An under-registration of 13.1 % of on-site leakages was estimated in the City of Cape Town for meters younger than 3 years. However, for older meters this percentage is expected to be much greater as the error curve deteriorates over time and usage. In Bloemfontein an under-registration of 2.7 % of meters younger than 3 years old were found, however this was due to a large proportion of the leaks having flowrates near or greater than the transitional flowrate.

4 Meter database analysis to estimate meter error

4.1 Introduction

There have been a number of meter testing methods and variations of each method used and described in literature to estimate the error of a water meter installed in the field. The consumer's meter is either removed from the field and tested in the laboratory or is tested in-situ in the field. Both of these methods can become very expensive and time consuming exercises and as a result restricted to small sample sizes that may not appropriately represent the meter population.

The above drawbacks of meter testing stated above makes the possible use of meter databases to estimate meter error an attractive option. The benefit of meter database analysis is that it makes use of a very large quantity of data that is already available in the municipalities meter reading database.

The following list the objectives of this study:

- To develop a methodology to use data recorded in a meter database to estimate meter error.
- Estimate meter error for different meter models and consumers according to meter age and registered volumes.
- Determine the practicality of meter database analysis as a method of estimating meter error.

The meter replacement database collected from the eThekweni Water and Sanitation (EWS) unit was used for analysis. The database included 158 409 domestic and non-domestic consumers that had their meter replaced at least once between June 2004 and February 2011.

The data in the database was cleaned and stratified according to homogenous groups according to factors that affect the accuracy of a meter, so that the data could be used to estimate meter error as a function of age and registered volume.

The meter error of each replaced meter in the database is computed by subtracting the registered consumption before and after the replacement of the consumer's meter. A period of

12 months of registered consumption before and after replacement was used to account for seasonal variation in consumption.

Due to the large number of data points required to reduce variability and the impact of erroneous data, only the 15mm positive displacement meters for domestic users could be analyzed in this study.

4.2 Data

4.2.1 Introduction

The meter replacement database obtained from the eThekweni Water and Sanitation (EWS) unit was used to determine the accuracy of consumer meters with different ages and accumulated registered volumes. The database included 158 409 domestic and non-domestic consumers that had their meter replaced at least once between June 2004 and February 2011.

The database includes meters that have been replaced due to a number of reasons:

- Meter stopped.
- Meter dial damaged or unreadable.
- Replacement due to replacement policy.
- Meter replaced and the connection moved from inside consumer property to the outside boundary.
- Meter removed for testing due to consumer complaint for various billing issue queries.

It is important that the database has fields that at the minimum record:

- Meter information i.e. manufacturer, type, size, class
- Consumer information i.e. user type, location
- Installation date of the replaced meter
- Installation date of the new meter
- At least 12 months of monthly billed consumption data before and after the installation date of the new meter.

If any one of the above fields is missing, it is not possible to use meter database analysis as a method of estimating meter error.

4.2.2 COINS meter database

The meter replacement database provided by the eThekweni Water and Sanitation unit has the required minimum fields to perform an analysis for meter error (Table 4.1).

The eThekweni Water and Sanitation unit has a policy that all their consumer meters in their supply area are read on a monthly basis (Scruton, 2011). Therefore, estimations of monthly consumption are not the norm.

Table 4.1: Data fields found in meter replacement database

Field name	Description
CONN_NO	Connection number
USAGE_TYPE	Domestic user, Flats, Commercial, Industrial, Education etc.
TYPE	Standard meter connection, Cap n Tap, Water dispenser etc.
CON_SIZE	Connection size
METER_SIZE	Nominal bore diameter of the meter
PROPERTKEY	Property key
STR_NUM	Street number
STR_NAME	Street name
SUBURB	Suburb
TOWN	Town
CONSUMER	Consumer
DATE_INSTL	Installation date of first meter
M_YYYYMMDD	Meter number and date the meter was read
C_YYYYMMDD	Monthly consumption in kL/ day and date it was read
Date of (1 st) Meter Change	Date of first meter change
No. of Meter Changes	Number of meter changes since first installation date

4.2.3 Shortcomings of database

Due to the large amount of data and how it was presented, it needed to be prepared to obtain meter ages and registered volumes.

A typical meter installation date would be 19980929 and first meter change would be 20081102. The *Format Cell* function in Microsoft Excel is incapable to change the text into dates to calculate age. Therefore the age was estimated by subtracting the installation date from the first meter change and dividing the difference by 10 000. For example:

Meter age = $(20081102 - 19980929) / 10\ 000 = 10.0173$ years.

As there are no records available for the registered consumption from when the meter was installed in the database supplied, it needed to be estimated. The registered consumption of a meter was estimated by multiplying the registered consumption of one year after replacement by the age of the meter.

4.3 Methodology

4.3.1 Introduction

This section describes the processes used for data cleaning, the stratification of meter data and computing meter error.

The database includes many meters that have been replaced due to meter failure and have zero consumption monthly data before or after replacement. This data is cleaned from the database to improve the probability of the actual consumption before and after the meter replacement is equal, to ensure that the difference of registered consumption is only due to meter error from accuracy deterioration.

4.3.2 Data cleaning

Before any useful data could be extracted a process of data cleaning had to be undertaken. The data cleaning process included removing the following meters from the database:

- Meters without 12 months of consumption data before and after replacement. This is required to comply with the 12 months consumption before and after rule to take into account seasonal variation in consumption
- Meters that has been replaced more than once. This was done as some of the meters were replaced within 12 months of the latest replacement. Therefore to avoid this and writing further calculation steps and complicating the spreadsheets, these meters were avoided.
- Meters with any zero consumption months the year before and after replacement. This was done for two reasons: the first is to improve the probability that actual

consumption the year before and after are equal and the second to remove any meters that have been 'stopped'.

- Meters less than a year old were removed. This occurred when a meter had a first meter change within a year after the meter's installation date. These meters also had consumption the year before and therefore weren't removed in the 3rd bullet point.
- Meters that did not have installation dates.

4.3.3 Stratifying meter data

One of the important features of analyzing meter inaccuracy is to stratify meters into homogenous groups according to factors that affect the meter's accuracy and to track trends in the data.

The consumer meters were stratified according to manufacturer, meter type, meter size, connection size, age, registered volume and type of consumer. Age groups of 5 year increments and 1000 kl increments were chosen for the age and registered volume groups respectively. The meter accuracy is analyzed for all the meters in their respective groups for the whole eThekweni municipal supply area and again for each town.

It is important to separate meter groups into different towns as they each have their own characteristic network pressure, system pipe burst frequencies and consumption patterns which affect a meter's accuracy:

- Towns with a high network pressure will experience a higher occurrence of on-site leakages with higher flowrates compared to areas with lower network pressures.
- Pipe burst frequency in an area increases the chance of sediment such as sand particles to enter the consumer meters and reduce the efficiency of their sensors. Therefore, it is intuitively expected that meters will degrade faster in areas with high pipe burst frequencies opposed to areas with lower pipe burst frequencies.
- Consumers in different towns will have different consumption patterns according to the characteristics of their plumbing and financial standing.

It is assumed that over a large sample of meters (i.e. greater than 1000 for a municipal supply area and 100 for a town), that on average the network pressures, pipe burst frequencies and consumption patterns fluctuate around a fixed average.

4.3.1 Computing meter error

When testing a water meter, the meter error is calculated by subtracting the indicated volume (Q_i) of a meter from the actual volume (Q_a) passing through the meter and dividing the difference by the actual volume. The fraction is then converted to a percentage, with a negative percentage being an under-registration and a positive percentage being an over-registration of the actual volume (Equation 4.1).

$$\text{Meter error (\%)} = \frac{Q_i - Q_a}{Q_a} \dots\dots\dots (4.1)$$

In database analysis, the indicated volume refers to the 12 months of consumption registered by the old meter before it is replaced. The actual volume refers to the actual 12 months of consumption registered before the old meter is replaced. As the actual consumption before the old meter is replaced is unknown, it is estimated by the new meter installed with 12 months of registered consumption after replacement. The following assumptions need to be made and are discussed and verified in the next section:

- The actual consumption one year before and after replacement is assumed to be equal when the sample is large.
- The new meter is assumed to have negligible error compared to the replaced meter.

4.4 Analyzing factors that may affect meter error

4.4.1 Introduction

The biggest concern of the reliability of using database analysis to estimate meter error is that it assumes that the actual consumption between any two consecutive years are equal over a large sample of consumers. The validity of this assumption depends on the impact of climate change and local factors such as: demand management programmes, consumer behaviour, metering accuracy and the selling price of water on consumption patterns. The main objective of this section is to check the validity of this assumption.

The impact of new meter error will also be discussed and taken into account in this section.

4.4.2 Change in consumer annual consumption

There is a clear seasonal variation in consumption visible in Figure 4.1 and an increase in total domestic consumption each year. In conjunction with the increase total consumption, there is an increase in total domestic connections each year (Figure 4.2).

In order to determine the impact of factors that may change consumer demand, the average consumption per connection needs to be analyzed. In Figure 4.3, there is a clear decrease in average consumption per domestic connection. This decrease could be due to two reasons:

1. The individual consumers are actually using less water due to climate change i.e. droughts or local factors such as demand management programmes.
2. There is an increase consumers connected to the supply system which are low consumers of water i.e. they consume less water per day than the average consumer.

The first reason has an impact on the meter error calculation, whereas the second reason does not. The second reason may imply a decrease in the consumption per connection in Figure 4.3, but is in fact not a true decrease or change in the consumer's consumption for the supply area.

The weighting of the impact of the above reasons on Figure 4.3 is unknown. Figure 4.1 shows no clear evidence of change in consumer demand due to climate or local factors, which implies that the 2nd reason is most likely the reason for the change in annual average consumption per domestic connection.

Therefore, with the aid of Figure 4.1, 4.2 and 4.3, it is concluded that the actual consumption between any two consecutive years are equal is a good assumption.

The law of averages also assist with the validity of this assumption over a large sample, in that it is probable that there will be an equal amount of individual consumers having an increased demand as there are having a decreased demand between any two consecutive years.

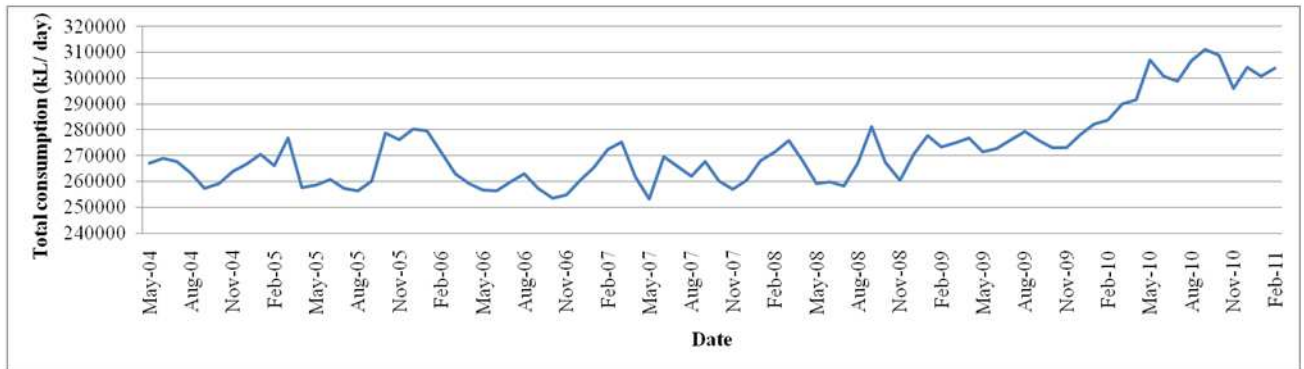


Figure 4.1: Total consumption of domestic consumers in the eThekweni supply area

(Scruton, 2011)

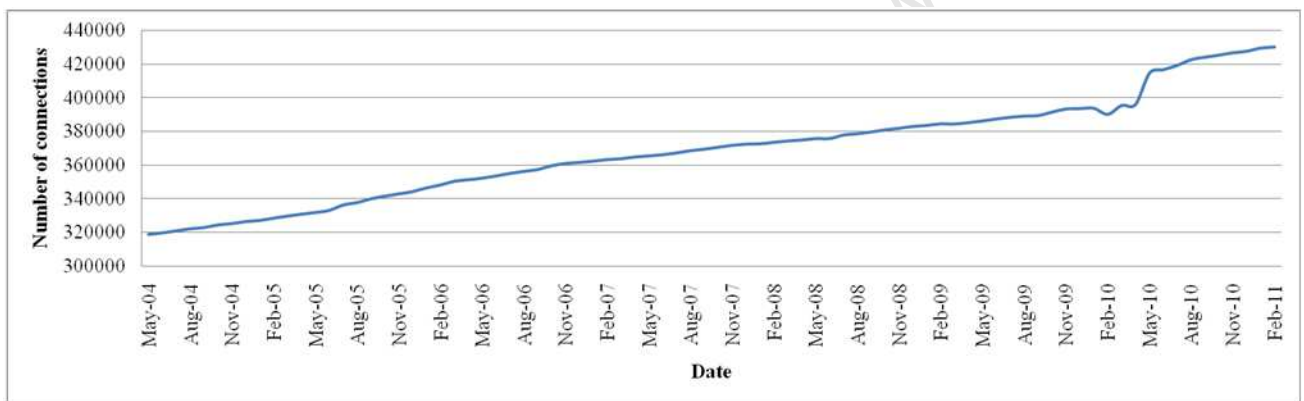


Figure 4.2: Total number of domestic connections in the eThekweni supply area (Scruton,

2011)

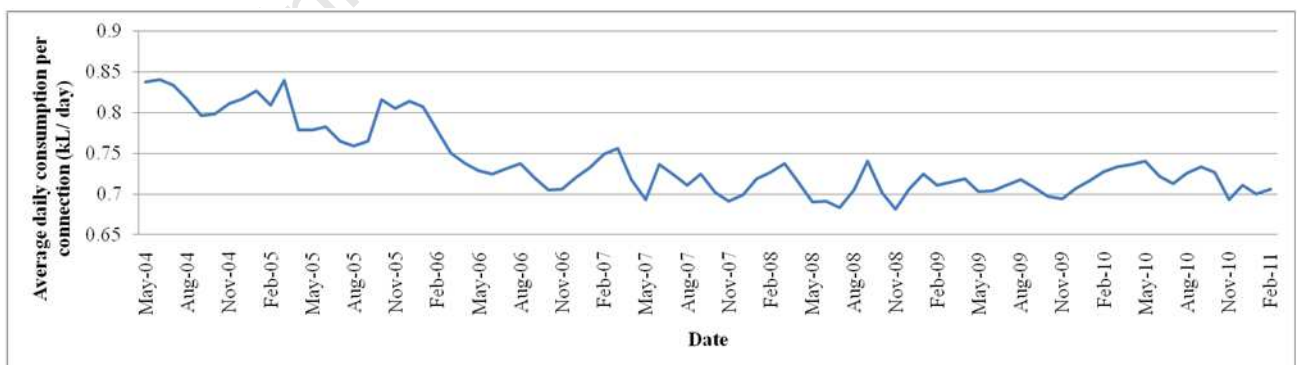


Figure 4.3: Average daily consumption per domestic connection in the eThekweni supply

area (Scruton, 2011)

4.4.3 New meter error

The new meter installed on the consumer's property which is measuring the actual consumption does not measure without error. All meters from the moment it is installed have a measuring error and its error will probably increase after a year in service. This error will vary for different factors that impact meter accuracy, therefore the only way to estimate it will be by physically testing a sample of meters in the field.

It is assumed in this analysis that new meters have negligible error.

4.5 Results and discussion

4.5.1 Introduction

This section provides the results of the analysis of the data derived from the meter database by:

- Describing the composition of the data after the data cleaning and stratifying processes.
- Presenting the results of the analysis for meter error versus age and registered volume for the municipality as a whole and again for each town.
- The results of the analysis are then discussed within the relevant sections.

4.5.2 Data

Of the 142 858 positive displacement 15mm domestic meters of the same manufacturer represented 90.2 % of the total connections in the EWS meter replacement database. Only 65067 survived the data cleaning process (Table 4.2).

Table 4.2: Description of data cleaning

Data	Number	Percentage (%)
15mm positive displacement domestic meters with standard connection	142 858	100
Meters without installation dates	32	0.0
Meters replaced more than once in sample period	26553	18.6
Meters with replacement dates younger than 20050606 and older than 20100328	33262	23.3
Meters less than a year old	785	0.5
Meters older than 40 years	12	0.0
Meters with zero consumption months before or after replacement	17147	12.0
Meters surviving data cleaning process	65067	45.5

The meters were categorized into both 5 year increments for age and 1000 kL increments for consumption volume registered. Table 4.3 depicts the number of meters in their respective age groups with their corresponding registered volume group, with cells in grey highlighting the highest number of meters in each age group.

Table 4.3: Meter age versus volume registered evaluation

Volume (ML)	Number of meters								Sum
	1 to 5 yrs	5 to 10 yrs	10 to 15 yrs	15 to 20 yrs	20 to 25 yrs	25 to 30 yrs	30 to 35 yrs	35 to 40 yrs	
0 to 1	4983	7537	1073	190	16	2	1	1	13803
1 to 2	2065	7762	2470	876	73	20	12	7	13285
2 to 3	523	3965	2423	1704	119	66	18	14	8832
3 to 4	136	1789	1878	2141	174	114	47	27	6306
4 to 5	56	783	1347	2186	258	162	63	39	4894
5 to 6	21	336	854	2003	262	222	72	32	3802
6 to 7	10	184	571	1577	257	253	88	56	2996
7 to 8	7	99	339	1253	216	275	109	73	2371
8 to 9	3	62	238	955	162	241	106	85	1852
9 to 10	4	48	150	697	156	213	101	86	1455
10 to 11	1	32	105	456	103	182	84	87	1050
> 11	6	65	288	1254	359	774	647	1028	4421
Sum	7815	22662	11736	15292	2155	2524	1348	1535	65067

4.5.3 Meter error versus age

The descriptive statistics table (Table 4.4), frequency distribution diagram for age groups 1 to 5 years and 15 to 20 years as an example (Figure 4.4 and 4.5) and cumulative frequencies diagram using the same example (Figure 4.6 and 4.7) show that: the data tends toward a central location, but is bounded to an under-registration of -100 % and unbounded for over-registration. This behaviour of the data regarding the frequency distribution diagrams and cumulative frequency diagrams are evident in all the age groups (Appendix C and D respectively). The median as a result is the preferred measure of central location to that of mean.

Table 4.4: Descriptive statistics for meter error versus age

Statistic	Meter error (%)							
	0 to 5 yrs	5 to 10 yrs	10 to 15 yrs	15 to 20 yrs	20 to 25 yrs	25 to 30 yrs	30 to 35 yrs	35 to 40 yrs
Mean	25.05	20.21	13.27	8.00	2.76	-1.53	0.71	-1.21
Standard Error	1.84	1.00	2.01	0.96	1.53	0.84	1.50	1.04
Median	0.25	-3.85	-5.12	-7.86	-8.37	-8.16	-5.60	-7.17
Standard Deviation	162.78	151.29	217.95	118.80	70.90	41.98	55.20	40.63
Kurtosis	1004.32	2075.93	5824.42	1033.41	137.96	37.61	247.14	22.79
Skewness	24.59	32.19	68.84	25.70	9.27	4.46	12.19	3.42
Minimum	-99.11	-98.60	-99.76	-99.75	-96.89	-84.96	-94.75	-85.84
Maximum	8035.94	12114.98	19581.32	5807.14	1337.04	559.11	1301.28	404.18
Samples (number)	7815	22662	11736	15292	2155	2524	1348	1535

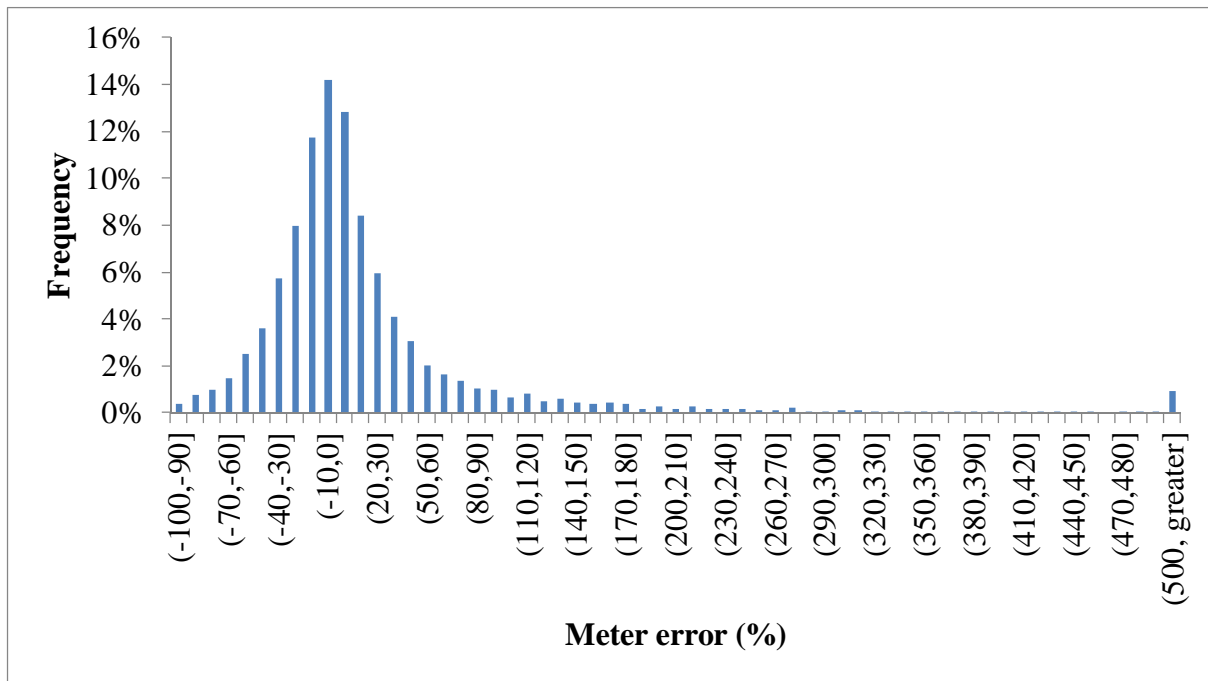


Figure 4.4: Frequency distribution diagram for the 1-5 meter age group

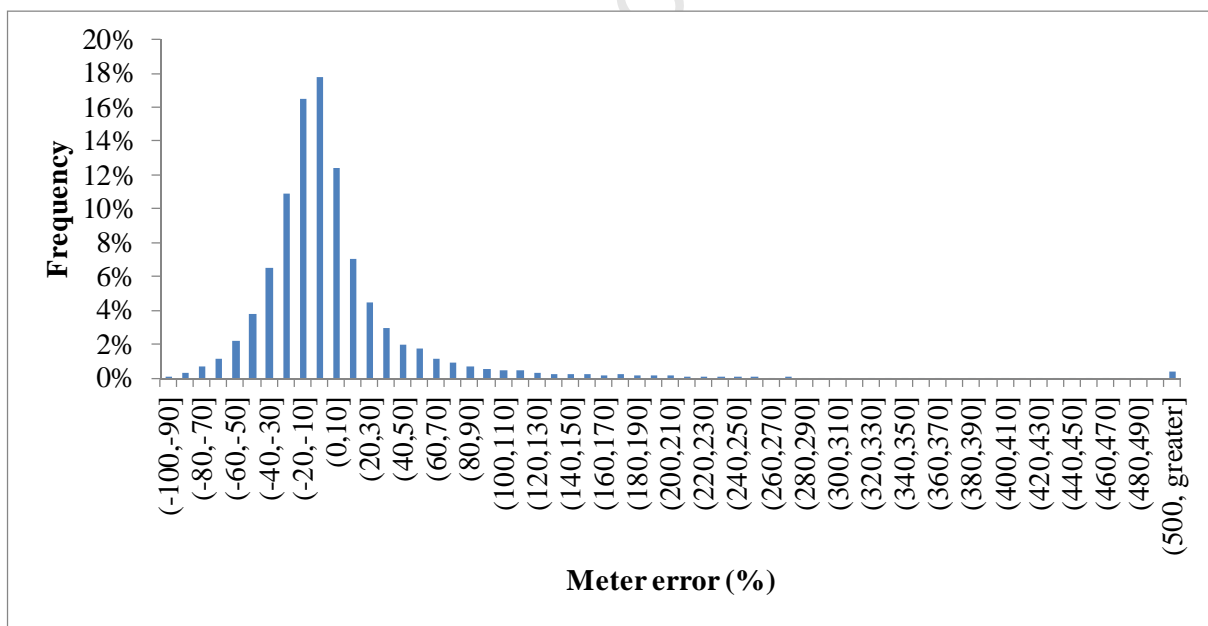


Figure 4.5: Frequency distribution diagram for the 15-20 meter age group

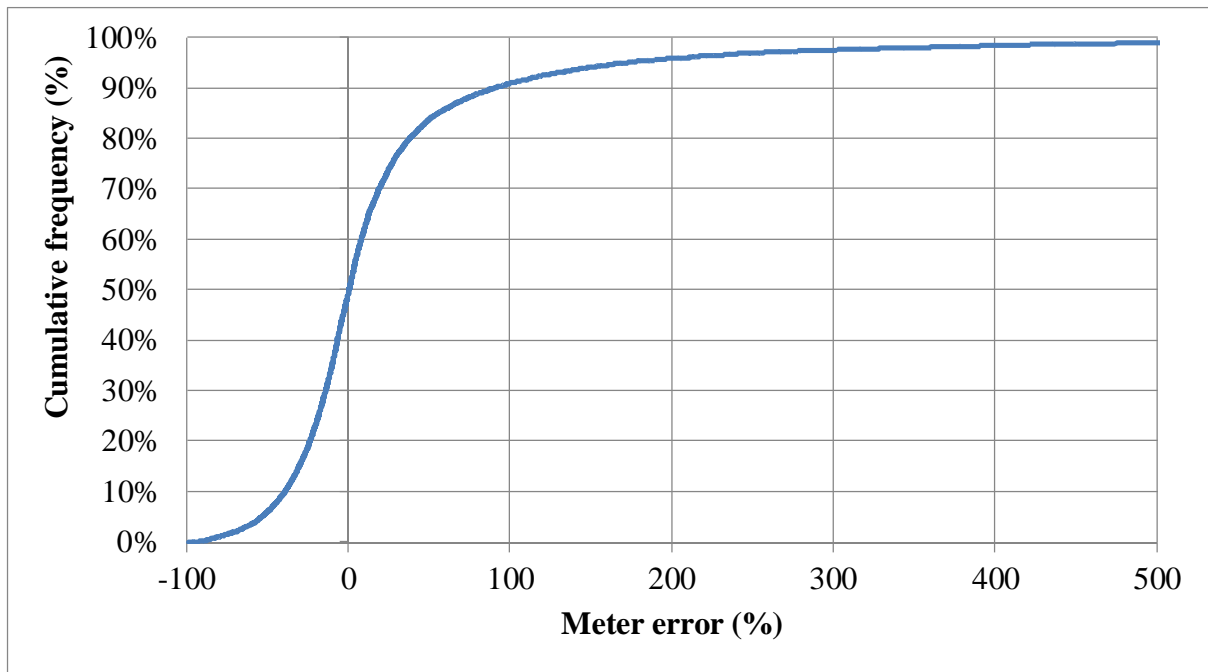


Figure 4.6: Cumulative frequency distribution diagram for the 1-5 meter age group

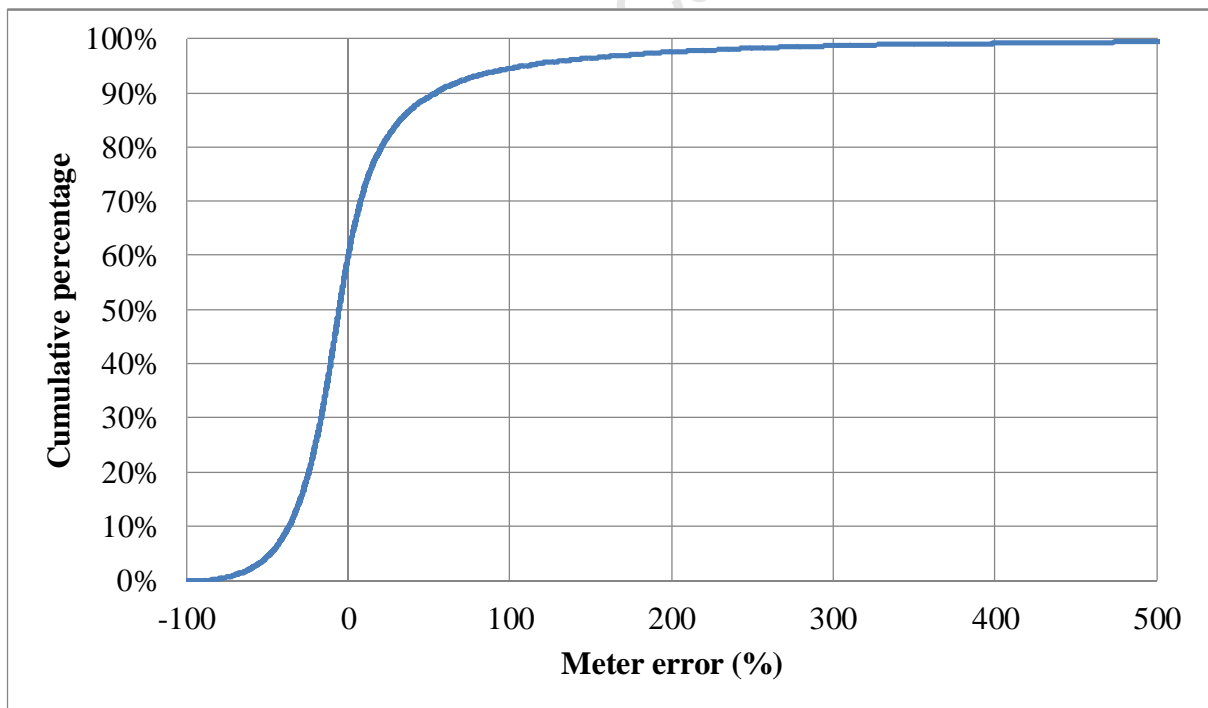


Figure 4.7: Cumulative frequency distribution diagram for the 15-20 meter age group

The median meter error in Table 4.4 was plotted against age in Figure 4.8. It can be seen that the data has a linear fit for meters younger than 25 years, with 0.36 %-points deterioration in

the meter’s accuracy per year. The meters older than 25 years do not fit the linear trend, which could be due to the following reasons:

- These meters may be of better quality than the younger meters, which could be the reason why they stayed in service for so long.
- These meters could be generally on consumer properties that may be from a specific area that have low on-site leakages, consumption patterns skewed to high flowrates, low network pressures and low burst frequencies.
- In Table 4.3, it can be seen that these meters have fewer samples to that of the younger groups, with the 20 to 25 group being the exception. This could be the reason why the older meters deviate from the linear trend.

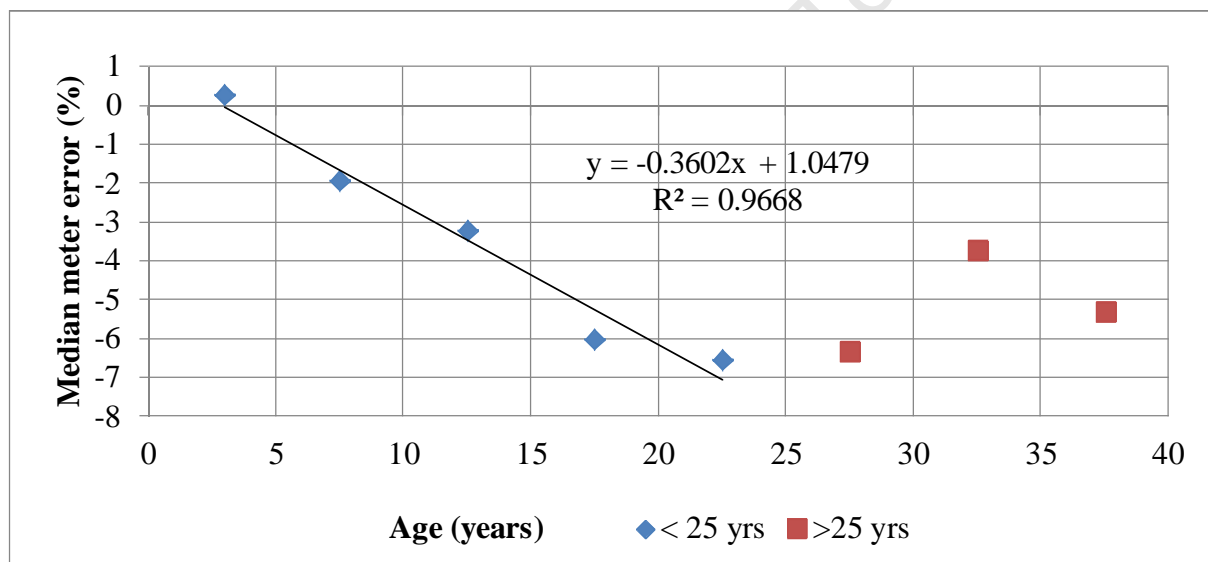


Figure 4.8: Median meter error versus age

4.5.4 Meter error versus registered volume

The descriptive statistics table (Table 4.5), frequency distribution diagram (Figure 4.9 and 4.10), cumulative frequencies diagram (Figure 4.11 and 4.12) show that, as with the meter age analysis: the data tends toward a central location and is bounded by an under-registration of -100 % and unbounded for over-registration. This behaviour of the data regarding the frequency distribution diagrams and cumulative frequency diagrams are evident in all the registered volume groups (Appendix C and D respectively). The median as a result is the preferred measure of central location to that of mean.

Table 4.5: Descriptive statistics for meter error versus registered volume (uncorrected for new meter error)

Statistic	Meter error (%)										
	0 to 1 MI	1 to 2 MI	2 to 3 MI	3 to 4 MI	4 to 5 MI	5 to 6 MI	6 to 7 MI	7 to 8 MI	8 to 9 MI	9 to 10 MI	10 to 11 MI
Mean	54.4	19.6	8.5	4.8	4.5	-0.7	-1.7	-4.8	-4.8	-6.4	-6.2
Standard Error	1.9	1.4	0.8	0.8	4.1	0.9	1.0	0.8	1.0	1.0	1.3
Median	8.3	-1.3	-3.5	-4.5	-7.5	-7.1	-8.2	-8.7	-8.5	-9.7	-9.5
Standard Deviation	223.7	157.4	73.6	65.9	285.1	54.5	55.7	39.0	41.7	38.8	41.1
Kurtosis	914.5	1428.5	153.5	215.3	4547.0	270.8	189.1	32.0	57.0	33.3	64.3
Skewness	22.2	30.6	9.0	10.5	66.2	11.0	10.2	3.7	5.3	3.9	5.5
Minimum	-98.9	-98.3	-99.1	-96.6	-97.2	-96.2	-96.0	-98.6	-96.9	-93.7	-95.7
Maximum	12359.3	9518.8	1779.0	1909.4	19581.3	1697.8	1329.3	483.3	615.0	467.5	605.8
Samples (number)	13803	13285	8832	6306	4894	3802	2996	2371	1852	1455	1050

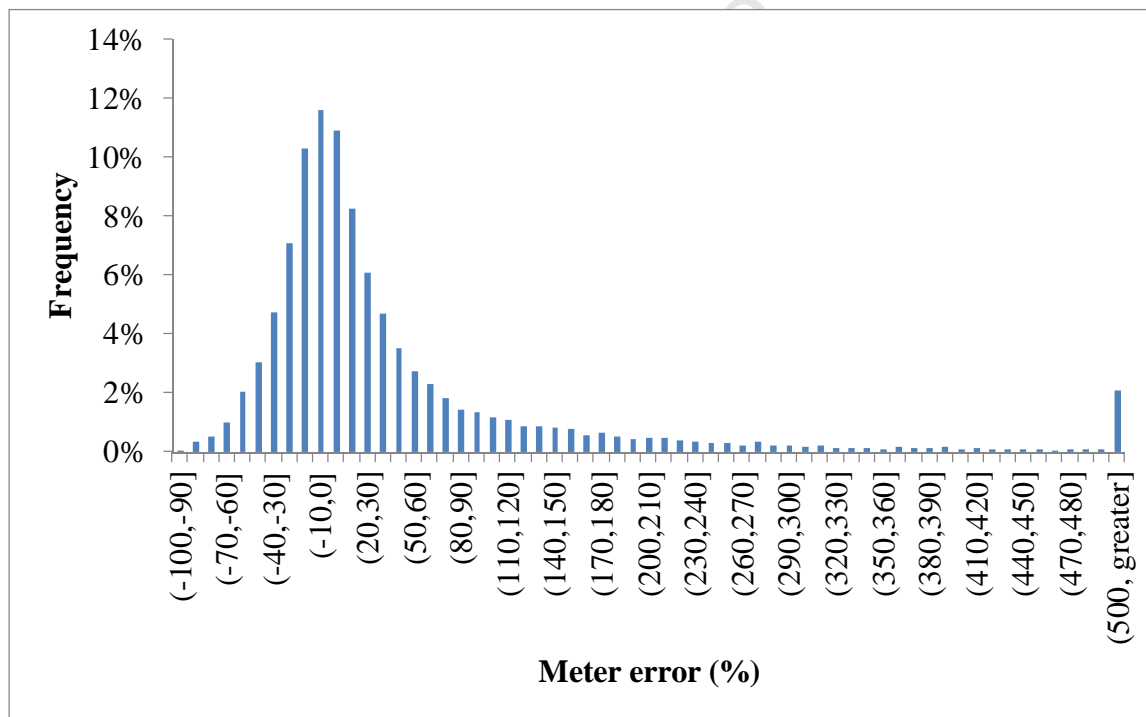


Figure 4.9: Frequency distribution diagram for 0-1000 kl meter registered volume group

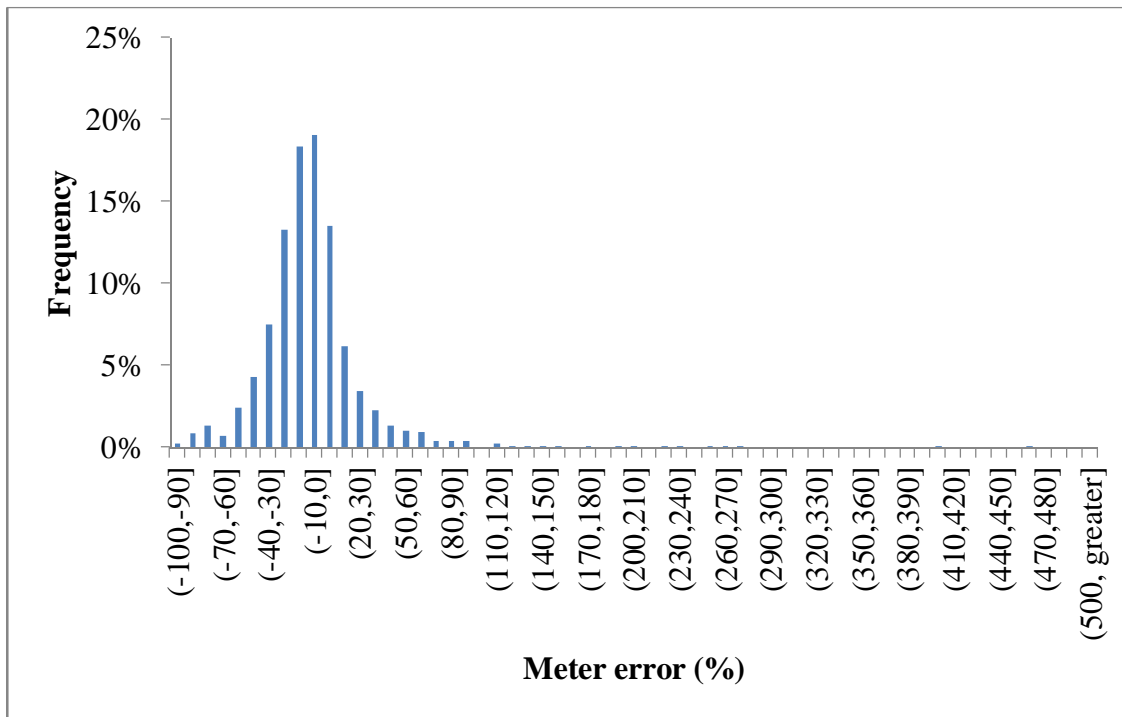


Figure 4.10: Frequency distribution diagram for 9 000-10 000 kL meter registered volume group

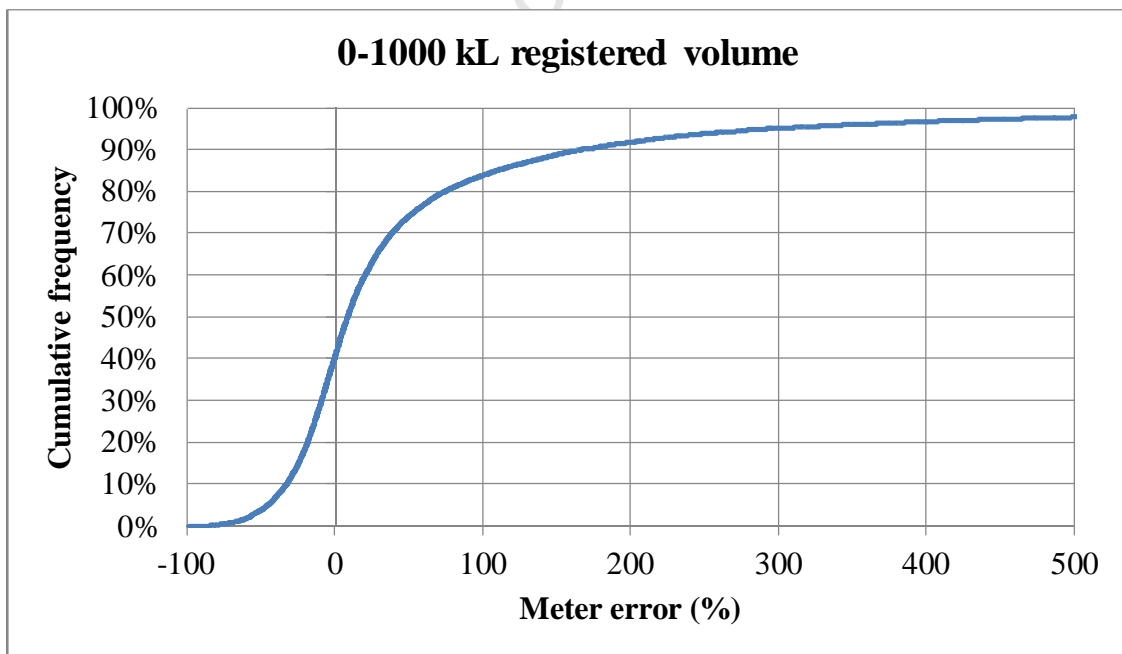


Figure 4.11: Cumulative frequency distribution diagram for 0-1000 kL meter registered volume group

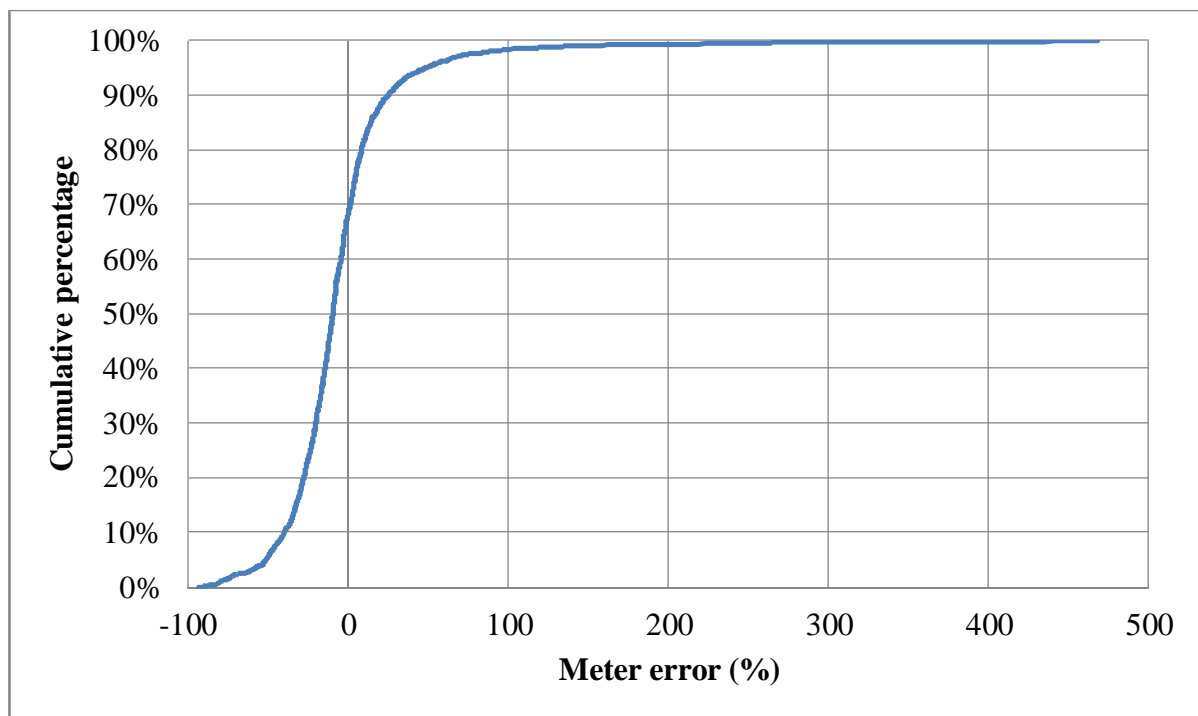


Figure 4.12: Cumulative frequency distribution diagram for 9000-10 000 kL meter registered volume group

The median meter error in Table 4.6 was plotted against registered volume in Figure 4.13. It can be seen that the data has a linear fit for meters with registered volumes greater than 1000 kl, with 0.9 %-points deterioration in the meter’s accuracy per 1000 kl registered.

The meters with registered volumes less than 1000 kl do not fit the linear trend. This could be attributed to these meters being of poor quality from the meter supplier and over-registering in the field. Other unknown site conditions could play a part in these meters over-registering as well. The methodology of estimating the registered volume of these meters, already described in Section 4.2.3, may also play a considerable part. All the meters which have decreased their consumption the year after replacement, get picked up with this method and results in meters with high over-registrations being pooled in this group. The over-registration therefore may be due to an actual change in consumption rather than a meter error.

The meters with registered volumes greater than 11 000 kl were not considered in the analysis, as they did not have the required 1000 data points.

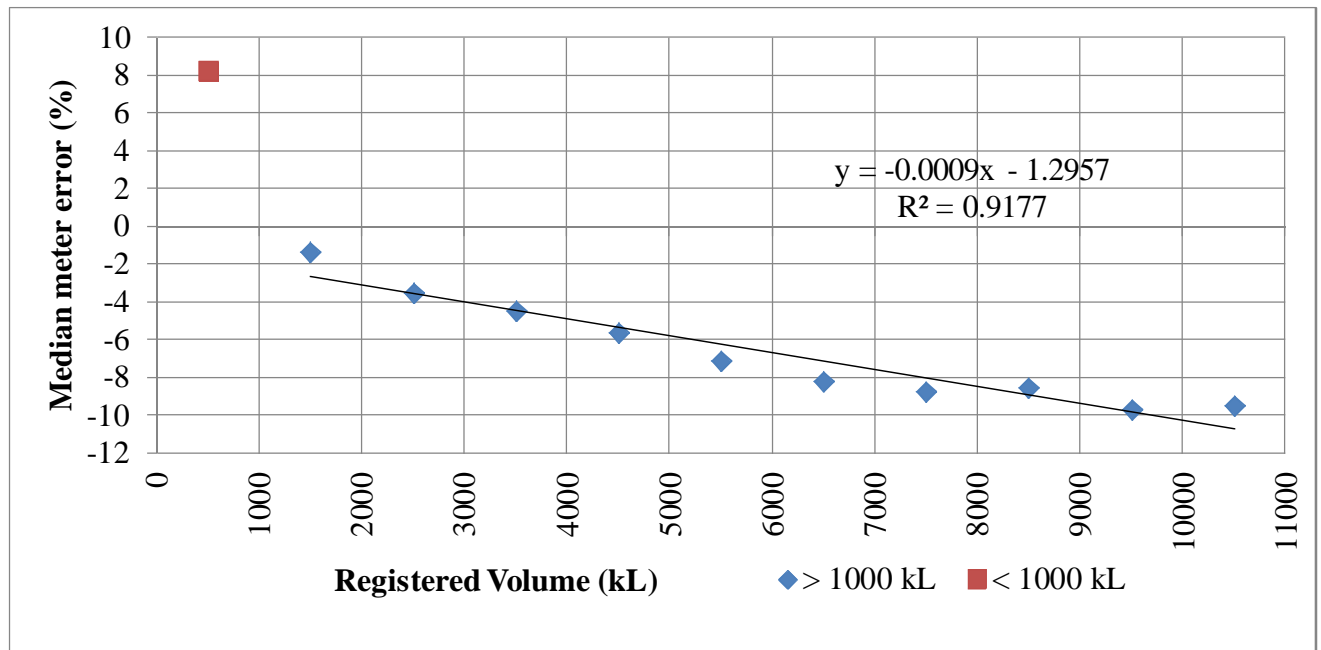


Figure 4.13: Median meter error versus registered volume

4.5.5 Comparing meter error between Towns

The median meter errors for each town for the 1 to 5 years age group and 0 to 1000 kl registered volume group, which have a minimum of 100 samples, are plotted in Figure 4.14 Figure 4.15 respectively. The results of the other age and registered volume groups can be found in Appendix E. The differences in meter error between towns could be as a result of the differences already discussed in Section 4.3.3.

When comparing each of the town-meter error graphs, it can be seen that for some of the towns, that they do not follow a linear trend for meter error versus age or meter error versus registered volume. The reason for this may lay in that a restriction of only 100 samples was decided on for this analysis. This means that the meters replaced in these towns could be skewed to meters which are special cases within that town for that age or registered volume group. If a restriction of 1000 samples was decided on, there would be too few towns to do any comparison.

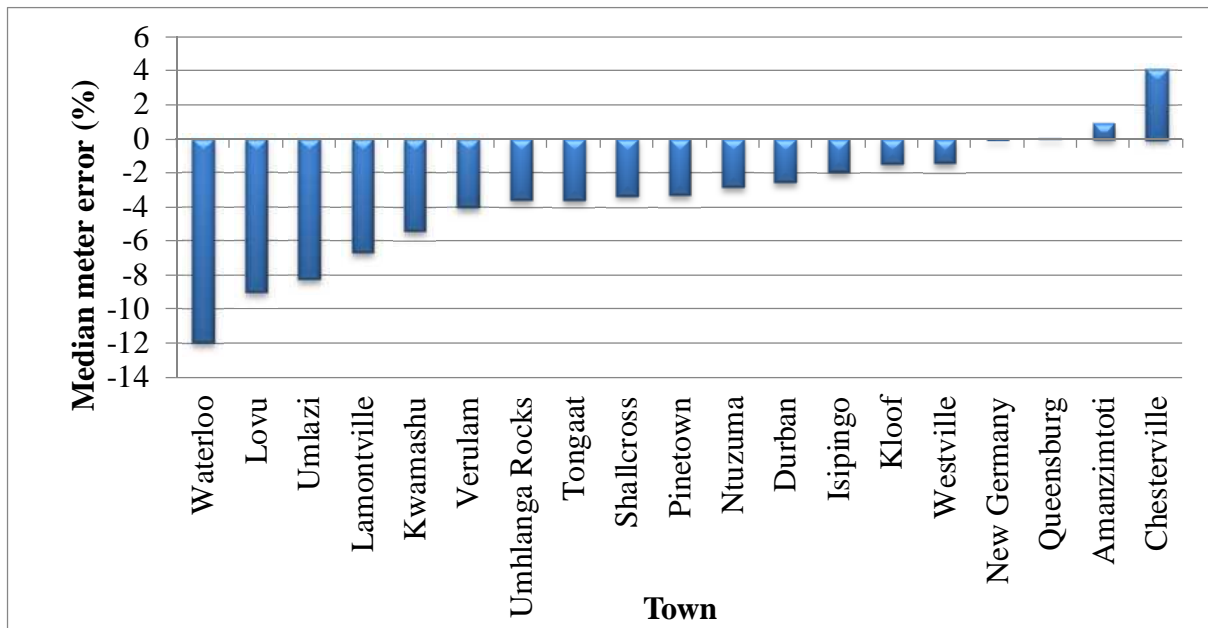


Figure 4.14: Comparison of meter error between towns for meter ages 10 to 15 years old

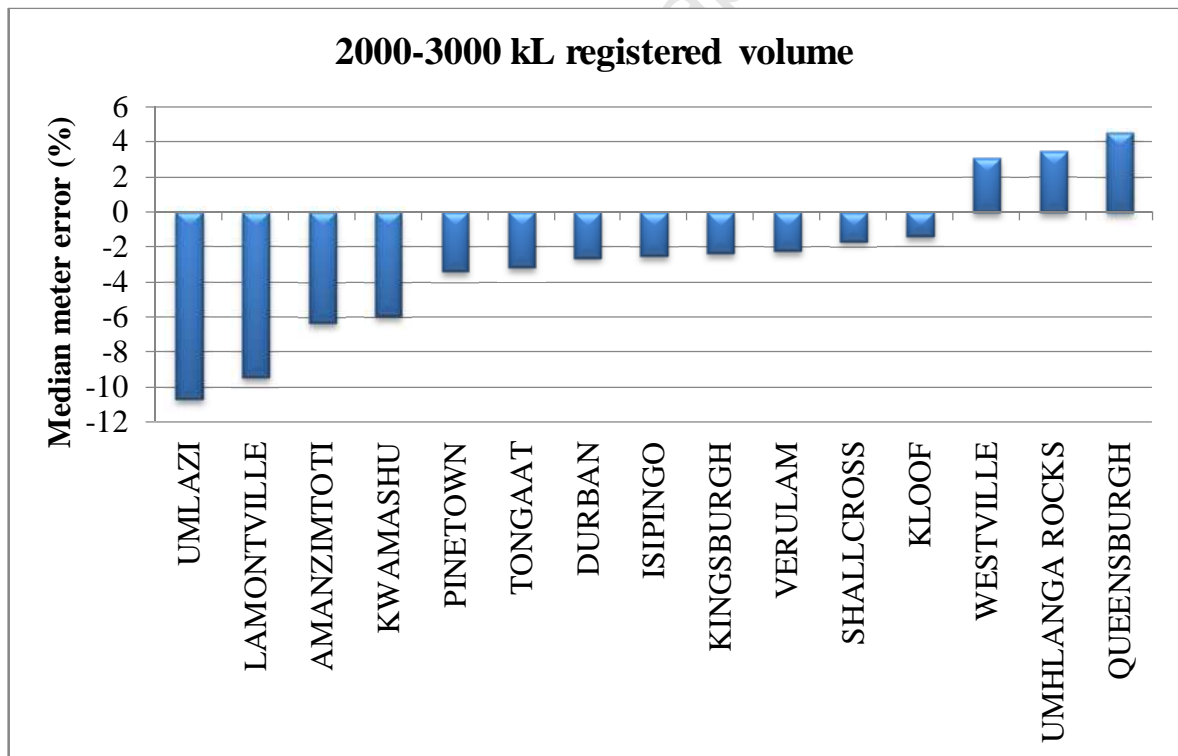


Figure 4.15: Comparison of meter error between towns for meters with registered volumes between 2000 and 3000 kl

4.6 Conclusion

A methodology was developed to use data recorded in a meter database to estimate meter error in this study. The main drawback was that a minimum of 1000 meter samples per age or volume group were required to obtain data that fits the expected linear trend of deterioration of the meter error curve. This meant that meter error for only the 15 mm positive displacement meters could be estimated with this methodology, as they accounted for 90.2% of the 158 409 meter connections in the database and only 45.5 % of the 90.2 % could be used in the analysis after data cleaning.

The meter error curves for both the age and registered volume groups, showed a good linear fit. The deterioration of meter error was 0.36 %-points per year and 0.9 %-points per 1000 kl registered for age and registered volume respectively.

This study shows that meter database analysis as an alternative method of quantifying meter error to that of meter testing, is both practical and useful to understand the performance of meters in the distribution network and between different towns.

The following are the recommendations made for this study:

- This analysis of the meter database of other municipalities, using the developed methodology, need to be performed to verify and support the results.
- The accuracy of a meter in the field with only one year's service needs to be tested in the field, to improve the assumption of new meter error which has an impact on the final results.

5 Flow logging of domestic consumer meters and UFRs

5.1 Introduction

The Average Weighted Error is calculated by multiplying the error curve of the meter by the actual flowrate passing through it, which is weighted according to the volume of water used at each actual flowrate. This chapter investigates the consumption profile of 5 domestic properties and 3 with a UFR installed.

The objective of this study was to:

- Test master meters to be used for flow logging in a laboratory at a number of selected flowrates
- Log the consumption profile of domestic consumers using a master meter installed in-line with the consumer meter.
- Log the consumption profile of domestic consumers with a UFR fitted in-line with the master meter.
- Determine the impact of a UFR on meter under-registration.

The study was performed on consumer meters in the City of Cape Town which commenced on 12 January 2012 and ended on 8 March 2012. There were many problems encountered in the field regarding consumers giving permission for logging of their meter, which devoted a lot of the projects time. As a result, only 8 meters were logged and general statements about meters in Cape Town cannot be made.

Only 15 mm positive displacement consumer meters were tested in the field as positive displacement master meters were used. Positive displacement meters measure packets of water when consumption occurs and pulses the flow, which changes the flow profile and may impact the accuracy of velocity meters.

Despite the small data set, some interesting observations are made by inspection of the consumption patterns and impacts of UFRs.

5.2 Meter database

The same meter database used in the on-site leakage study (Chapter 3) was used to select properties. Properties were randomly selected in a spreadsheet to reduce bias error.

5.3 Methodology

5.3.1 Introduction

An experienced plumbing contractor was employed to carry out all flow logging of consumer meters in the field and notifying them of the test. A number of problems were encountered in the field relating to getting permission from consumers to allow for their meter to be logged and therefore only 8 meters were logged.

The master meters were tested in a laboratory under a number of flowrates to estimate its error curve. This was done to correct the flowrate data recorded by the data logger in the field to correct the data for meter error and estimate the actual consumption.

Data loggers with a 1 litre pulse output were used and 15 mm Class C positive displacement meters.

5.3.2 Laboratory testing of master meter

A total of fifteen Class C positive displacement master meters were tested at the manufacturer's laboratory at 7 flowrates of 5, 15, 22.5, 37.5, 75, 150 and 270 litres/ hour. See Appendix F for individual meter error curves of each master meter tested in the laboratory. Table 5.1 tabulates the results of the meter error tested at each flowrate in the laboratory for each master meter and Figure 5.1 plots the average error curve from the lab tests.

Table 5.1: Meter error tested at each flowrate in the laboratory

Meter serial number	Actual flowrate used for testing (l/ h)						
	2700	1500	750	375	22.5	15	5
DA11BA042035	0.07 %	0.27 %	0.65 %	1.12 %	1.24 %	0.92 %	-1.93 %
DA11BA042036	0.04 %	0.37 %	0.78 %	1.10 %	1.64 %	1.25 %	-1.39 %
DA11BA042037	0.07 %	0.26 %	0.64 %	1.13 %	1.56 %	1.30 %	-1.20 %
DA11BA042038	0.16 %	0.35 %	0.83 %	1.17 %	1.61 %	1.15 %	-1.55 %
DA11BA042039	0.01 %	0.19 %	0.70 %	1.08 %	1.37 %	0.92 %	-2.29 %
DA11BA042040	0.10 %	0.29 %	0.65 %	1.18 %	1.41 %	1.07 %	-1.89 %
DA11BA042041	0.11 %	0.35 %	0.86 %	1.14 %	1.63 %	1.33 %	-0.95 %
DA11BA042042	0.12 %	0.36 %	0.72 %	1.12 %	1.46 %	1.02 %	-2.04 %
DA11BA042043	0.03 %	0.22 %	0.79 %	1.15 %	1.50 %	1.05 %	-2.24 %
DA11BA042044	0.14 %	0.41 %	0.93 %	1.13 %	1.5 %	1.06 %	-2.00 %
DA11BA042045	0.24 %	0.48 %	1.00 %	1.24 %	1.46 %	1.09 %	-2.09 %
DA11BA042046	0.13 %	0.36 %	0.76 %	1.11 %	1.39 %	0.84 %	-2.81 %
DA11BA042047	0.17 %	0.29 %	0.79 %	1.19 %	1.63 %	1.17 %	-1.56 %
DA11BA042048	-0.97 %	-0.12 %	0.51 %	1.03 %	1.37 %	1.05 %	-1.60 %
DA11BA042049	-0.06 %	0.27 %	0.64 %	1.01 %	1.45 %	1.18 %	-1.41 %
Average	0.02 %	0.29 %	0.75 %	1.13 %	1.48 %	1.09 %	-1.80 %

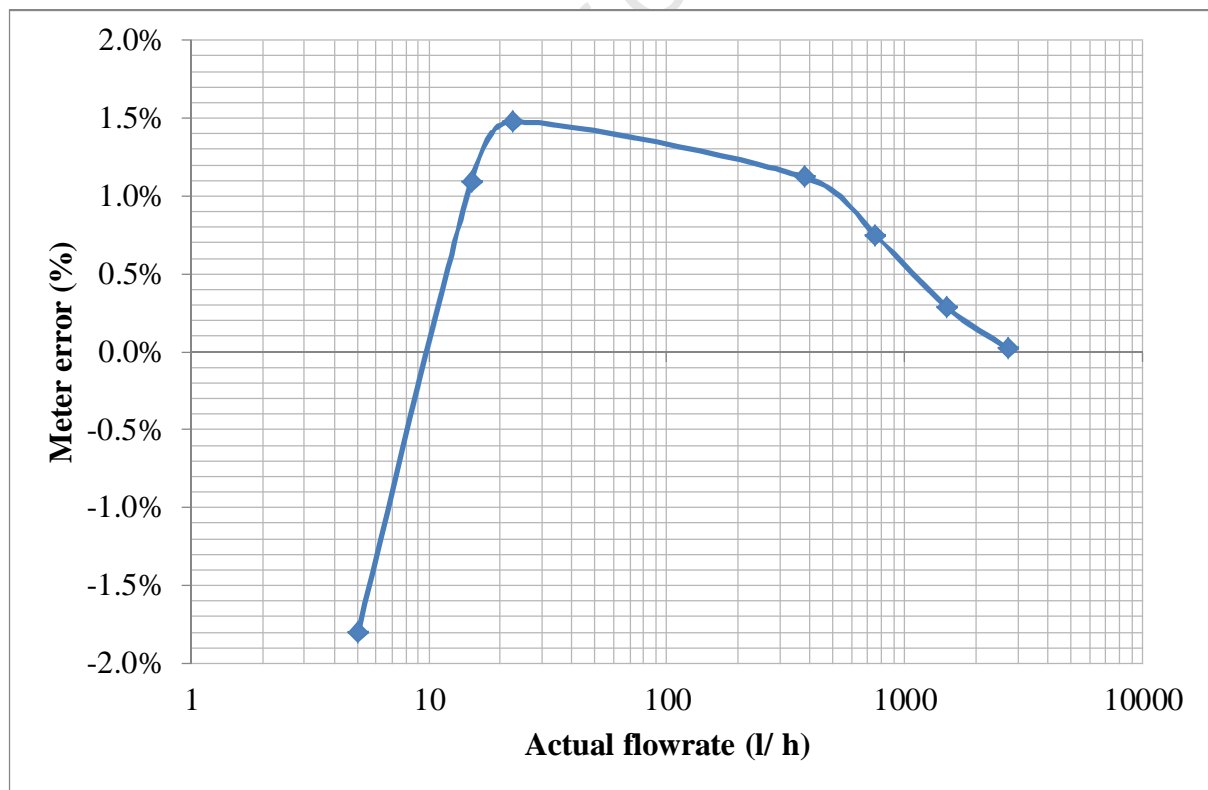


Figure 5.1: Average error curve of fifteen master meters tested in the laboratory

5.3.3 Selection of study area

A few suburbs were investigated for meter error and impact of UFRs on meter accuracy starting 12 January 2012 and ending on 08 March 2012. Table 5.2 lists the number of consumers investigated and testing periods.

Table 5.2: List of consumer meters tested with and without UFR

Master meter ID	Suburb	Testing period without UFR	Testing Period with UFR
CL1	Claremont	12/01/2012 – 12/02/2012	
CL2	Claremont		03/03/2012 – 08/03/2012
CL3	Claremont	12/01/2012 – 11/02/2012	
LD1	Lansdowne	27/01/2012 – 27/02/2012	
LD2	Lansdowne		03/03/2012 – 08/03/2012
LD3	Lansdowne	26/01/2012 – 26/02/2012	
LD4	Lansdowne	26/01/2012 – 26/02/2012	
AT1	Athlone		03/03/2012 – 08/03/2012

5.3.4 Procedure for flow logging meters and UFRs in the field

The following describes the procedure of testing consumer meters and UFRs in the field:

1. Select consumer meters
 - a. Consumer meters were selected randomly from the Swift database described in Table 3.1.
2. Notify consumer
 - a. The consumer was made aware of the study by placing a letter in their mailbox about a week before the scheduled visit.
 - b. On the day of the visit, the consumer's door bell was rung, and if home, is made aware of the scheduled test and asked for permission to access their meter for testing.
3. Testing the consumer meter
 - a. The consumer's water supply was shut-off for a few minutes so that the master meter can be installed.
 - b. The master meter with data logger inside a locked meter box was installed in-line with the consumer meter. The data logger was programmed to measure each 1 litre pulse of the meter's sensor.
 - c. The consumer's water supply was then opened and the master meter is then left installed in-line with the consumer's meter for a minimum of a week.

- d. If given permission, a UFR is installed in-line with the master meter for a minimum of a week.

5.3.5 Master meter error

To correct the consumption patterns for error by the master meter, a function of the actual flowrate in terms of the indicated flowrate needs to be found. Firstly, using the error curve in Figure 5.1, the ratio Indicated Flowrate/ Actual Flowrate (Q_i/ Q_a) is plotted against the Actual Flowrate to obtain a 3rd order polynomial in Figure 5.2.

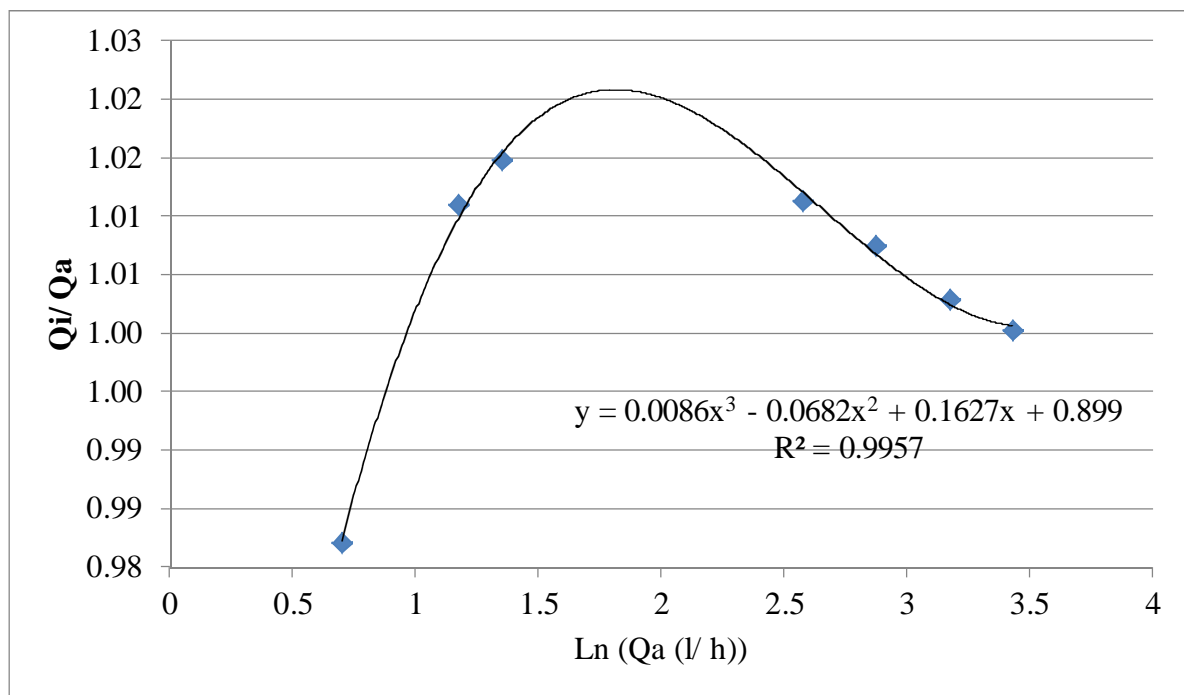


Figure 5.2: Ratio of Indicated and Actual Flowrate versus the Actual Flowrate

Using the 3rd order polynomial in Figure 5.2, a table of Indicated Flowrates and associated Actual Flowrates can be calculated. As this could not be plotted accurately with the regression formulae made available in Excel, the table was used with the aid of the VLOOKUP function to find associated actual flowrates for indicated flowrates. Any flowrates smaller than the starting indicated flowrate was assumed to be the actual starting flowrate.

The error of each master meter was calculated by summing all of the 1 litre pulse flowrates of the indicated flowrates and subtracting it from the sum of actual flowrates, then dividing the difference by the summed actual flowrates.

5.4 Results and discussion

5.4.1 Introduction

This section provides the results and analysis of the flow logging of domestic meters with and without UFRs by:

- Comparing the errors of the master meters with and without a UFR installed.
- Showing the consumption patterns with respect to fraction of time and fraction of volume.
- Comparing the consumption patterns in this study with one performed in Spain and South America.
- Comparing the consumption patterns of domestic consumers with and without UFRs installed in-line with their meter.

5.4.2 Master meter error

Observing Tables 5.3 and 5.4, there appears to be no genuine improvement in meter accuracy when installing a UFR in-line with the master meter. However, this data set is too small to make any concrete conclusions with any statistical support.

All the master meters showed very good accuracy, with meter errors in the order of less than 1 %. As a result, there was no need to adjust the consumption pattern histograms (Figure 5.3, 5.4, 5.5 and 5.6), as they are the same.

Table 5.3: Meter error of master meters logged without UFR installed

Master meter ID	Meter Error (%)
CL1	0.57
CL3	0.67
LD1	0.74
LD3	0.95
LD4	0.76
Average	0.74

Table 5.4: Meter error of master meters logged with UFR installed

Master meter ID	Meter Error (%)
CL2	0.75
LD2	0.54
AT1	0.76
Average	0.68

5.4.3 Domestic consumer consumption patterns

A total of 79.4 % of the time a flowrate of 0-12 l/h is used (Table 5.5 and Figure 5.3), which only accounts for 6.2 % of the total volume consumed (Table 5.6 and Figure 5.4). A total of 75.0 % of the volume consumed is at flowrates between 180-1500 l/h at 4.5 % of the time. See histograms of individual properties in Appendix G.

In Figure 5.5, the consumption patterns in this study are compared with that found in Spain and South America (Arregui, Cabrera, Cobacho, & Garcia-Serra, 2006 a). The consumption pattern in Spain and South America were determined by logging 34 single households during the summer. In Spain and South America, 17 % of the fraction of volume used is at 1500-3000 l/h compared to just 1 % in Cape Town.

Table 5.5: Fraction of time demand used per domestic consumer without UFR installed

Flowrate (l/h)	Fraction of time (%)					
	CL1	CL3	LD1	LD3	LD4	Mean
0-12	92.7	97.2	77.8	66.8	62.7	79.4
12-24	1.8	0.8	9.8	3.4	10.5	5.3
24-36	0.8	0.3	3.5	1.3	6.2	2.4
36-72	0.8	0.3	2.6	12.7	9.7	5.2
72-180	0.7	0.1	1.6	9.2	4.0	3.1
180-1500	3.2	1.3	4.7	6.4	7.0	4.5
1500-3000	0.0	0.0	0.0	0.1	0.0	0.0
> 3000	0.0	0.0	0.0	0.0	0.0	0.0

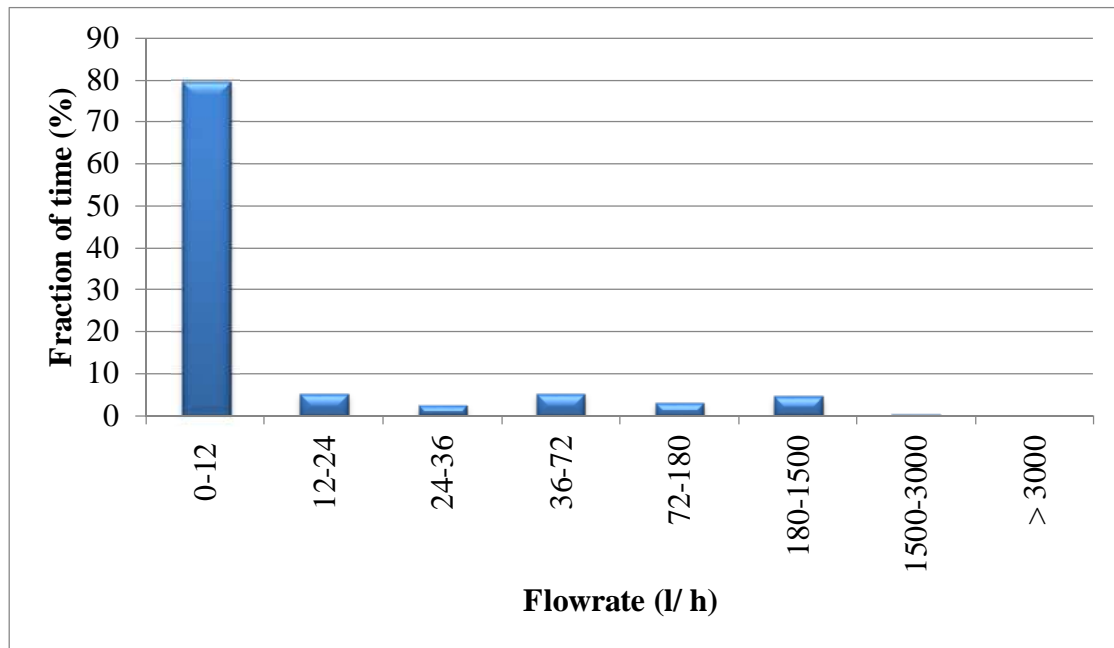


Figure 5.3: Average Fraction of time demand used of domestic consumers without UFR installed

Table 5.6: Fraction of volume used at each demand period per domestic consumer without UFR installed

Flowrate (l/h)	Fraction of volume (%)					
	CL1	CL3	LD1	LD3	LD4	Mean
0-12	4.4	6.9	12.5	3.2	4.1	6.2
12-24	1.0	1.3	4.1	1.2	3.6	2.2
24-36	0.8	0.8	2.6	0.8	3.7	1.7
36-72	1.3	1.3	3.3	13.2	9.6	5.7
72-180	2.9	1.3	4.6	23.0	8.6	8.1
180-1500	89.4	86.5	72.9	56.3	69.7	75.0
1500-3000	0.1	1.9	0.0	2.3	0.8	1.0
> 3000	0	0.0	0.0	0.0	0.0	0.0

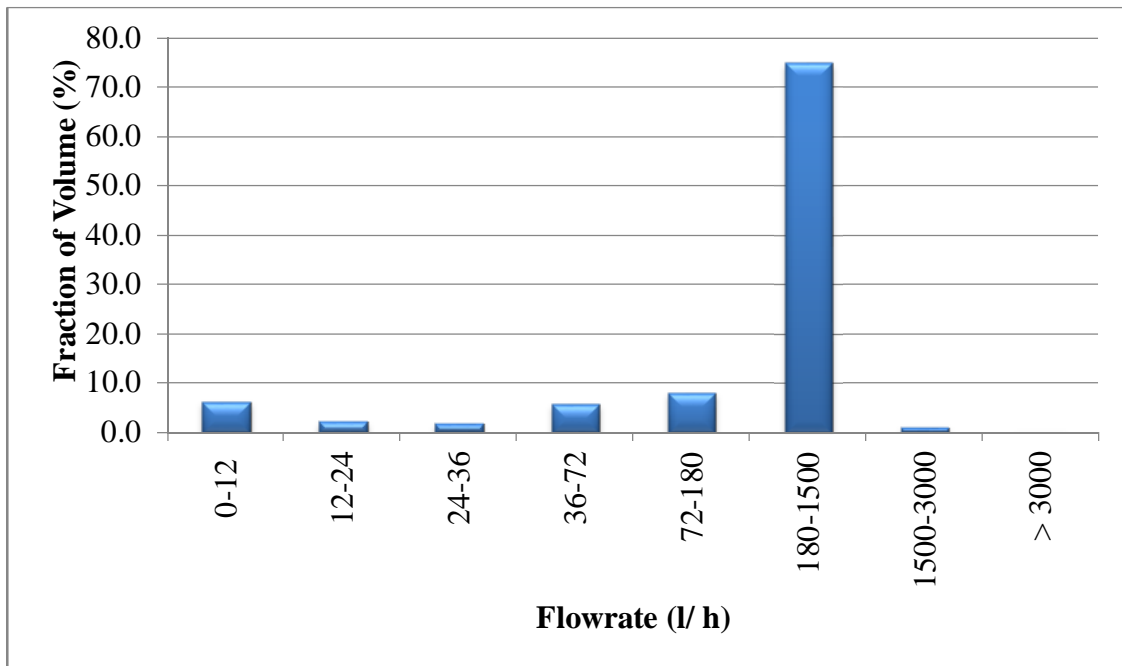


Figure 5.4: Average fraction of volume used at each demand period for domestic consumers without a UFR installed

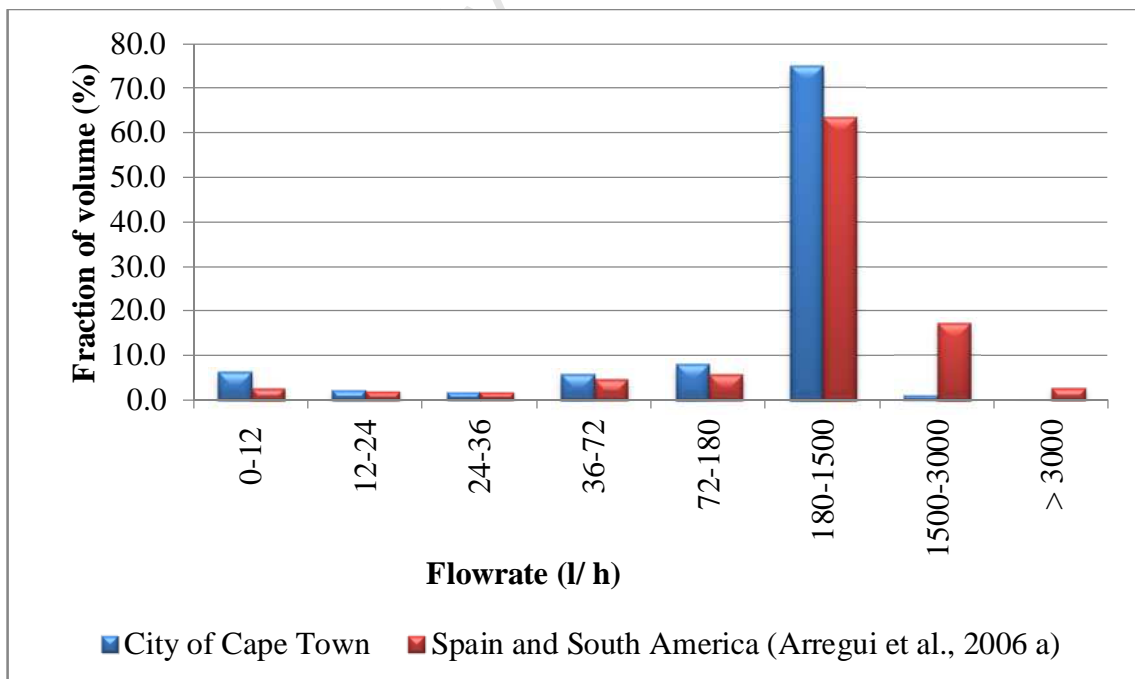


Figure 5.5: Comparison of consumption patterns in Cape Town with Spain and South America

5.4.4 Domestic consumer consumption patterns with UFR

A total of 91.4 % of the time a flowrate of 0-12 l/h is used (Table 5.7 and Figure 5.6), which accounts for 11.6 % of the volume consumed (Table 5.8 and Figure 5.7). A total of 69.5 % of the total volume consumed is used at 180-1500 l/h at 2.0 % of the time. See histograms of individual properties in Appendix H.

Comparing the results obtained from the master meter with and without a UFR installed, there appears to be no reduction in low flowrates less than 24 l/h from passing the consumer meter.

Table 5.7: Fraction of time demand used per domestic consumer with UFR installed

Flowrate (l/h)	Fraction of time (%)			
	AT1	CL2	LD2	Mean
0-12	89.5	93.0	91.8	91.4
12-24	4.5	3.2	2.3	3.3
24-36	1.2	0.7	1.5	1.1
36-72	1.2	0.8	1.6	1.2
72-180	0.7	0.7	1.3	0.9
180-1500	3.0	1.6	1.4	2.0
1500-3000	0.0	0.0	0.0	0.0
> 3000	0.0	0.0	0.0	0.0

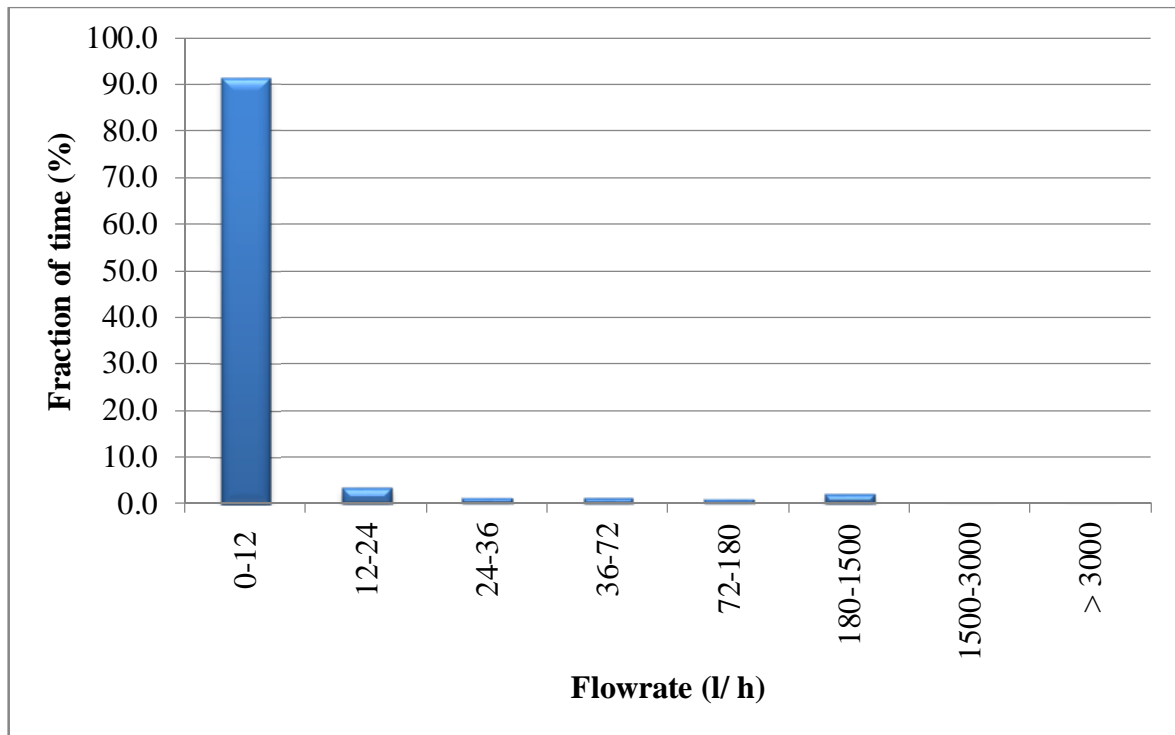


Figure 5.6: Average Fraction of time demand used of domestic consumers with UFR installed

Table 5.8: Fraction of volume used at each demand period per domestic consumer with a UFR installed

Flowrate (l/h)	Fraction of volume (%)			
	AT1	CL2	LD2	Mean
0-12	9.1	13.5	12.2	11.6
12-24	3.7	4.7	2.5	3.6
24-36	1.6	1.8	2.7	2.0
36-72	2.8	3.7	4.9	3.8
72-180	3.5	7.4	9.6	6.8
180-1500	76.0	68.8	63.8	69.5
1500-3000	3.3	0.0	4.3	2.5
> 3000	0.0	0.0	0.0	0.0

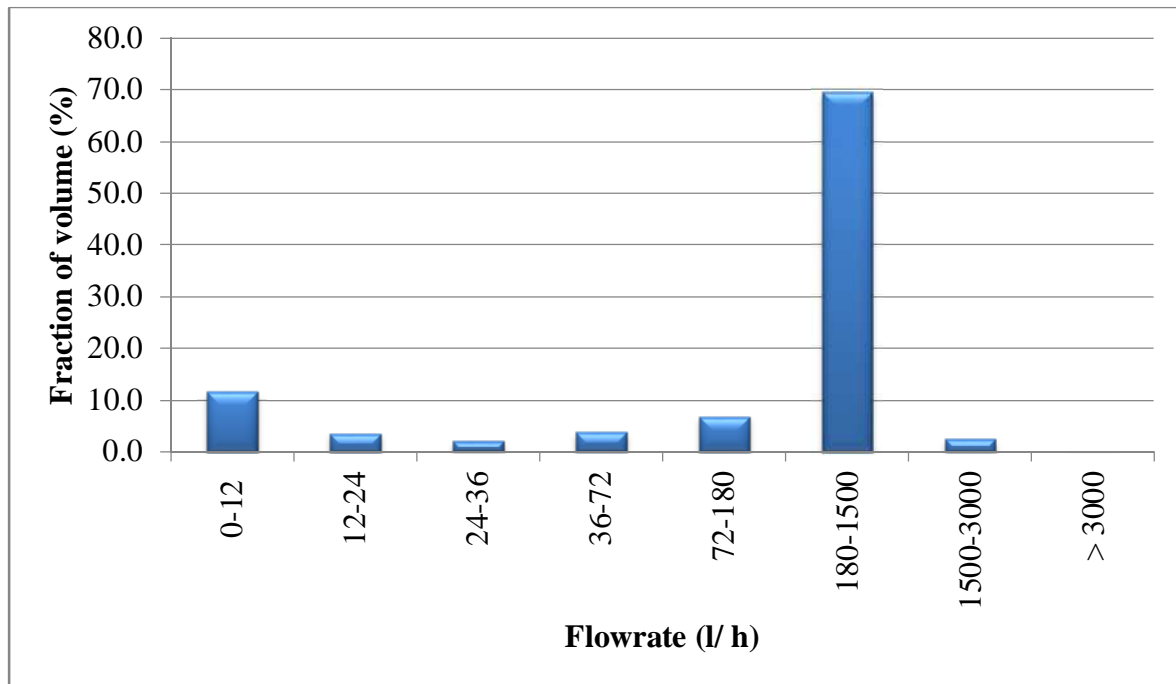


Figure 5.7: Average fraction of volume used at each demand period for domestic consumers with a UFR installed

5.4.5 Conclusion

A total of 8 properties were logged for flow using a master meter installed in-line with the consumer meter. Three of these properties had a UFR installed in-line with the master meter.

It was found that all the master meters showed very good accuracy with meter errors of less than 1 %, but there was no appreciable difference in accuracy with meter that were installed with and without a UFR. As the study only had 8 samples, there is no statistical conclusive evidence to prove that this is generally the case.

Comparing the results obtained from the master meter with and without a UFR installed, there appears to be no reduction in low flowrates less than 24 l/ h from passing the consumer meter installed with a UFR.

This study showed similar consumption patterns as that found in the Spain and South America study performed by Arregui et al. (2006 a). The exception was that 17 % of consumption volume occurred at flowrates between 1500-3000 l/ h in Spain and South America, compared to 1 % in this study.

6 Review of bulk consumer meter audits

6.1 Introduction

The non-domestic consumers in the industrial, commercial and institutional (ICI) sectors and domestic consumers usually in large flats or complexes fall under this category of bulk consumers.

Non-domestic consumers are usually associated with largest consumers in a municipal supply area. The City of Tshwane's, which is the largest metropolitan in South Africa, industrial and commercial consumers account for only 3 % of the total number of consumers in the City, yet account for 30 % of the total consumption (City of Tshwane, 2011).

The characteristic large consumption of these consumers, signify the importance of accurate water metering to mitigate apparent losses. Small errors in meter registration, meter reading and data acquisition can constitute to a large impact on the apparent losses for a municipal supply area. The importance of ensuring that meters are replaced at regular intervals, motivated by an economic analysis, and is read accurately and stored in the financial database without error is vital to ensure that apparent losses are economically minimized. The extent of unauthorized connections needs to be minimized as effectively as possible, especially for non-domestic users which use large quantities of water.

The major impact that bulk consumers can have on apparent losses, means that any good programme to reduce apparent losses should begin with these consumers to acquire the quickest return for the least amount of effort. This has necessitated the implementation of a number of meter audits by municipalities around the country to minimize apparent losses and increase revenue flows.

The chapter will review reports written for municipalities and conference papers on meter audits of bulk meters. The following list the objectives of this:

- To determine the condition and accuracy of bulk meters in the field
- To determine the extent of unauthorized consumption and meter reading error
- To get an indication of the contribution of bulk consumers to apparent losses

A meter audit involves the collecting and recording of meter and consumer information in the field to identify metering problems and comparing information in the field to existing information in the billing database of the municipality. A meter audit can provide a host of valuable information that can help direct an apparent loss programme to critical areas where small improvements can result in substantial returns. The following is typical information that is targeted in an audit:

- Un-metered or unauthorized connections
- Meters installed with incorrect orientation
- Meter location
- Meters damaged externally and illegible
- Erratic meters i.e. the register of the dial is not moving smoothly
- Stopped meters
- Old meters
- Leaks at or near meters
- Incorrectly sized meters
- Connections with incorrect meter type
- Meter reading to compare to financial database, which indicates meter reading and acquisition error
- Consumer and account details to compare to financial database
- Accuracy of meter to register consumption

As part of water loss projects undertaken around the country, municipalities have targeted bulk consumers to have the greatest impact on reducing apparent losses. The following municipalities have been researched:

- City of Tshwane
- Ekurhuleni Metropolitan Municipality
- Emfuleni Local Municipality
- eThekwin Municipality
- Pietermaritzburg-Msunduzi Transitional Local Council
- City of Cape Town

6.2 Reports and conference papers reviewed

All the literature on bulk meter audits performed around the country was collected from unpublished reports made available by municipalities and conference papers. Table 6.1 lists this literature on bulk meter audits collected.

Table 6.1: List of unpublished reports and conference papers on bulk meter audits performed on municipalities reviewed

Municipality	Contractor/ Consultant	Title	Unpublished report/ Conference paper	Reference
City of Tshwane	WRP Consulting Engineers	Tshwane Water Loss Project, Task: Meter Audit of Industrial Consumers	Unpublished report	(City of Tshwane, 2011)
Ekurhuleni Metropolitan Municipality	WRP Consulting Engineers	The Benefits of non-Domestic Consumer Meter Audits and Retrofitting- The Ekurhuleni Case Study	Conference paper	(Wegelin et al., 2009 a)
Emfuleni Municipality	WRP Consulting Engineers	The Emfuleni Water Loss Project - A Major Challenge	Conference paper	(Wegelin et al., 2009 b)
eThekweni Municipality	JOAT sales and service	Detailed meter audit and sizing analysis of top 200 consumers in the eThekweni municipal area	Unpublished report	(eThekweni Water Services, 2006)
Pietermaritzburg- Msunduzi Transitional Local Council	BKS	Water Leakage Management Project, Top 40 Consumer Analysis Report	Unpublished report	(PMLTC, 2001)
City of Cape Town	WRP Consulting Engineers	Pilot Meter Audit in Parow Industrial, City of Cape Town	Unpublished report	(City of Cape Town, 2009)
City of Cape Town	Sohlala Civil Projects	Parow Industrial Area Meter Audit	Unpublished report	(City of Cape Town, 2010)

6.3 City of Tshwane

As part of the Tshwane Water Loss Project, large consumer meter audits of industrial consumers were undertaken between 2006 and 2009 (City of Tshwane, 2011). The audit covered 2 497 consumers in 15 industrial and commercial areas, which included collecting both consumer and meter information amongst other tasks such as:

- Water supply shut-downs to identify un-metered connections. These tests are done by closing all metered connections on the consumer's property and then opening the end-use points to check if there is any flow. If there is flow, then the test is positive for an un-metered connection being present and vice versa.
- An economic impact of the audit for each area. Meters that were of poor condition were replaced and un-metered connections were metered. As a result, the economic impact was deduced by comparing monthly consumption data before and after the meter replacement period.

6.4 Ekurhuleni Metropolitan Municipality

A pilot Automatic Meter Reading (AMR) project was ensued in the Benoni South area, to determine the impact proper metering and billing would have on revenue flows from industrial consumers, which account for a large portion of the total water consumption in the municipal supply area (Wegelin et al., 2009 a).

A water meter audit of the 176 selected small and large industrial consumers in the project was performed before the commencement of the AMR project.

The meter audit included collecting consumer information, meter information, identifying un-metered connections through water supply shut-downs similar to that explained in the Tshwane case study and an economic impact assessment was done after the installation of the AMR system. Consumer meters that were of poor condition were replaced and un-metered connections were installed with a meter. Only the top 10 largest industrial consumers of the 176 were installed with the AMR system. The AMR system was installed in January 2008.

6.5 Emfuleni Local Municipality

As part of the Emfuleni water loss project, the meters of non-domestic consumers were audited in an effort to increase revenue flows to the municipality (Wegelin et al., 2009 b). A total of 350 meters were audited in the Tshepiso, Sharpeville, Bophelong, Boipatong, Sebokeng and Evaton areas. The primary focus of the audit was placed on schools, clinics, formal businesses and governmental buildings. Meter and consumer information were collected from the field and un-metered connections were located, however no economic impact after the audit was reported.

6.6 eThekweni Municipality

As part of eThekweni Municipality's water loss management programme, a water meter audit of the top 200 consumers was undertaken. The meter audit in this study is similar yet different to the others in that the municipality logged the flowrates for one week before and after recommended meters from the audit were replaced. The accuracy of the meters was then assessed by looking at the consumption from the week before and after the installed meter was replaced.

It was noted in the report that as the meters are monitored over a longer period of time, the results of the impact of the replacements will become more reliable. The accuracy of the logged data was confirmed with the billing database and all logged data that didn't conform within a reasonable range was removed from the data set according to the EWS report (eThekweni Water Services, 2006).

The data logging exercise also allowed for an accurate sizing assessment of the meters.

6.7 Pietermaritzburg-Msunduzi Transitional Local Council

The Pietermaritzburg Water Leakage Management Project involved auditing the meters of the top 40 consumers in the Pietermaritzburg-Msunduzi Transitional Local Council (PMTLC) (PMLTC, 2001). The meter audit started in March 2000 and ended in November that year.

The meter audit included collecting information in the field and logging the meters for about a period of two days to check the sizing and performance of each meter.

6.8 City of Cape Town

The City of Cape Town initiated a pilot meter audit in a section of the Parow Industrial area. The pilot only audited 40 of the total 280 consumers in the area, to determine if it was economically viable to audit the rest of the consumers (City of Cape Town, 2009). Water supply shut-downs were performed on only some of the consumer properties. The result of the pilot was that the whole area should be audited and that water supply shut-downs should be done to find un-metered connections.

The results of the meter audit of 122 of the remaining consumers to be audited were reported on the 15 December 2011 (City of Cape Town, 2010).

6.9 Integrated results and discussion of case studies

6.9.1 Introduction

This section integrates the results from all the case studies to meet the objective of this research by:

- Comparing the condition and accuracy data of each case study where possible.
- Comparing unauthorized and meter reading error data of each case study where possible.
- Comparing the extent of apparent losses from bulk water meters between each applicable case study from the actions taken from recommendation of the meter audit.

6.9.2 Meter condition and accuracy

The data regarding meter condition and age assessments from the different studies are integrated in Table 6.2, with the following main findings:

- There are many bulk meters in the field that are very old and need to be replaced.
- There are a number of meters in the field that have stopped working and not registering any consumption.
- A number of meters are incorrectly sized.
- There are a number of meters with illegible dials.

Table 6.2: Comparison of results from meter audit case studies regarding meter condition

Municipality	Audited connections	Age of meters	Condition of meters
City of Tshwane	2497	Not stated	Illegible, broken, stolen or erratic: - Sub-meter of combination meter (3.6 %) - Main meter of combination meter (6.2%) Connections with leaks at meter (1.6%)
Ekurhuleni Metropolitan Municipality	207	A significant number > 15 yrs	Illegible or stopped (23.7%) A number of leaking meters were found
Emfuleni Local Municipality	350	Not stated	Stopped (14%)
eThekwini Municipality	200	Unknown (7.5%) 0-2 yrs (13%) 3-5yrs (76%) 6-10 yrs (3.5%)	Incorrect size (2%) Un-loggable (12%) Damaged (0.5%)
Pietermaritzburg-Msunduzi Transitional Local Council	40	0-5 yrs (5%) 5-10 yrs (60%) > 15 yrs (35%)	Un-loggable (52.5%) Damaged (5%) Most meters appeared to be over-sized Some connections were installed with the incorrect meter type
City of Cape Town (Pilot audit)	47	> 20 yrs (48.9%), with some over 30 yrs	Stopped (2.1%)
City of Cape Town (Full Audit – in progress)	122	Not stated	Stopped (4.9%) Illegible (2.5%)

The accuracy of the top 200 bulk consumers in the eThekwini Municipal were investigated by comparing the logged flowrates recorded a week before the installed meter was replaced with the week after when the new meter was installed. The analysis could only be performed on 109 of the 138 meters that were replaced from recommendations made in the audit, as the remaining 29 replaced meters were un-loggable. All the meters that were logged were of the Woltmann type.

Table 6.3 presents the data collected from the meter accuracy assessments conducted by the eThekwini municipality and the meter error is calculated using Equation 4.1 in Chapter 4.

Table 6.3: Meter error versus age according to meter size in the eThekweni Municipality

(Scruton, 2011)

Diameter (mm)	Age (yrs)	Before replacement (m ³ / day)	After replacement (m ³ / day)	Meter error (%)	No. of meters	Apparent loss/ connection (m ³ / month)
50	1	626.64	626.40	0.04	1	-7.2
50	3	3373.68	3960.19	-14.8	25	703.8
50	4	2957.28	3643.68	-18.8	23	895.3
50	6	108.24	36.48	196.7	1	-2152.8
50	None	167.28	212.64	-21.3	2	680.4
50	Overall	7233.12	8479.392	-14.7	52	719.0
80	2	65.52	65.52	0	1	0.0
80	3	1704.72	1567.92	8.7	4	-1026.0
80	4	3781.68	3263.76	15.9	15	-1035.8
80	5	1672.56	1616.64	3.5	3	-559.2
80	Overall	7224.48	6513.84	10.9	23	-926.9
100	3	1264.56	1167.84	8.3	3	-967.2
100	4	4397.45	4875.84	-9.8	5	2870.3
100	5	325.92	365.04	-10.7	1	1173.6
100	Overall	5987.93	6408.72	-6.6	9	1402.6
150	2	562.56	418.56	34.4	1	-4320.0
150	3	140.64	110.88	26.8	2	-446.4
150	4	3313.44	3280.80	1.0	2	-489.6
150	5	5298.96	5451.36	-2.8	3	1524.0
150	7	1226.64	1200.72	2.2	1	-777.6
150	Overall	10542.24	10462.32	0.8	9	-266.4
200	5	2264.64	6201.84	-63.5	1	118116.0
200	Overall	2264.64	6201.84	-63.5	1	118116.0
No diameter	No age	4022.40	4099.44	-1.9	15	154.1
No diameter	Overall	4022.40	4099.44	-1.9	15	154.1
Overall		33252.41	38066.11	-12.6	109	1324.9
Overall (excl. 200mm)		30987.77	31864.27	-2.8	108	243.5

Due to the small sample captured in Table 6.3, it is not possible to make any concrete conclusions regarding the 'Error versus Age' relationship for meters with different diameters.

However, the 3 and 4 year old 50 mm diameter meters have 25 and 23 samples respectively. It was found that the 3 and 4 year old 50 mm diameter meters have an under-registration of 14.8 % and 18.8 % respectively with an increase in error of -4 % from the 3rd to 4th year. This reaffirms the general rule that these meters need to be replaced frequently (according to an economic analysis) and require routine maintenance to ensure quality performance and extend the meter's life.

By further inspection of the data set, it was found that 51 of the 109 meter's were in fact over-registering, which reduces the impact of under-registration and subsequent apparent losses. However, as the logging of consumption only occurred for one week each for the old and new meter, this could just be indicating that approximately half the consumers consumed less water the week after replacement and the other half consumed more.

The meter error of all the 109 meters was -12.6 %, but when disregarding the 200 mm meter the meter error dropped to -2.8 %. This illustrates the importance of such audits, which finds meters that are grossly under-registering large volumes of water being consumed.

6.9.3 Unauthorized connections and meter reading error

The occurrence of un-metered connections and meter reading error assessments of each case study is presented in Table 6.4. The following issues were identified in the field:

- A number of properties have un-metered connections used for daily operations.
- A number of meters are billed according to historical billed consumption data.
- A number of meters are buried or located inside the consumer's property and therefore difficult to access.
- Some consumers do not receive a bill.
- Some consumers do not have an account number.
- A number of meters could not be located in the field.
- A number of discrepancies between meter readings found in the field and the readings found in the billing database.

Table 6.4: Comparison between case studies regarding unauthorized connections and meter reading error

Municipality	Audited connections	Un-metered connections (%)	Meter reading error
City of Tshwane	2497	5.1	Not stated
Ekurhuleni Metropolitan Municipality	207	12.1	A significant number of consumers are billed according to historical billed consumption. Most meters were located below ground and buried making access difficult for meter reading.
Emfuleni Local Municipality	350	40	Most consumers reported that they do not receive a bill. Consumers that do not have account numbers (62.9 %)
eThekweni Municipality	200	0	Not stated
Pietermaritzburg-Msunduzi Transitional Local Council	40	5	Number of the meters could not be located (5 %) Number of inconsistencies between meter reading and billing database (5 %)
City of Cape Town (Pilot audit)	47	6.4	Meters buried (17.02 %) Number of meter readings on site 1000kl more than database reading (23.4 %) Number of meter readings in database more than on-site (17.02 %) Number of meters located inside the property
City of Cape Town (Full audit – in progress)	122	Not stated	Number of inconsistencies between meter reading and billing database (5.7 %)

6.9.4 Contribution to apparent losses

The City of Tshwane did an economic analysis of the impact the water meter audit had on its revenue collected. The audit involved the replacement of meters that were not working, old and illegible. Meters were also installed on unmetered connections. The analysis gives an indication of apparent losses caused by such metering inefficiencies (meter error, unauthorized consumption and meter reading errors). This analysis has only been performed on 4 out of the 15 audited areas to date and the results presented in Table 6.5. Table 6.6 shows the monthly apparent loss volume per connection for each industrial area, by dividing the increase in consumption by the number of connections investigated.

Table 6.5: Apparent loss after meter audit in the City of Tshwane (City of Tshwane, 2011)

Industrial area	Connections investigated/ Total connections	Period before replacement	Period after replacement	Before replacement (m ³ /month)	After replacement (m ³ /month)	Apparent loss (%)
Rosslyn North	73/ 138	Mar – Aug 06	Jan – Jun 07	18 900	23 900	20.9
Rosslyn South	78/ 236	Feb – May 07	Sep – Dec 07	31 000	34 000	8.8
Pretoria Industrial	56/ 144	Aug 06 - Mar 07	Jul 07 - Feb 08	22 600	29 900	24.4
Waltloo/ Silvertondale	175/ 550	Aug 07 - May 08	Oct – Dec 08	8 441	12 055	30.0
Overall	382/1068			80941	99855	18.9

Table 6.6: Apparent loss per stand after meter audit in the City of Tshwane (City of Tshwane, 2011)

Industrial area	Apparent loss/ connection (m ³ /month)
Rosslyn North	68
Rosslyn South	38
Pretoria Industrial	130
Waltloo/ Silvertondale	21
Overall	50

At the completion of the bulk meter audit in Ekurhuleni (Wegelin et al., 2009 a), the top 10 consumers that were installed with the AMR system had an apparent loss of 17.8 % which coincides with the 18.9% found in Tshwane.

6.10 Conclusion

It is quite clear from the meter audits researched that asset management regarding bulk consumer meters is not optimal and there is great scope for the implementation of interventions to reduce these losses. There are a large number of bulk consumers with:

- unauthorized connections
- meters that are in poor condition with some not even working.
- meters not being read as they are either buried or located inside the consumers property and difficult to access. In some cases the meter could not even be found.

Based on the increase in revenue investigations after the meter audits performed in Tshwane and Ekurhuleni, it seems that apparent losses of bulk consumers are potentially around 18 %. This gives huge incentive that meter audits should be performed in other municipalities and illustrates the importance of good metering practices.

7 Conclusion

7.1 Introduction

This study investigated the apparent water loss situation focusing on meter inaccuracy in selected areas of South Africa in a number of different ways by:

- Performing an international literature review on the topic of apparent losses due to meter inaccuracy.
- Interrogating new domestic consumer meters for on-site leakage.
- Using a consumer meter database to estimate meter error for different meter ages and registered volumes.
- Testing consumer meters in the field with a logged in-line master meter and the impact of Unmeasured Flow Reducers on meter accuracy.
- Reviewing reports of bulk consumer meter audits.

7.2 Main findings of each study

The following are the main findings from the different studies performed:

1. On-site leakage filed study of domestic consumers
 - a. It was found in this study that only 16 % of domestic properties in the City of Cape Town have a measurable on-site leakage compared to 28 % in Bloemfontein and 67 % found in the City of Johannesburg.
 - b. An under-registration of 13.1 % of on-site leakages was estimated in the City of Cape Town for meters younger than 3 years. However, for older meters this percentage is expected to be much greater as the error curve deteriorates over time and usage. In Bloemfontein an under-registration of 2.7 % of meters younger than 3 years old were found, however this was due to a large proportion of the leaks having flowrates near or greater than the transitional flowrate.
2. Meter database analysis to estimate meter error
 - a. The meter error curves for both the age and registered volume groups, showed a good linear fit. The deterioration of meter error was 0.36 %-points per year and 0.9 %-points per 1000 kl registered for age and registered volume respectively.
3. Flow logging of domestic consumer meters and UFRs

- a. It was found that all the master meters showed very good accuracy with meter errors of less than 1 %, but there was no appreciable difference in accuracy with meter that were installed with and without a UFR. As the study only had 8 samples, there is no statistical conclusive evidence to prove that this is generally the case.
 - b. Comparing the results obtained from the master meter with and without a UFR installed, there appears to be no reduction in low flowrates less than 24 l/h from passing the consumer meter installed with a UFR.
 - c. This study showed similar consumption patterns as that found in the Spain and South America study performed by Arregui et al. (2006 a). The exception was that 17 % of consumption volume occurred at flowrates between 1500-3000 l/h in Spain and South America, compared to 1 % in this study.
4. Review of bulk consumer meter audits
- a. Based on the increase in revenue investigations after the meter audits performed in Tshwane and Ekurhuleni, it seems that apparent losses of bulk consumers are potentially around 18 %. This gives huge incentive that meter audits should be performed in other municipalities and illustrates the importance of good metering practices.

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University of Cape Town

Appendix A: On-site leakage meter error curves

Note:

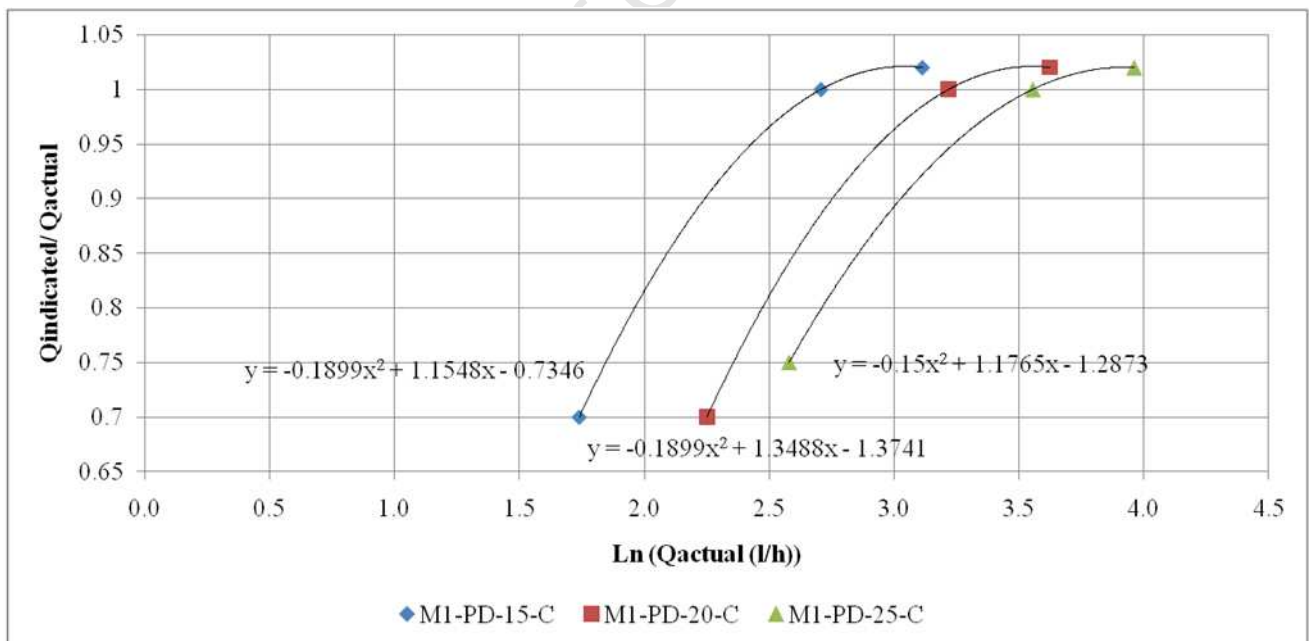
M – Manufacturer

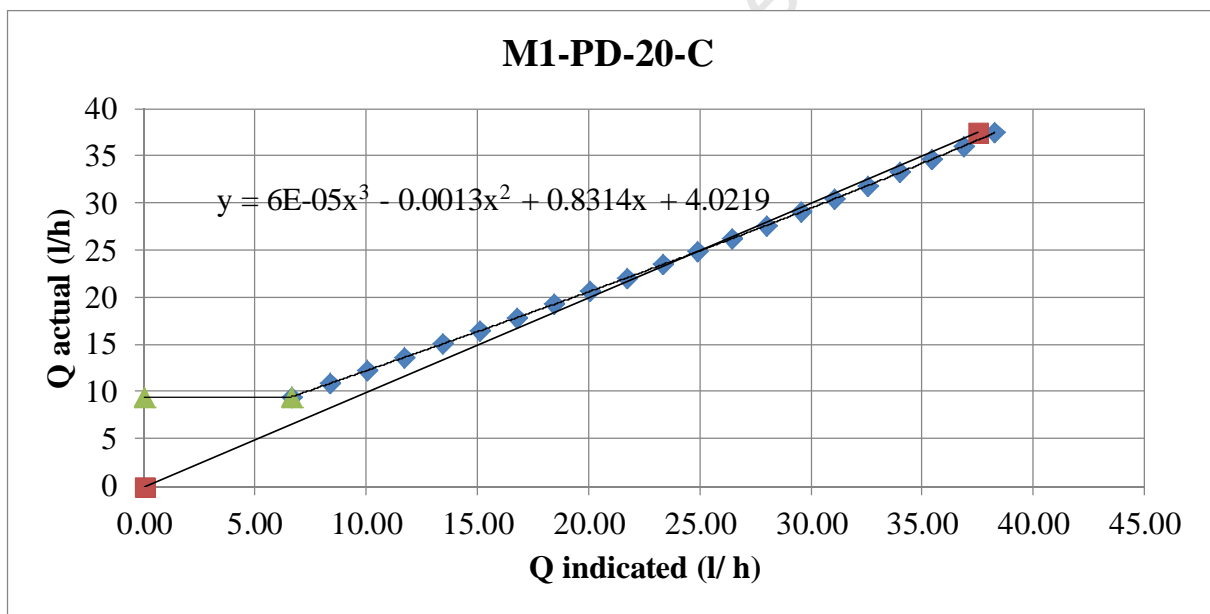
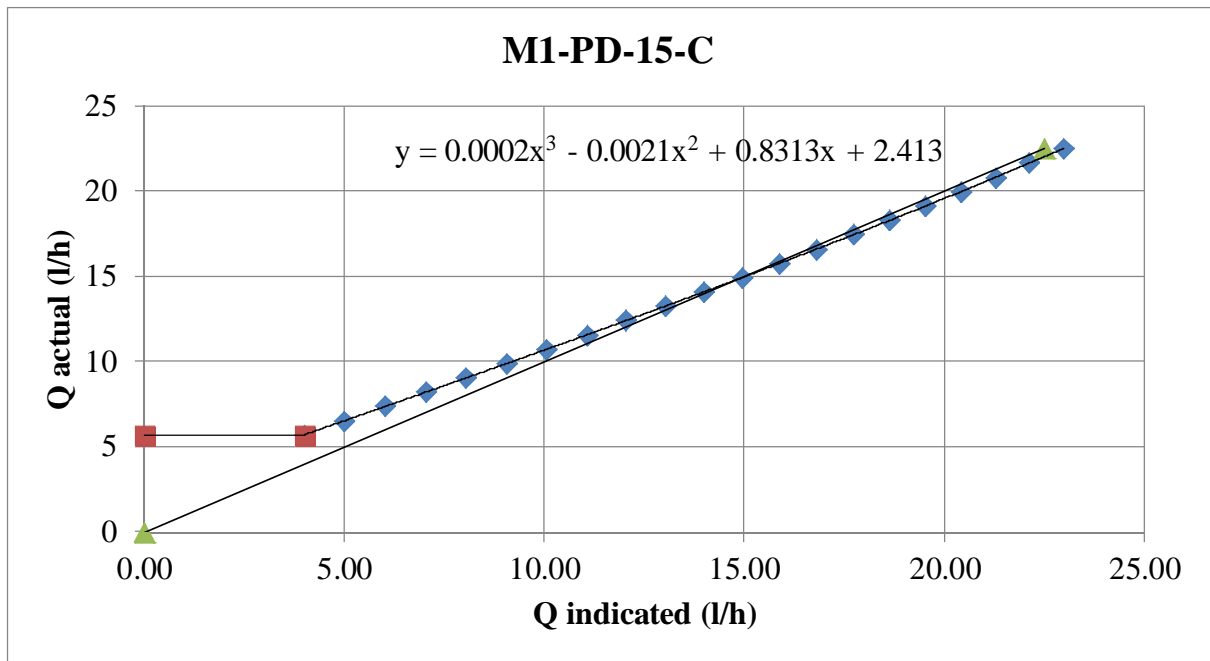
PD - Positive displacement meter

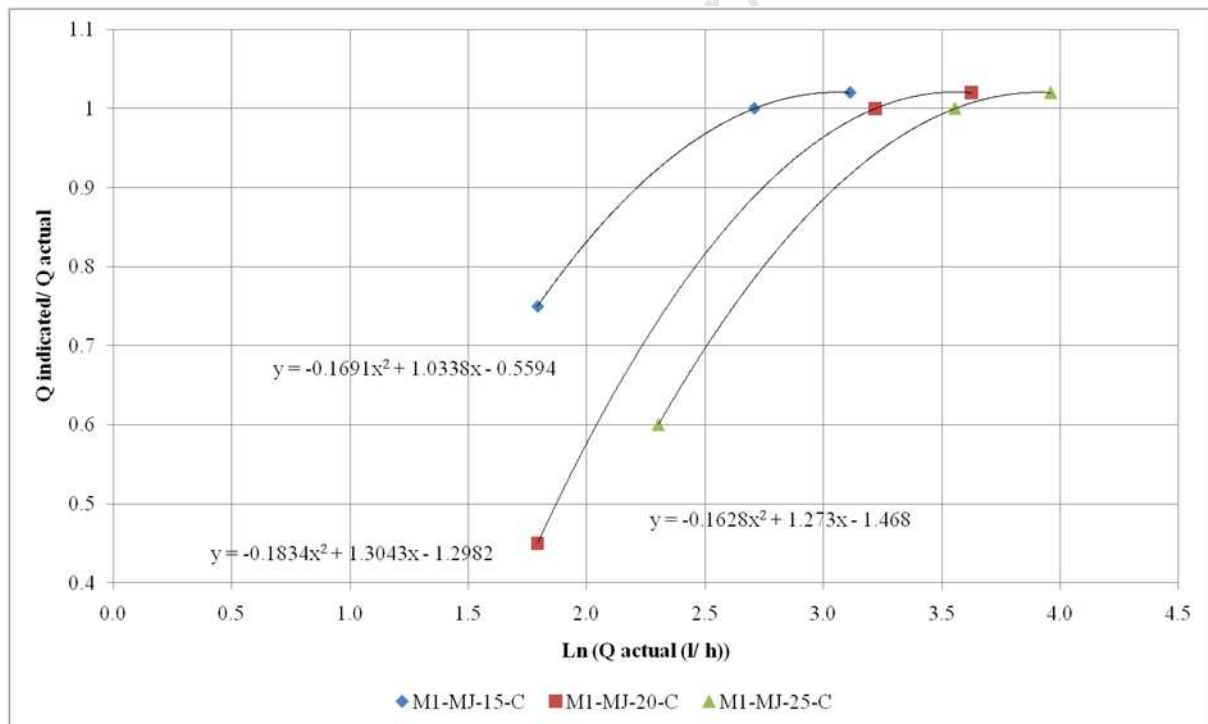
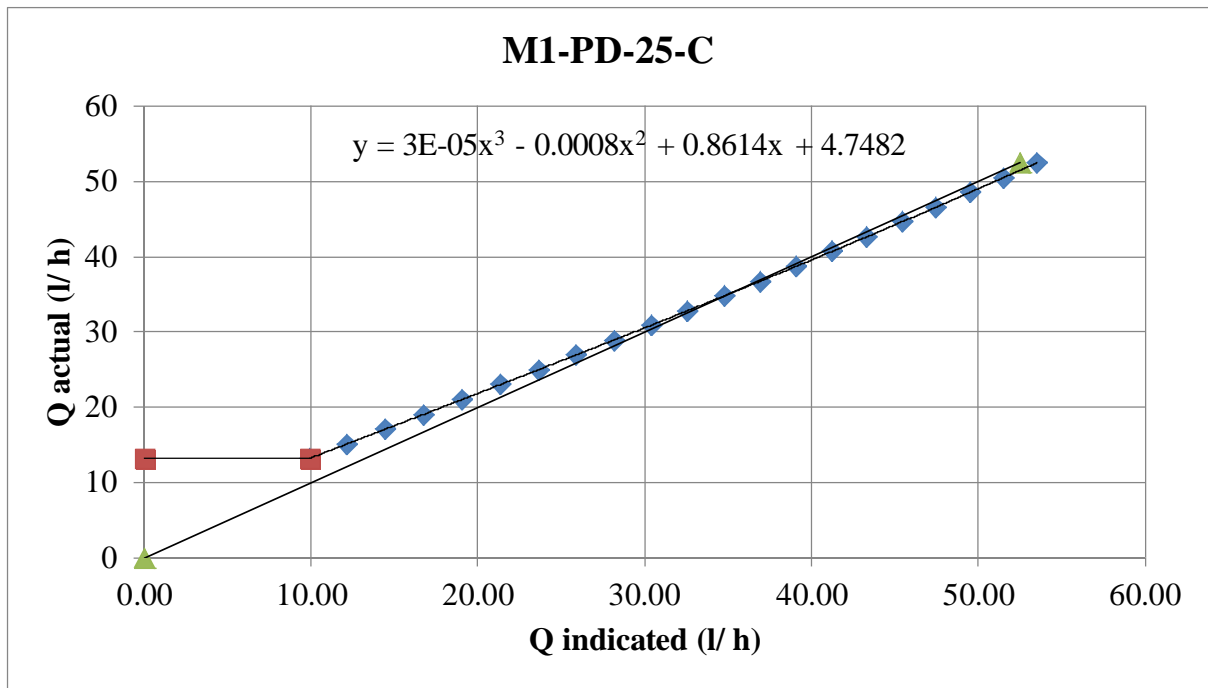
MJ – Multi-jet

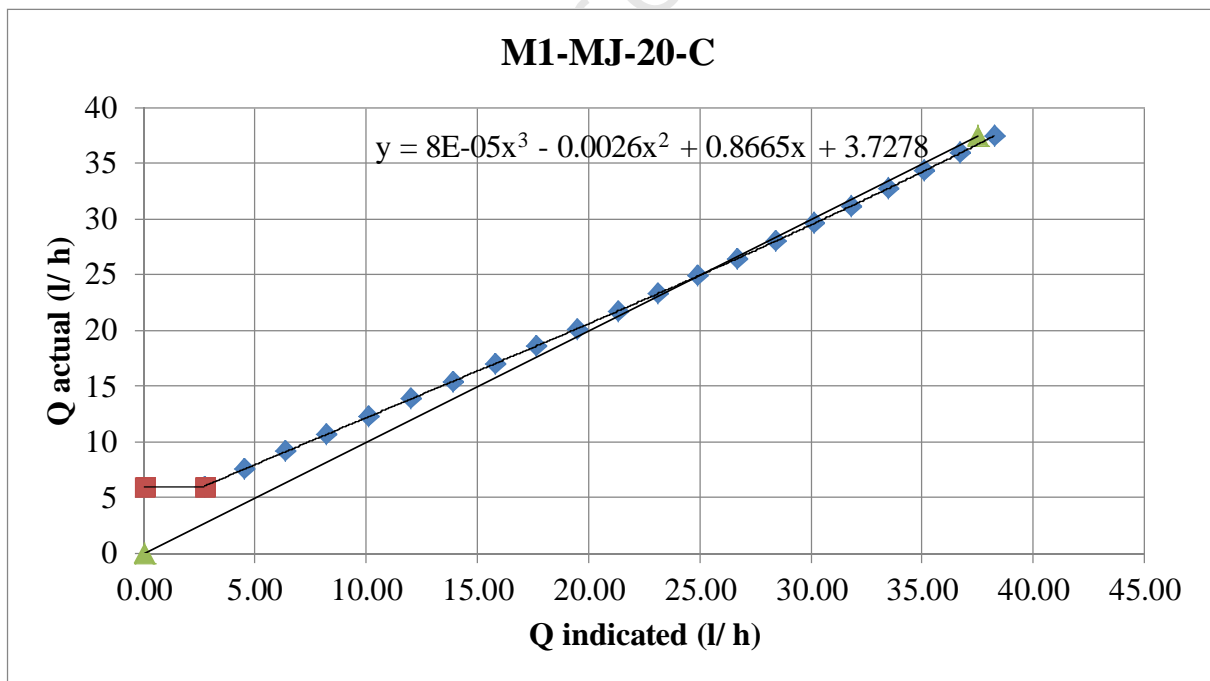
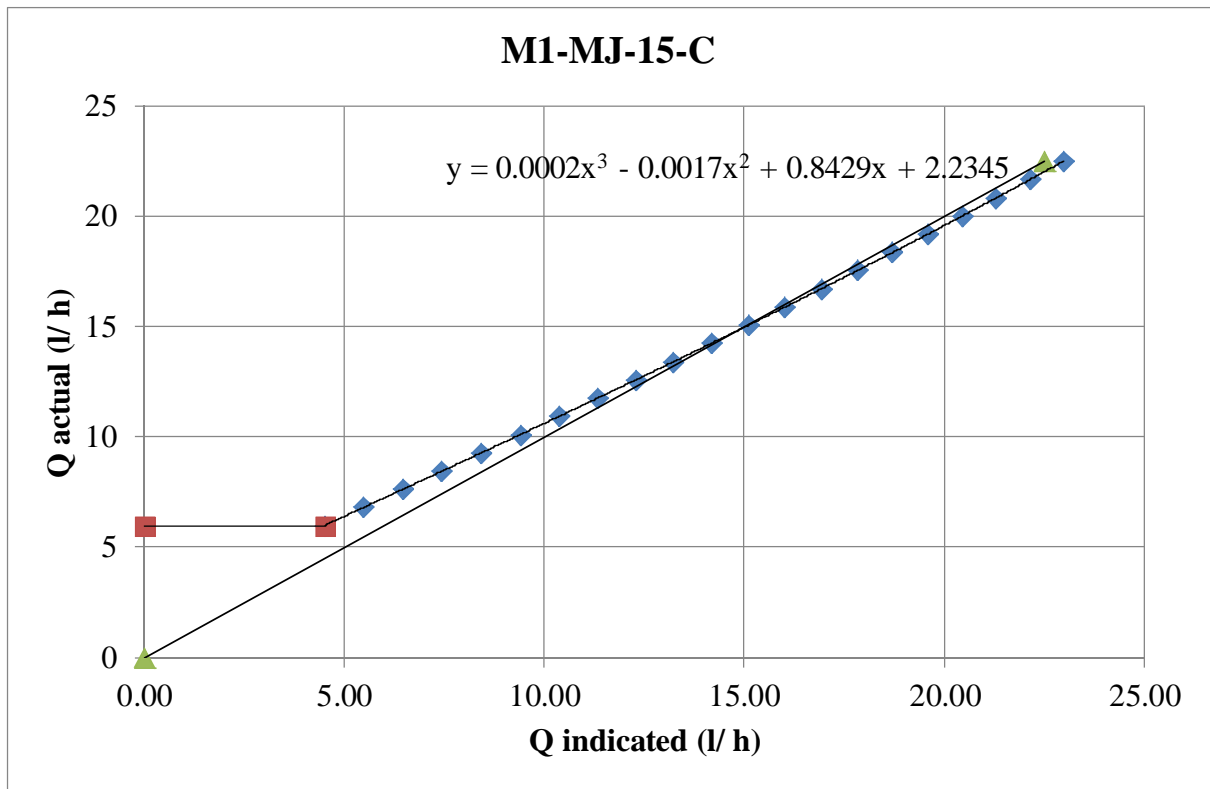
Number – meter size in mm

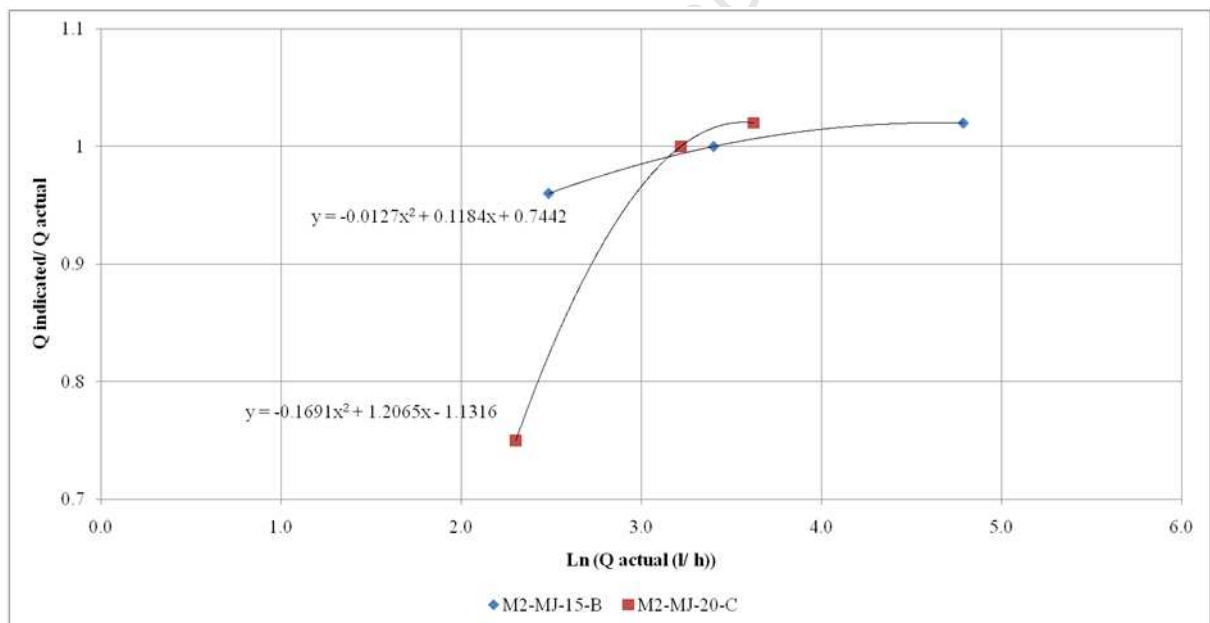
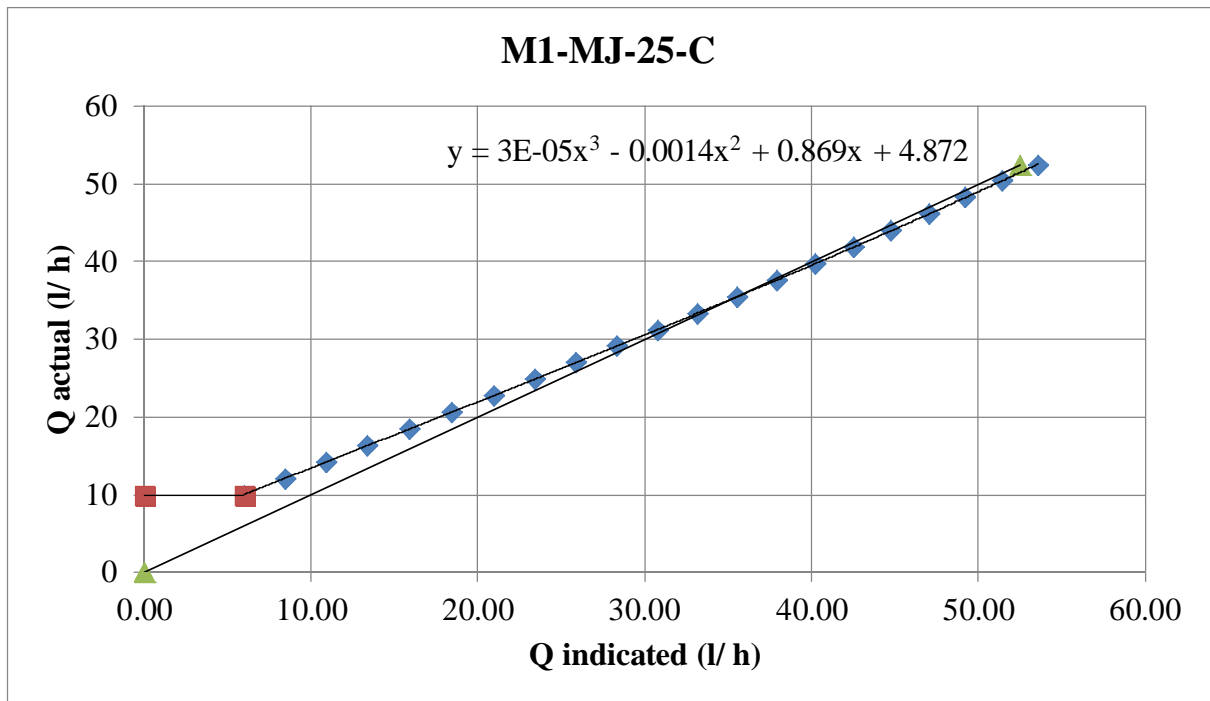
Letter – Class

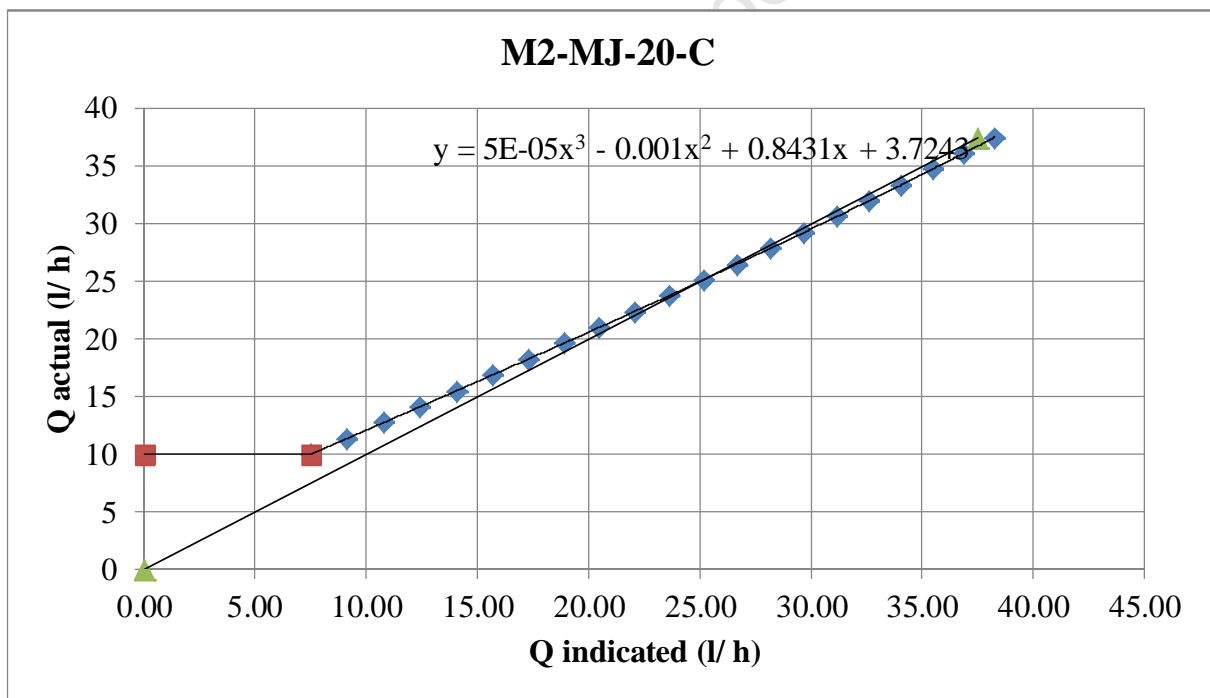
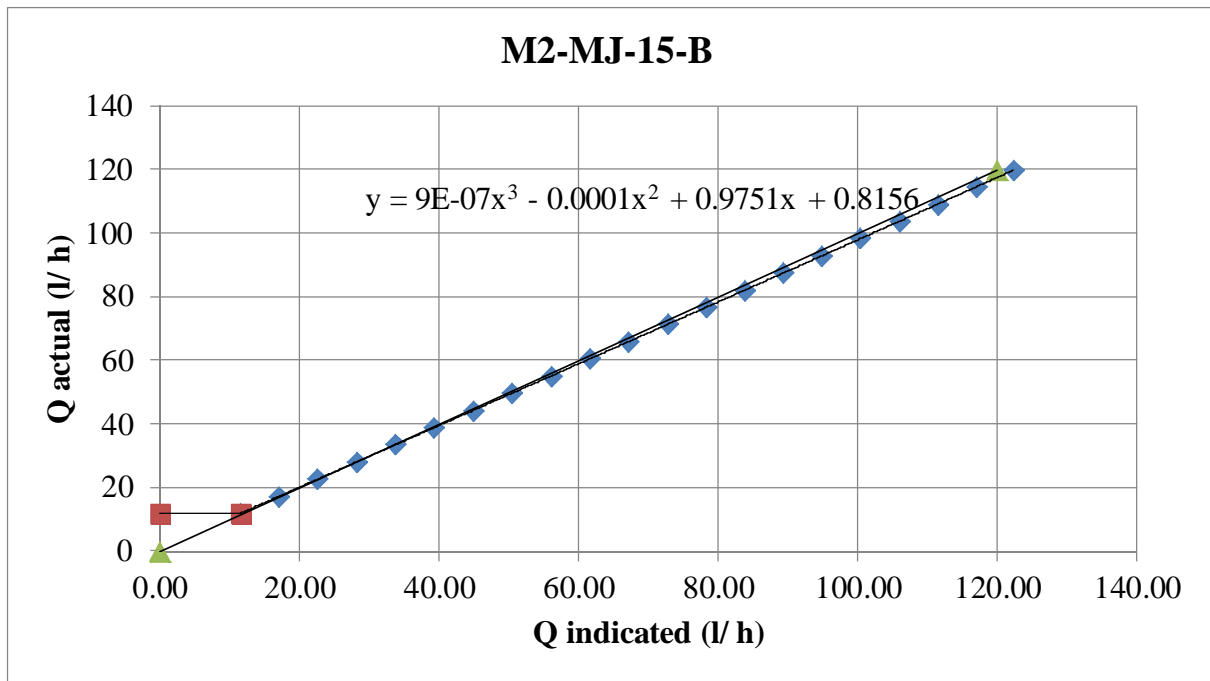


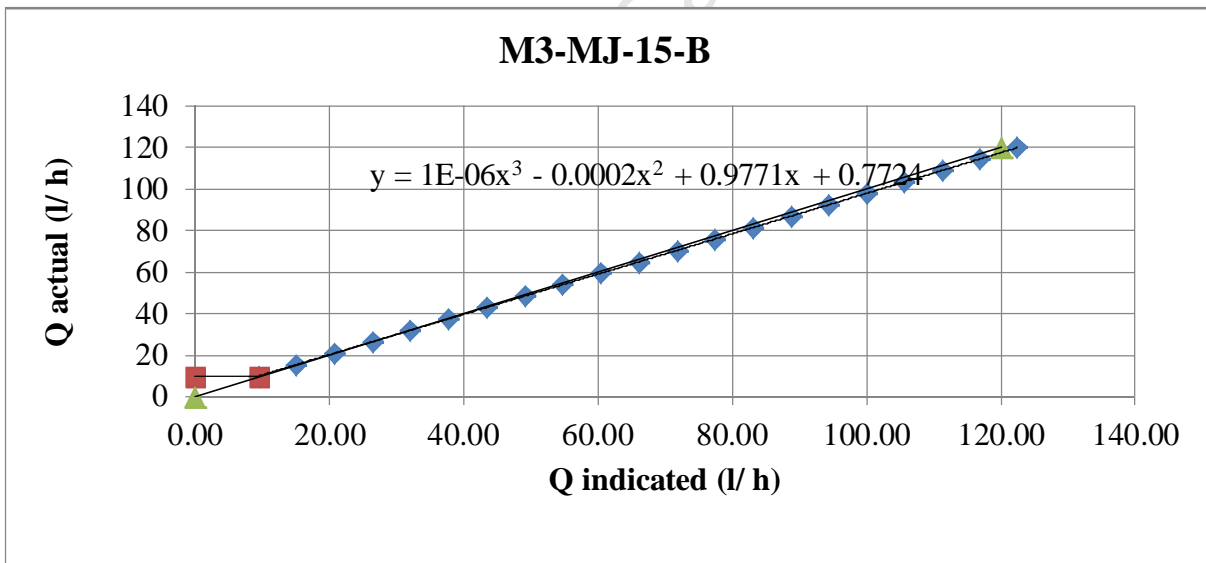
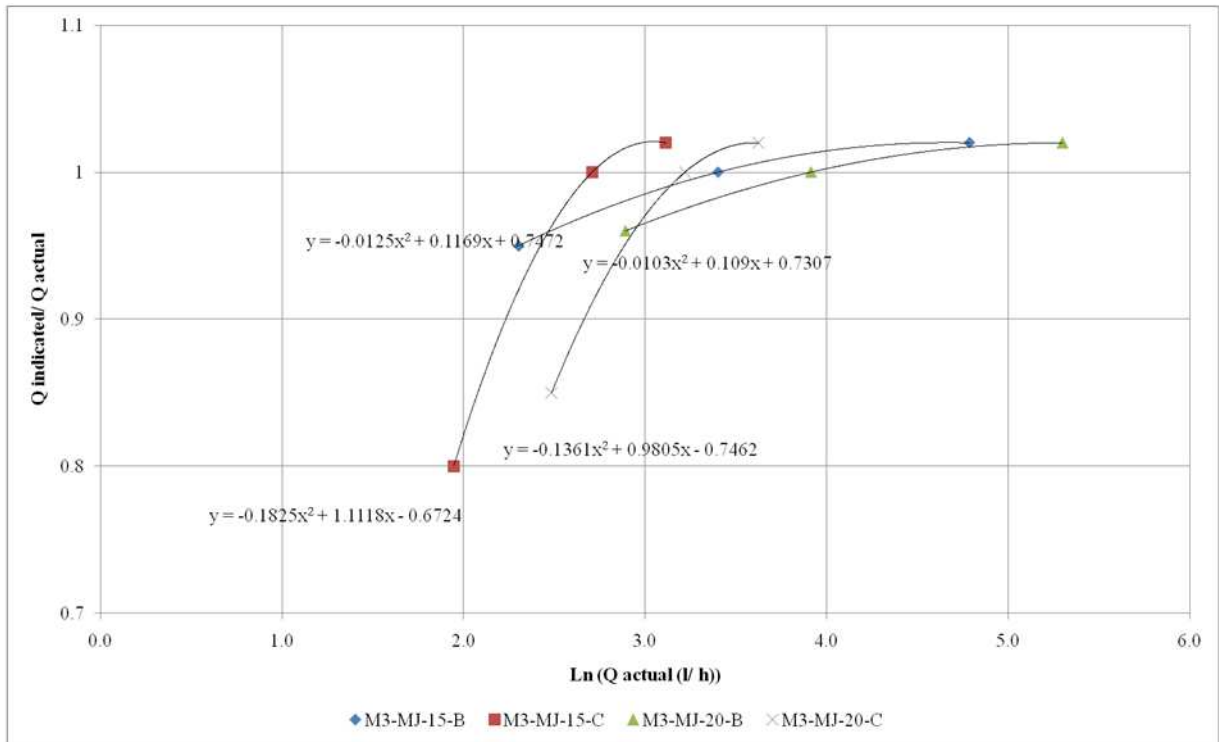


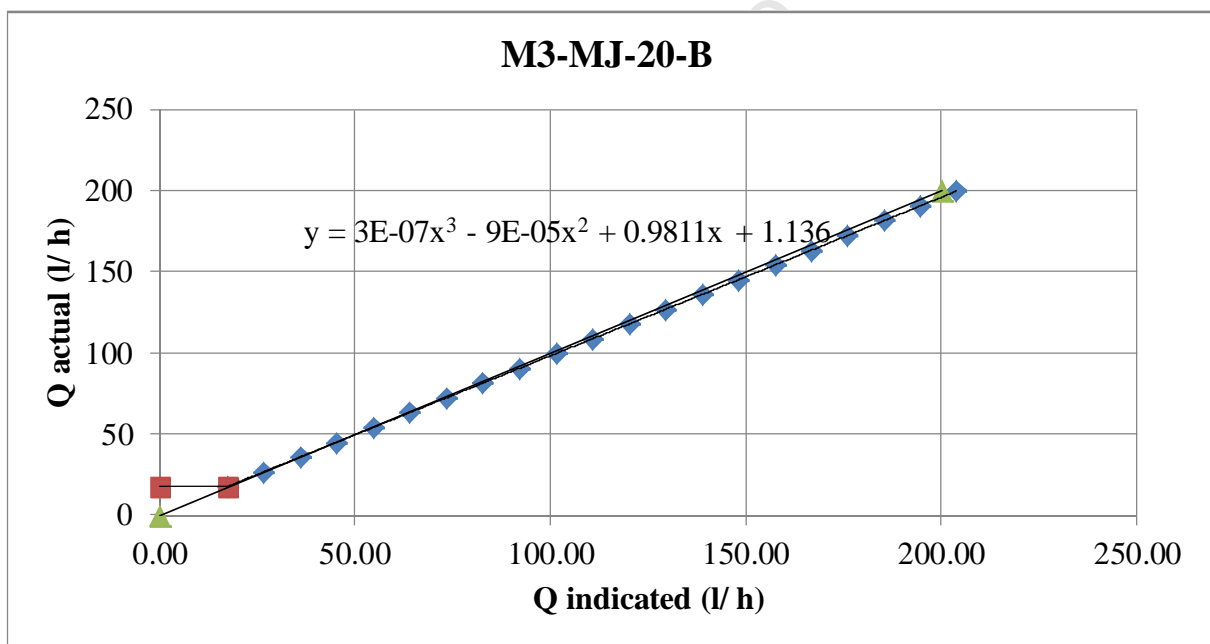
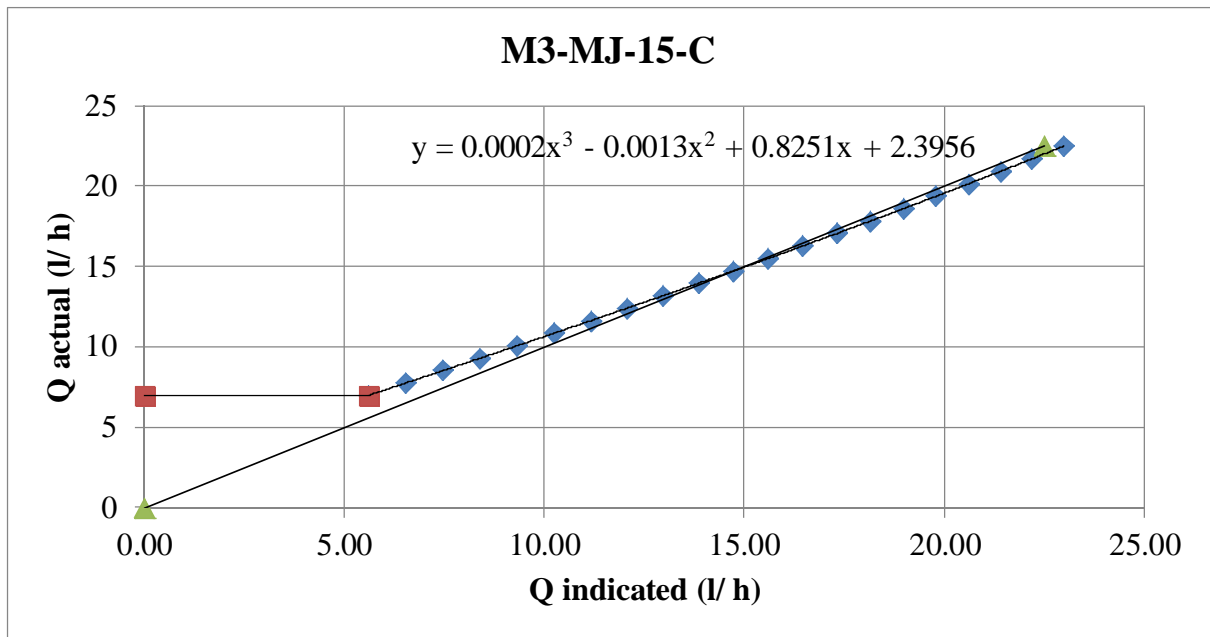


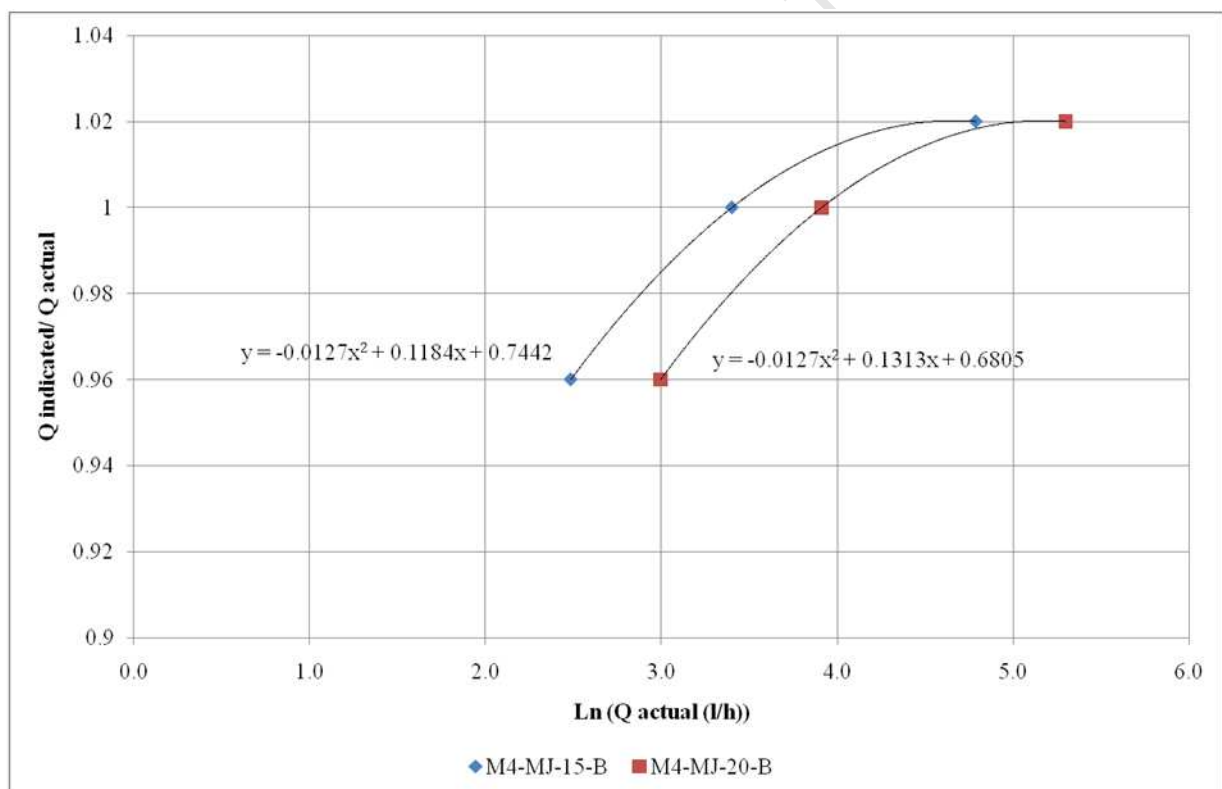
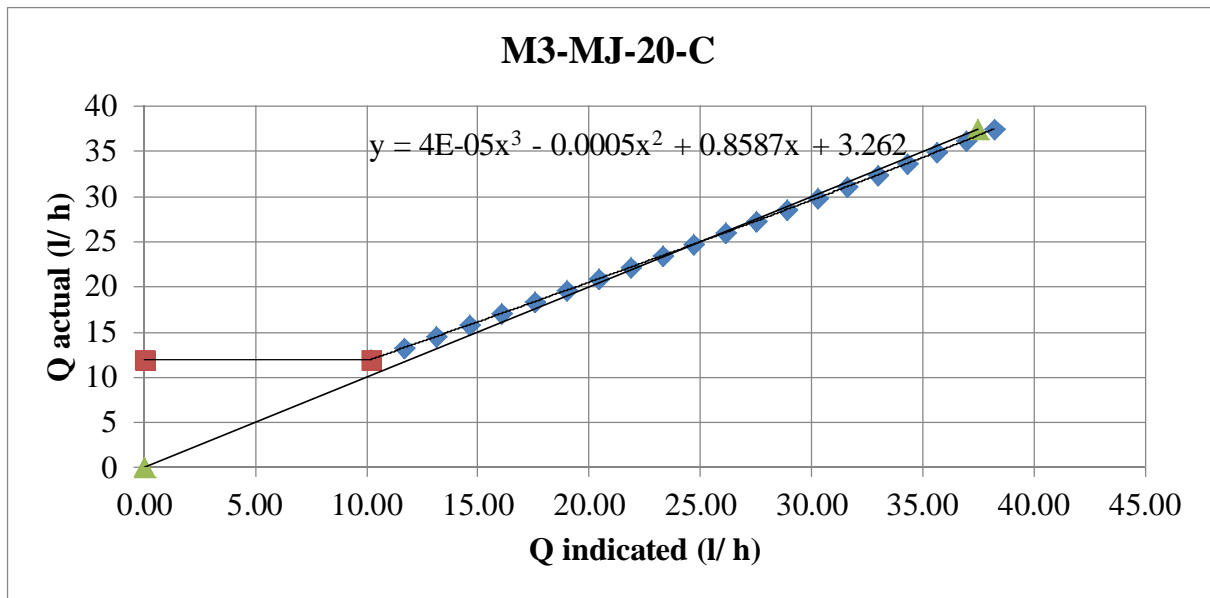


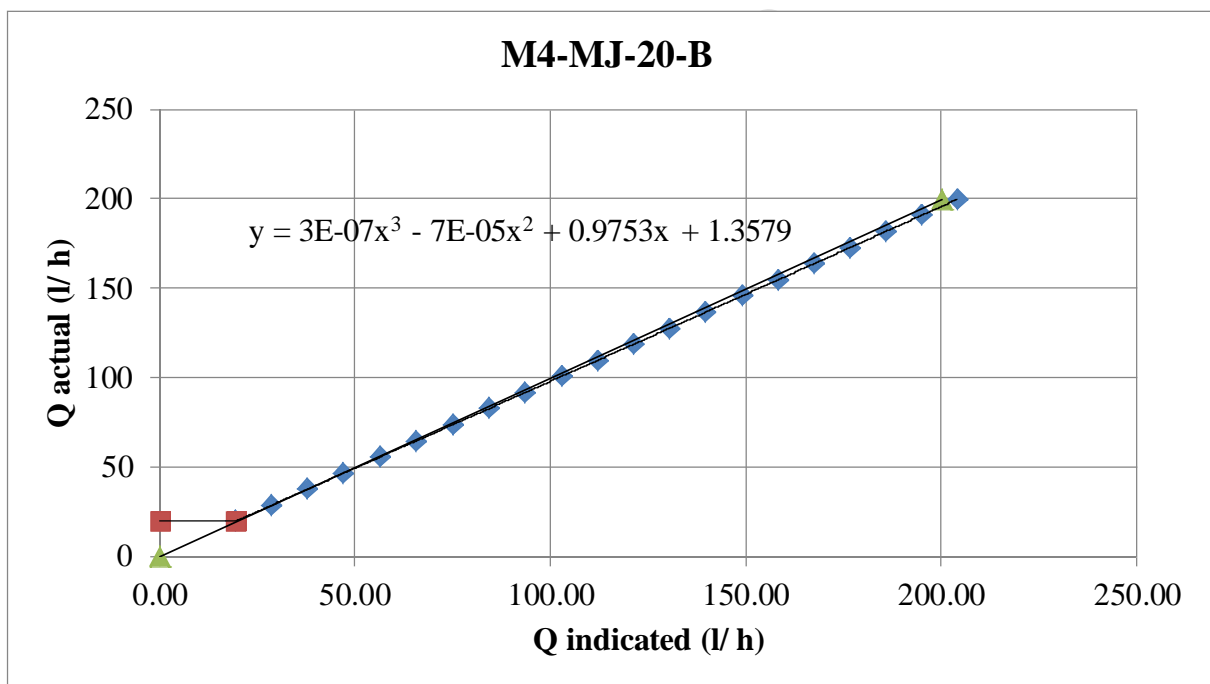
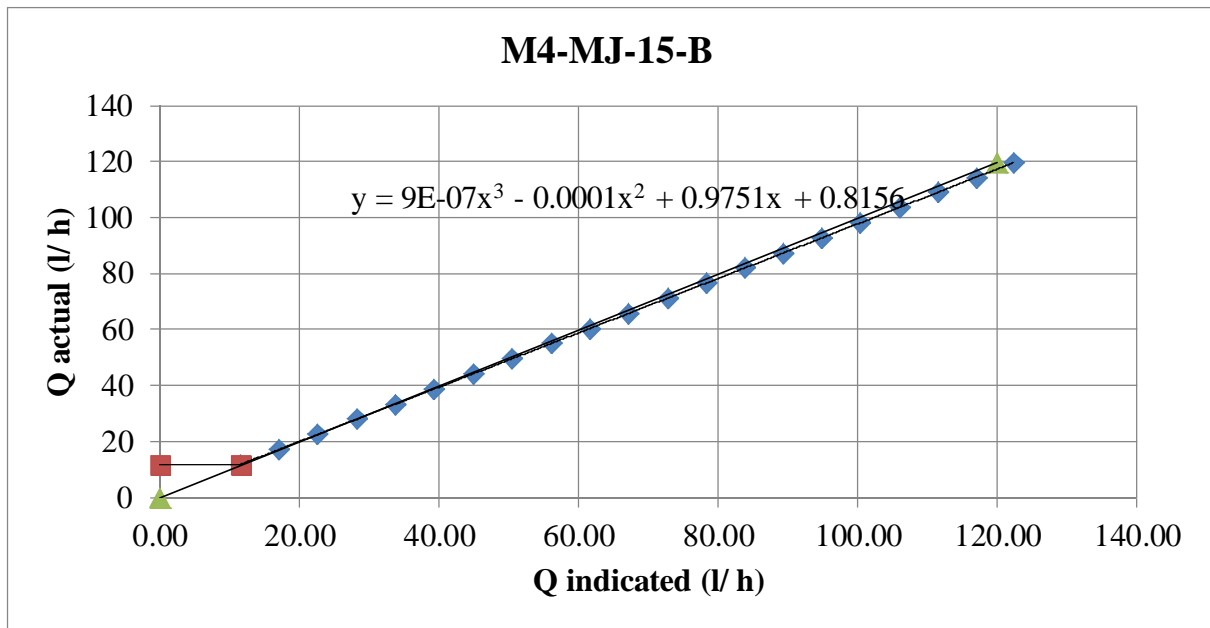








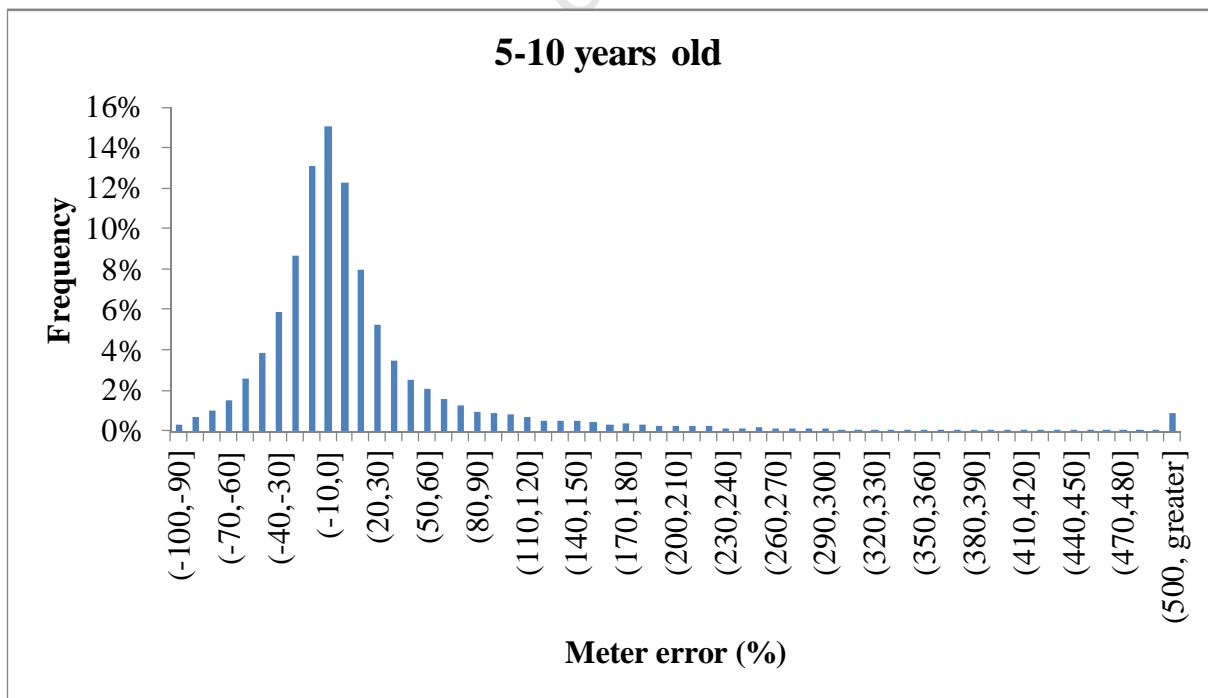
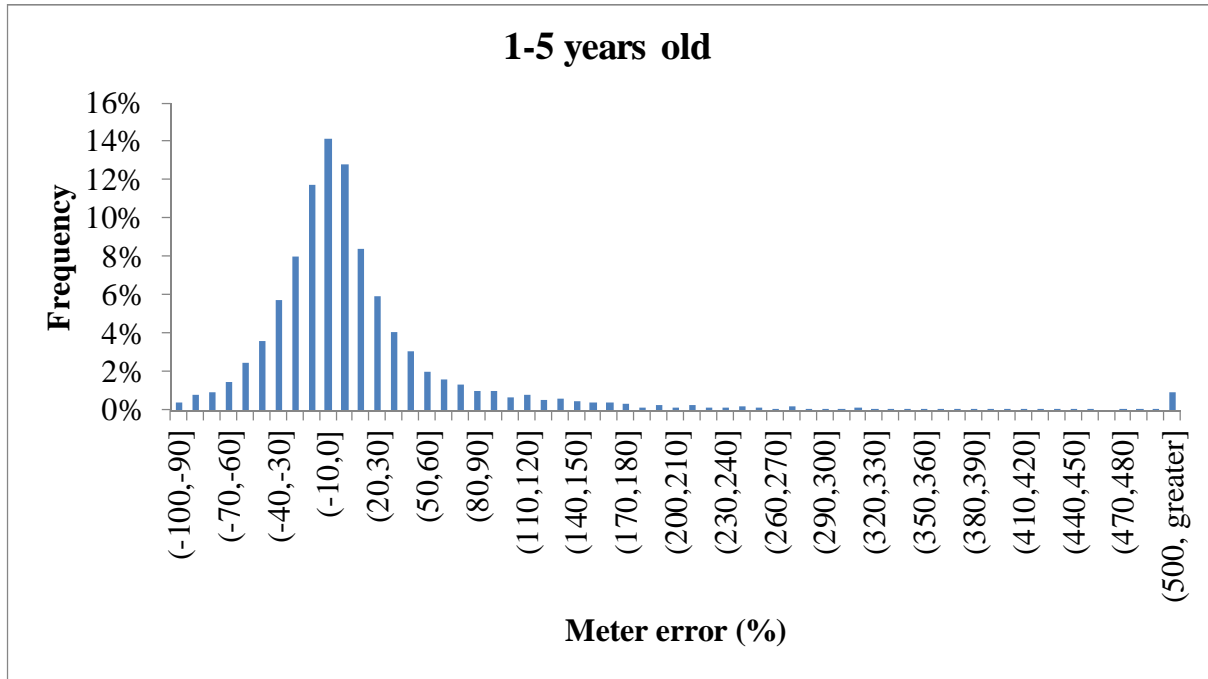


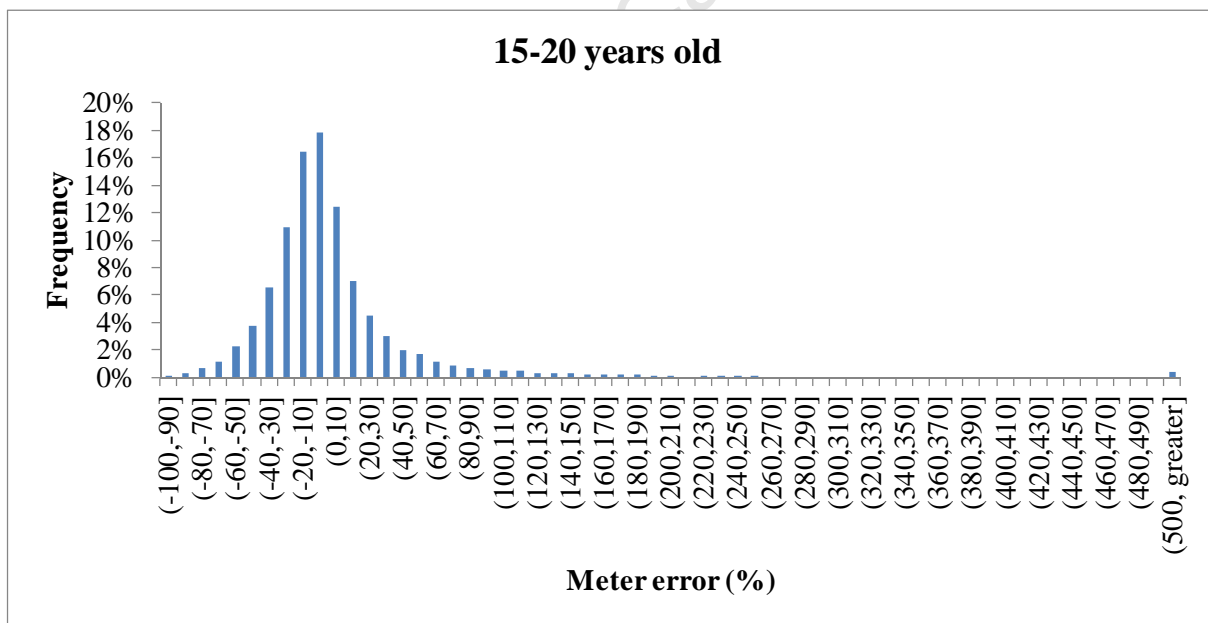
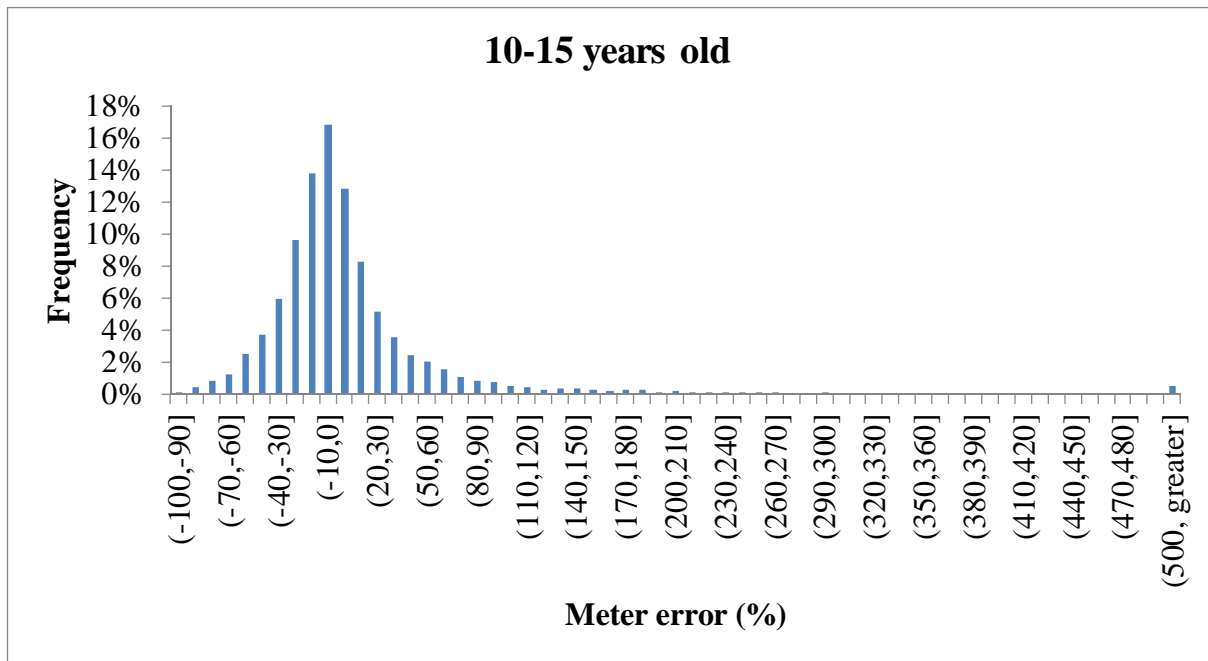


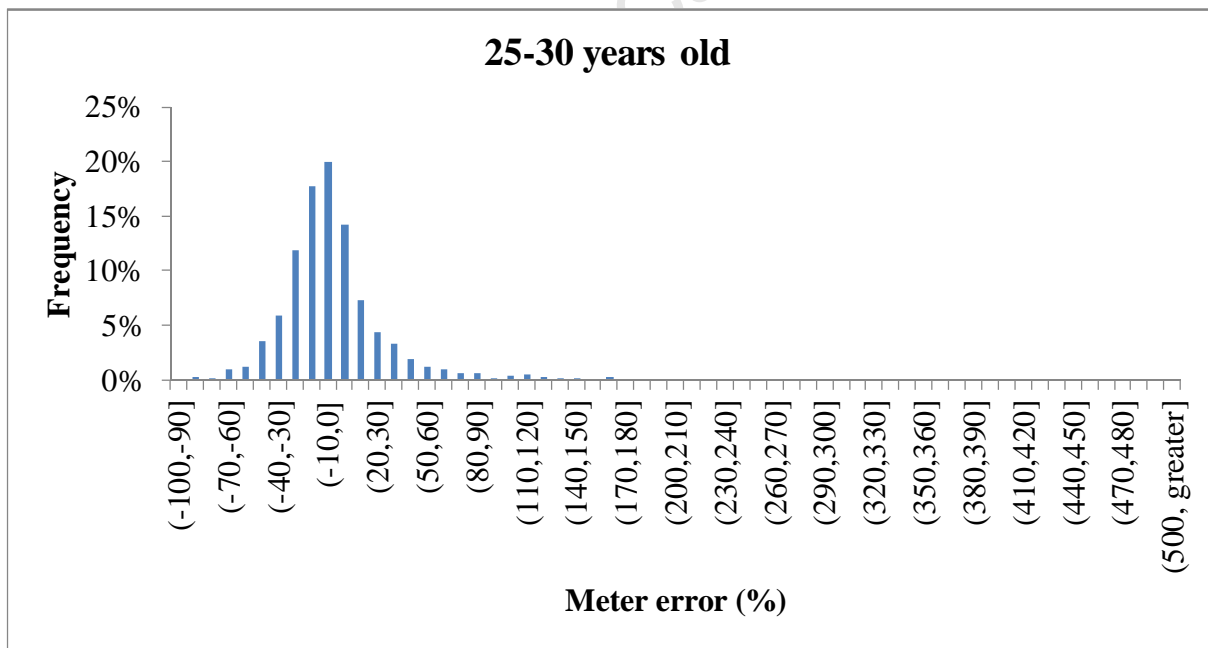
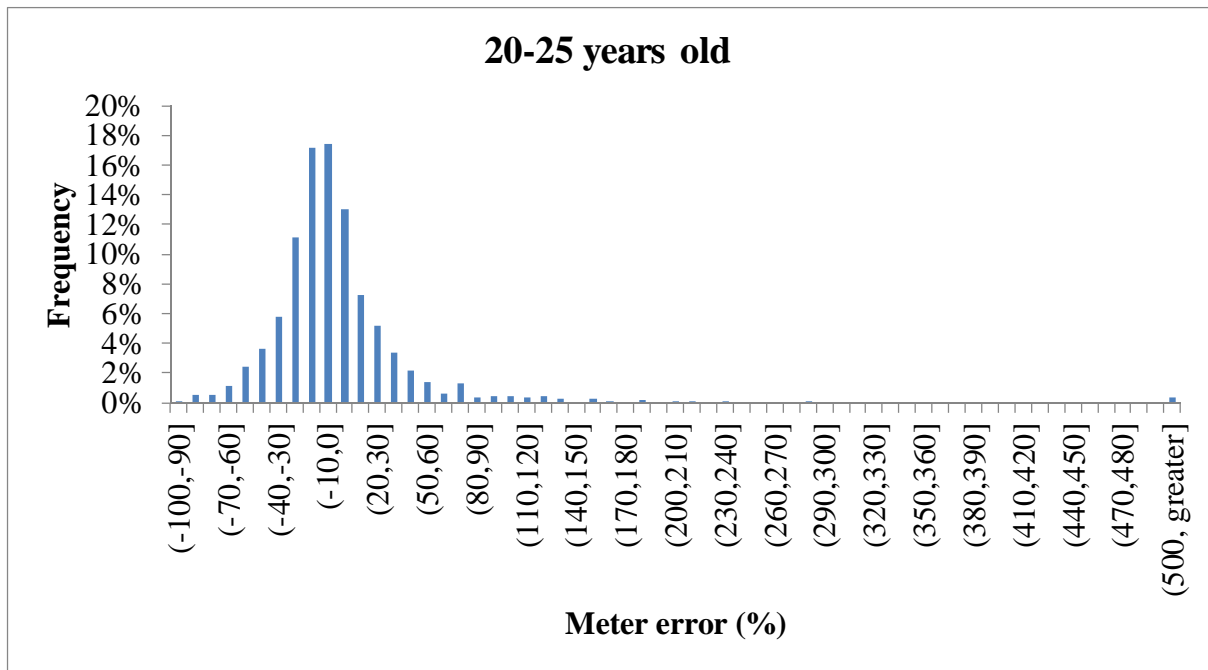
Appendix B: On-site leakage data collection field sheet

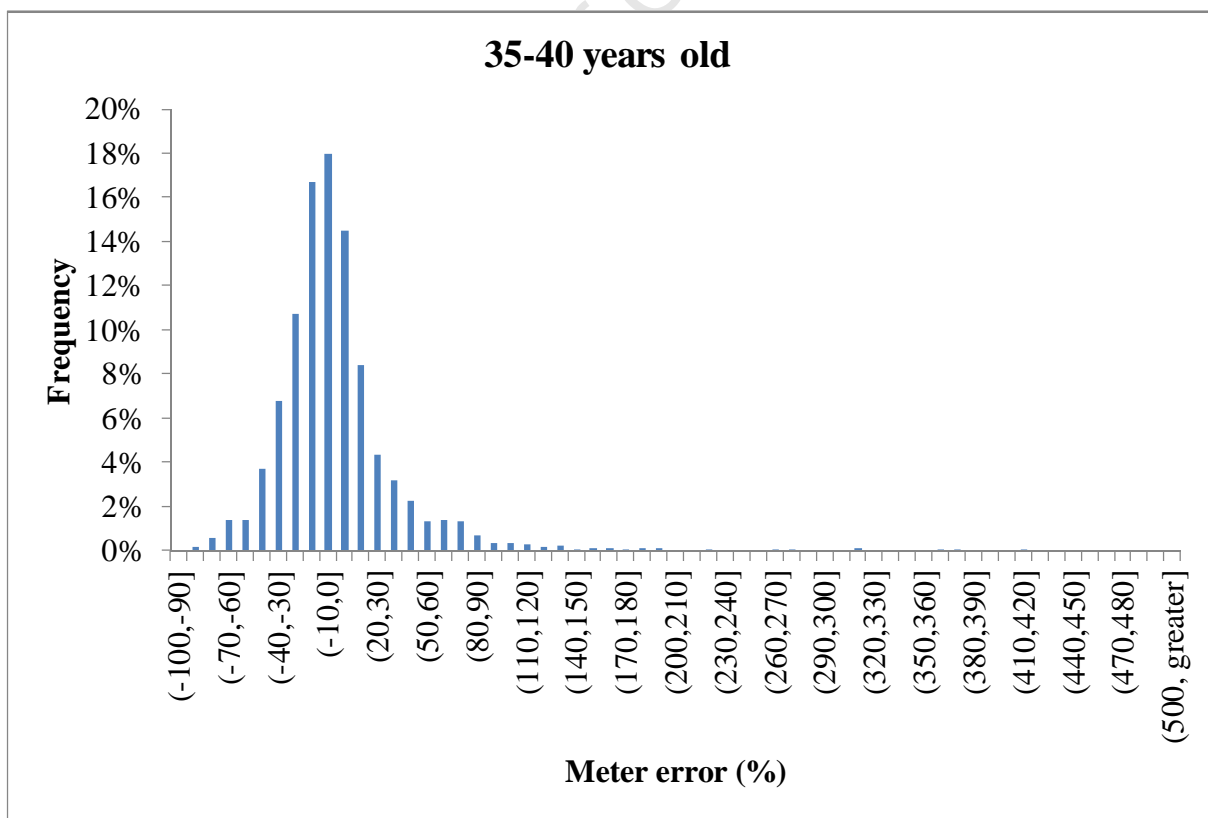
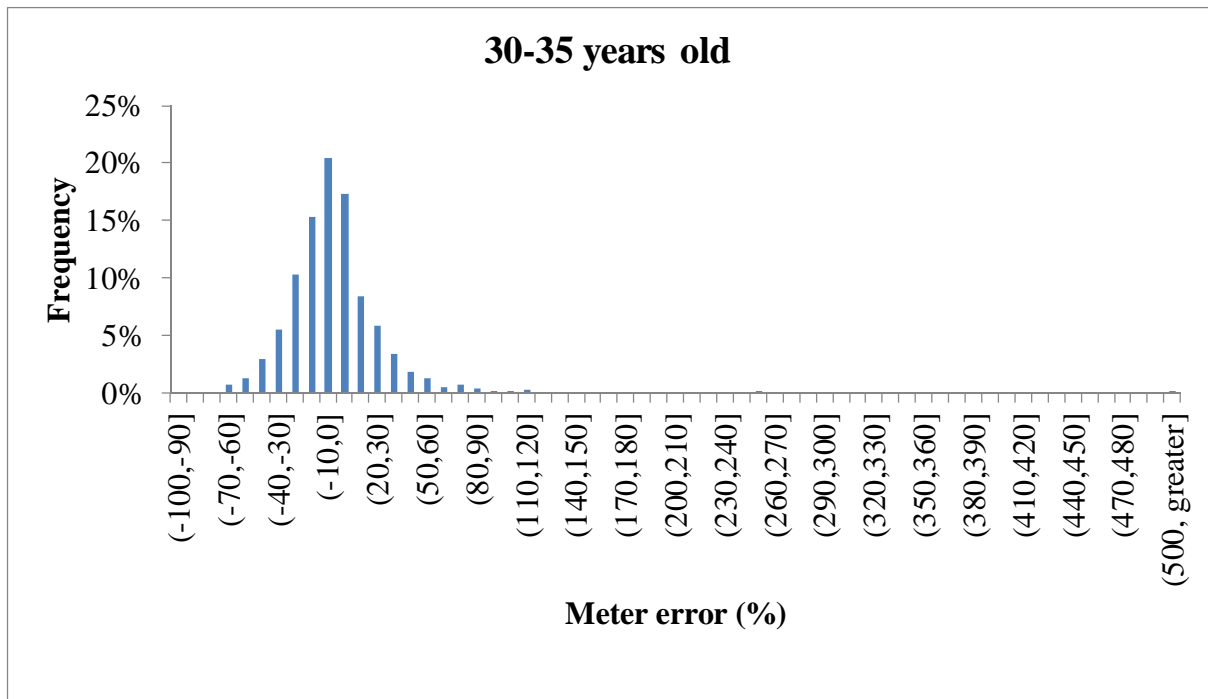
GENERAL INFORMATION (IDENTIFICATION)		OBSERVATION	
SUBURB:			
STREET NAME:			
HOUSE NUMBER:			
STAND NUMBER			
METER NUMBER			
CATEGORIE&TYPE			
		DOMESTIC	
		NON DOMESTIC	
		HOUSE	OFFICE
		BLOCK OF FLATS	SHOP
		TOWN HOUSE	RESTAURANT
		OTHER	HOTEL&GUEST
			SCHOOL
			HOSPITAL
			CHURCH
			OTHER
MEASUREMENTS INFORMATION		VISIT# 1	VISIT# 2
DATE/HOUR			
INITIAL METER READING			
READING AFTER	5 MIN	1	
	10 MIN	2	
	15 MIN	3	
	20 MIN	4	
VOLUME AFTER	5 MIN	1	
	10 MIN	2	
	15 MIN	3	
	20 MIN	4	
FLOW RATE (Litres/Hour)		1	
		2	
		3	
		4	
FINAL FLOW RATE (Litres/Hour)			
OBS :LEAK OR NO-LEAK			
COMMENTS AND OBSERVATIONS:			
meter were buried underground		Y/N	
meter box could not be opened			
meter could not be located			
meter dials were illegible			
meter without box cover			
meter were leaking			
customer at home - not at home			
washing machine			

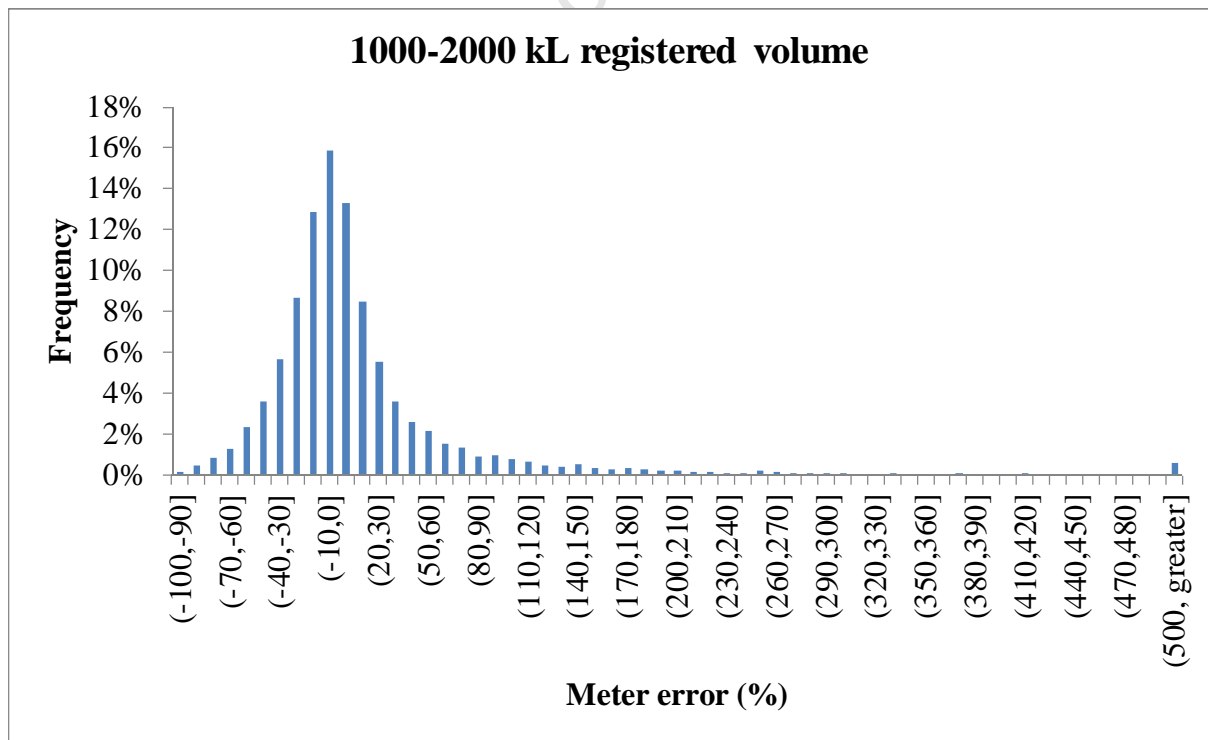
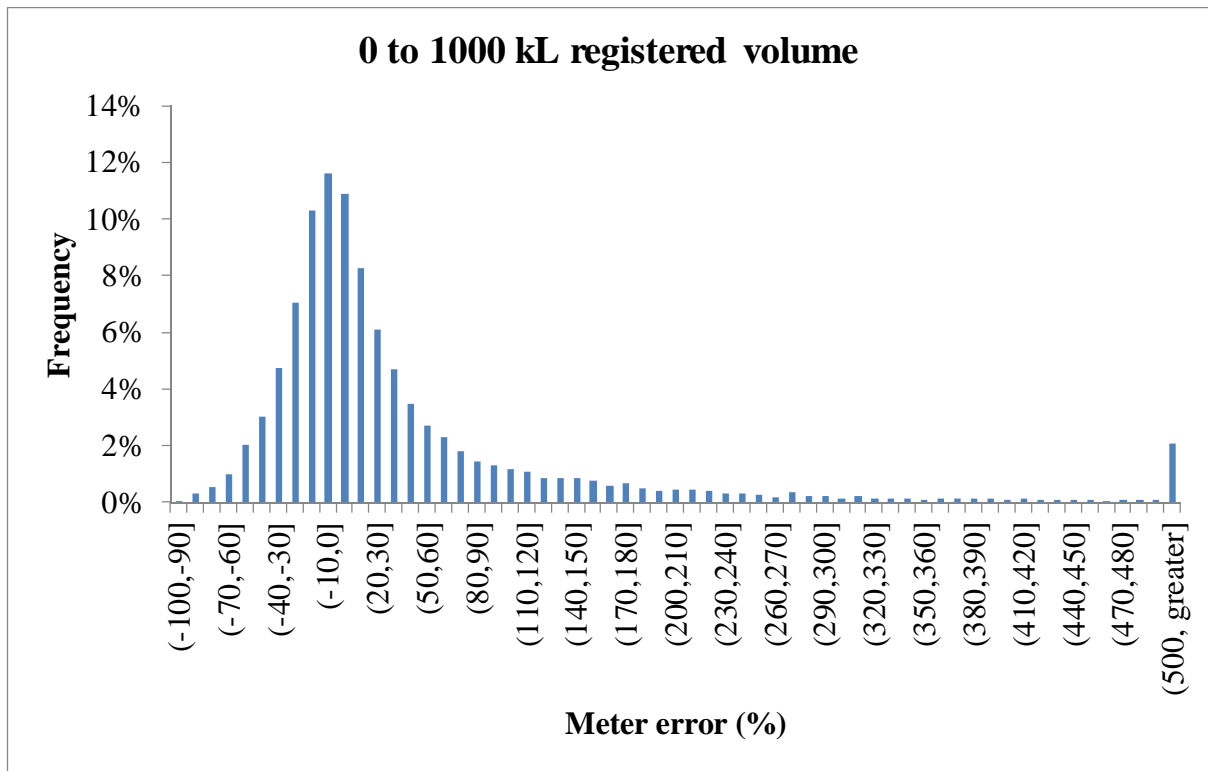
Appendix C: Database analysis histograms

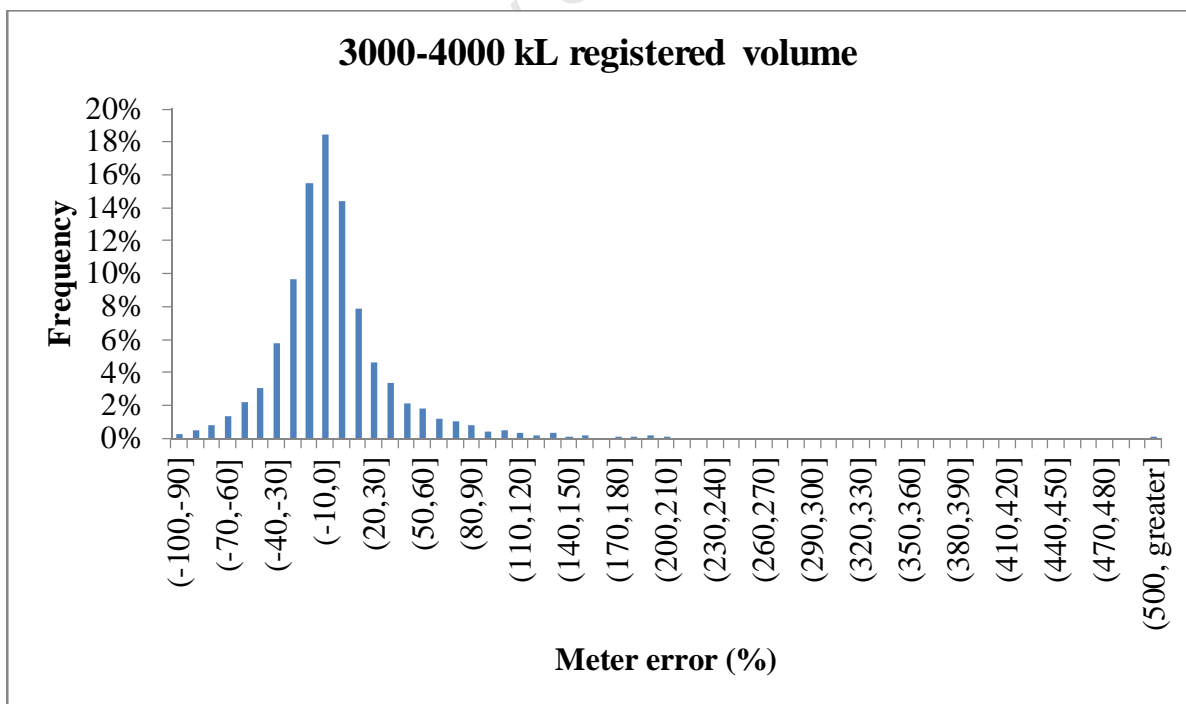
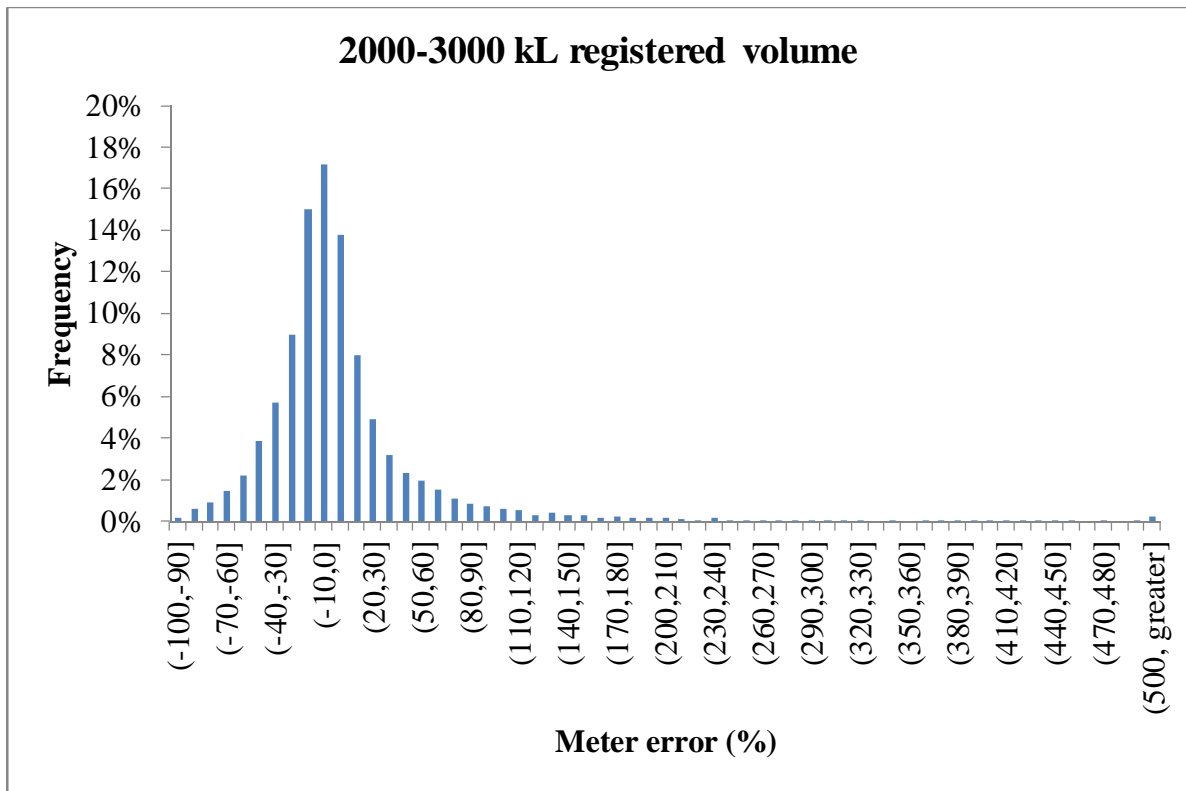


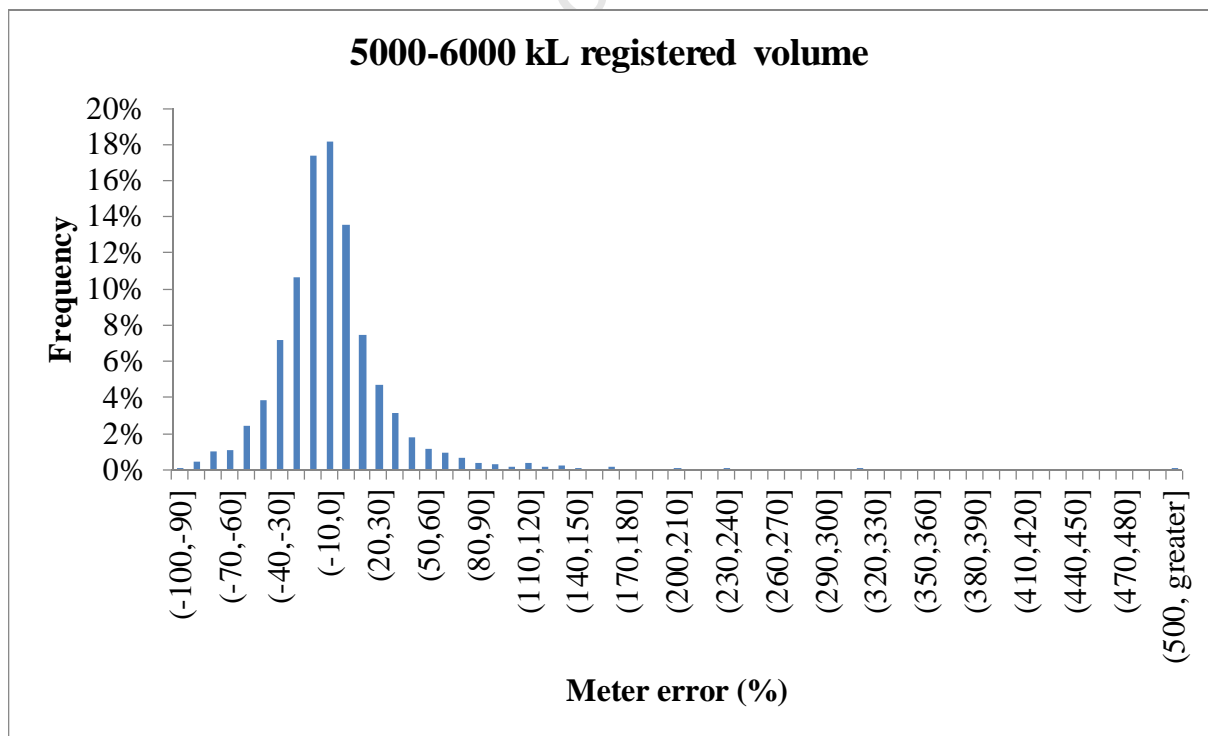
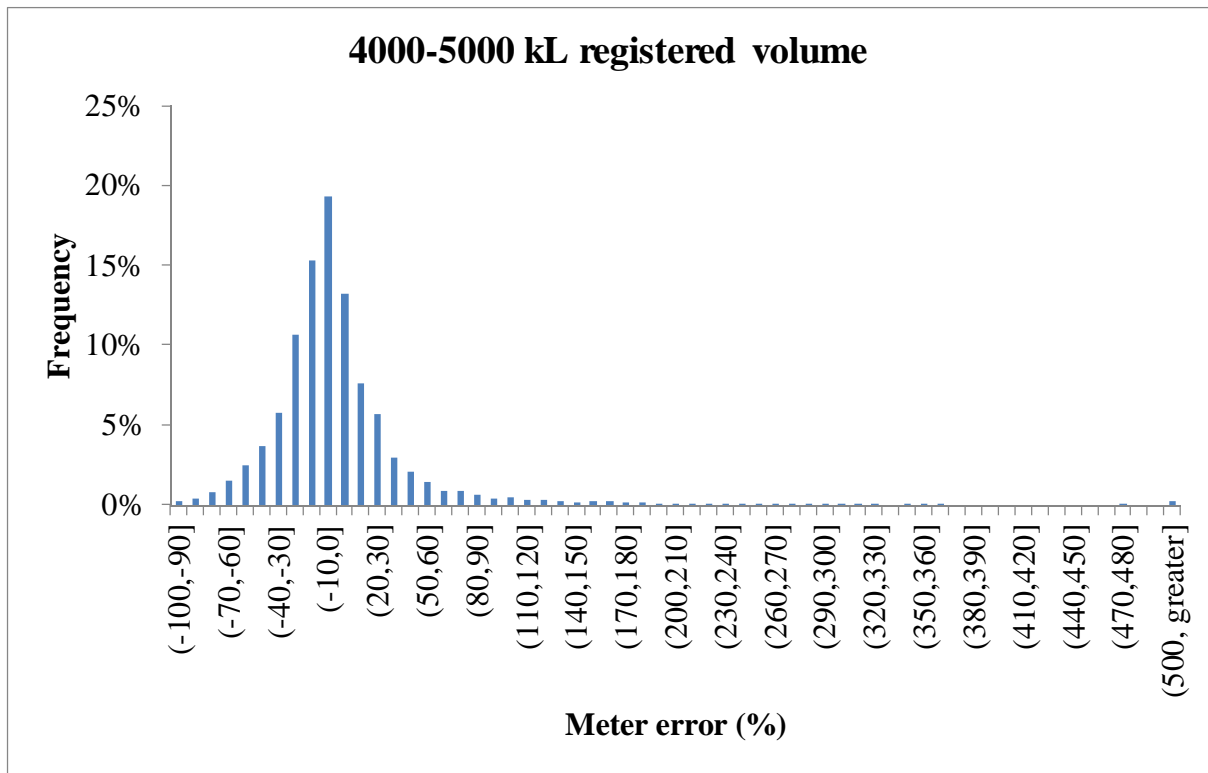


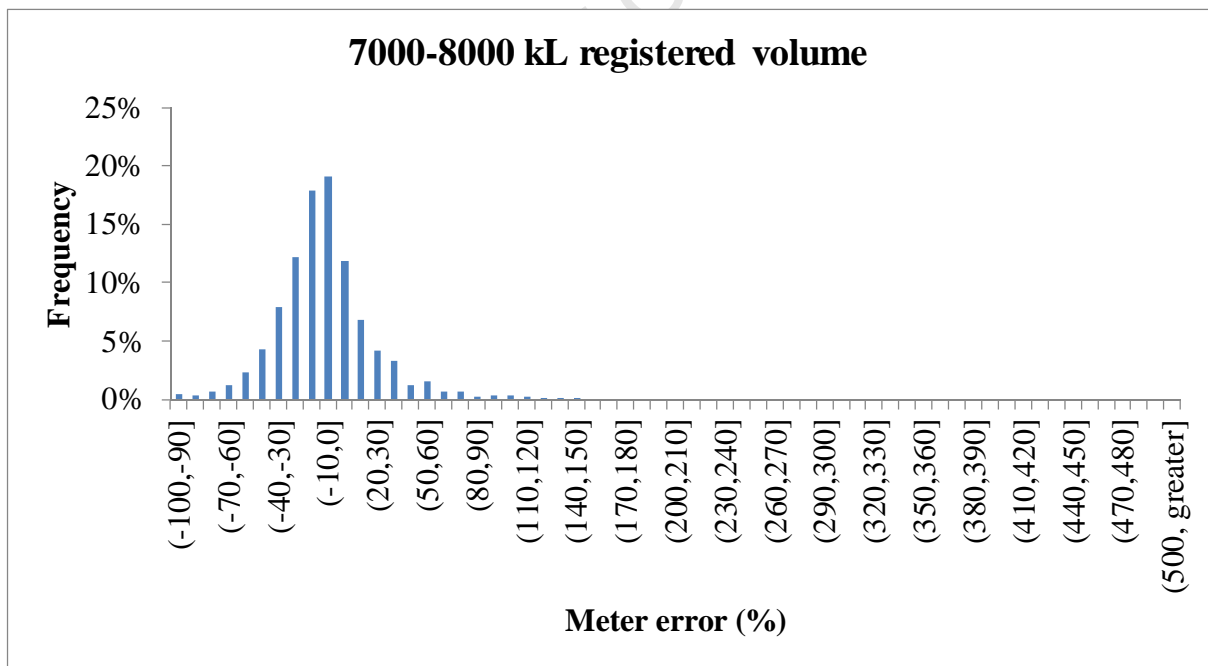
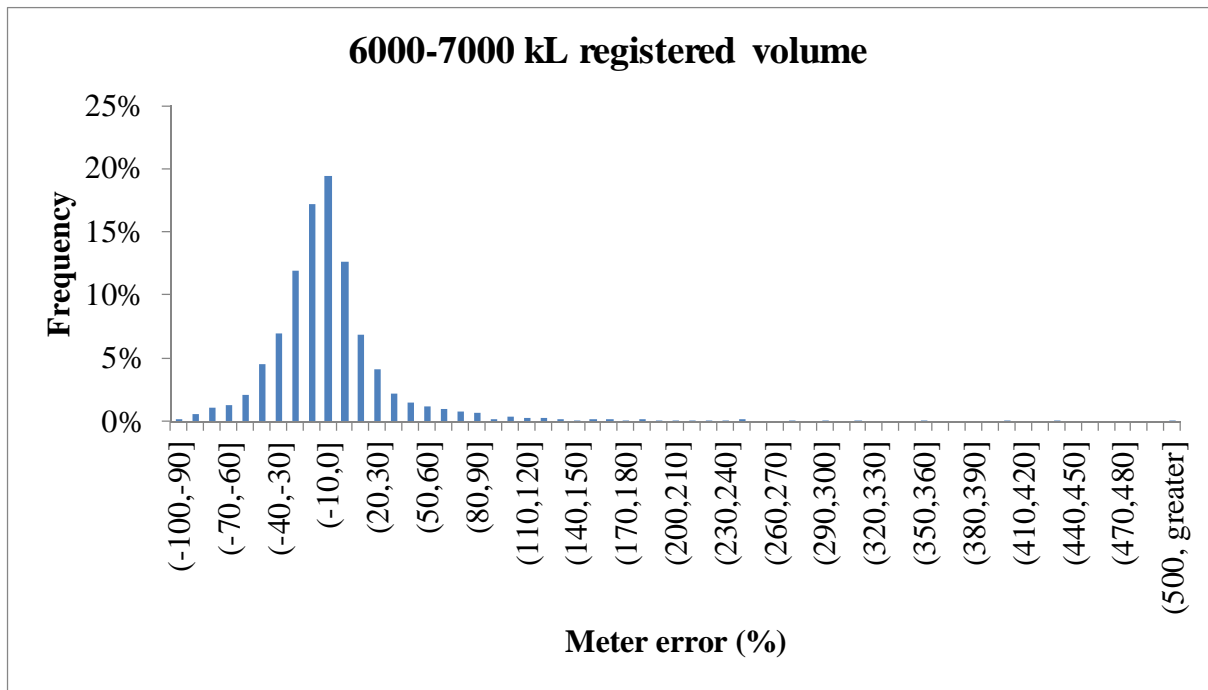


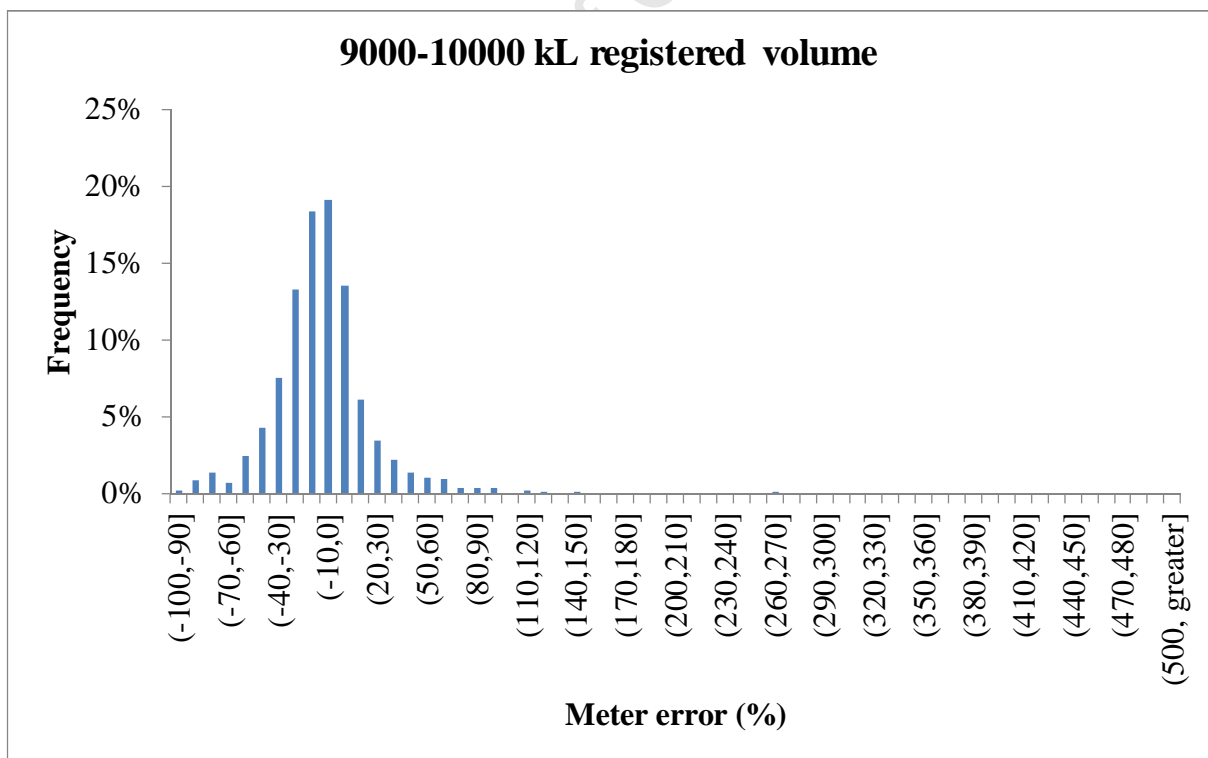
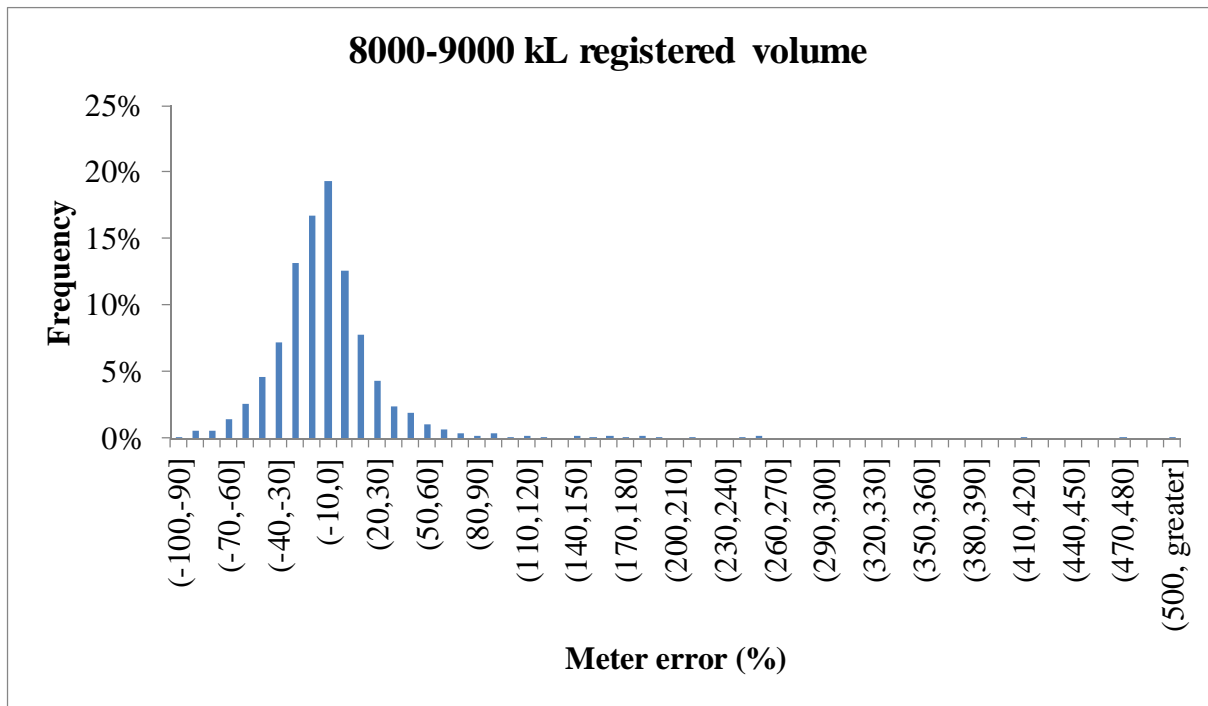


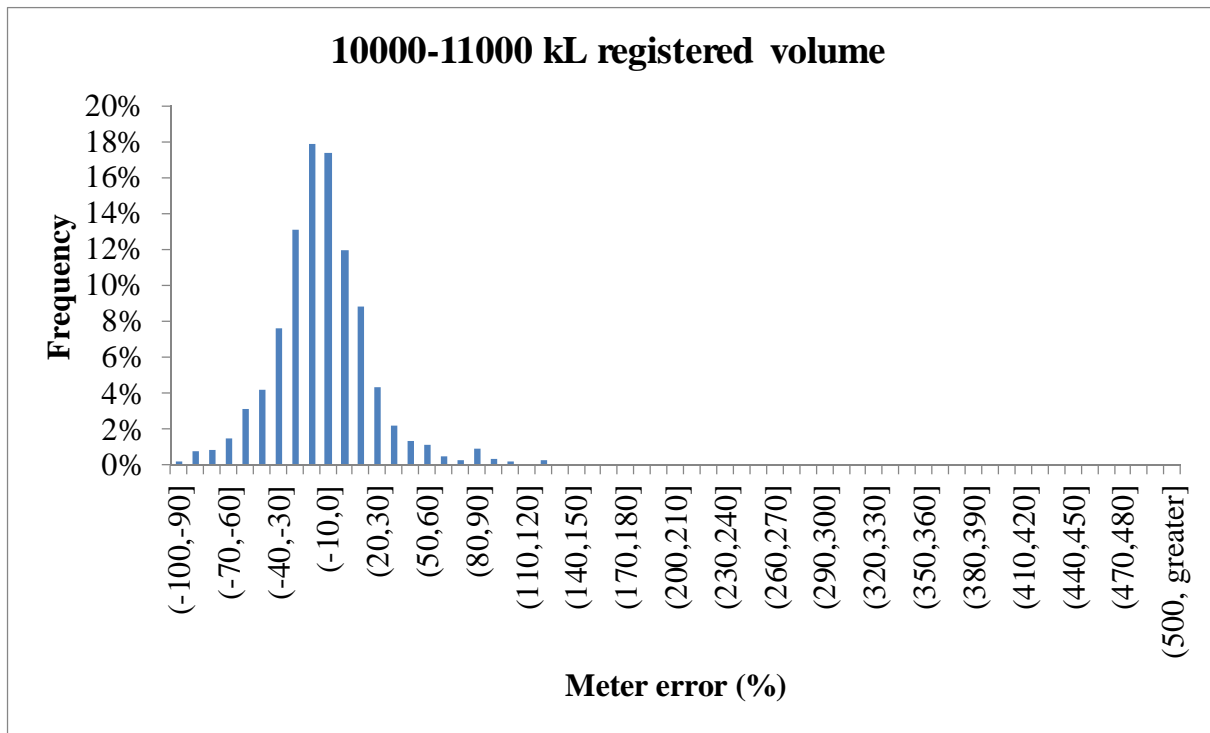






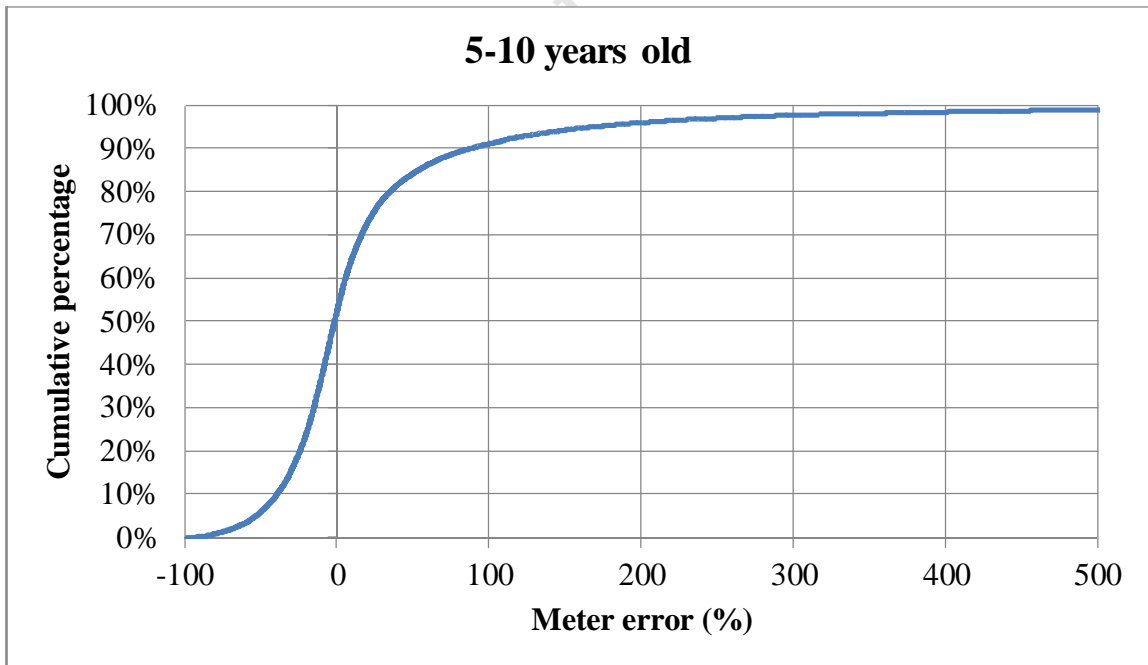
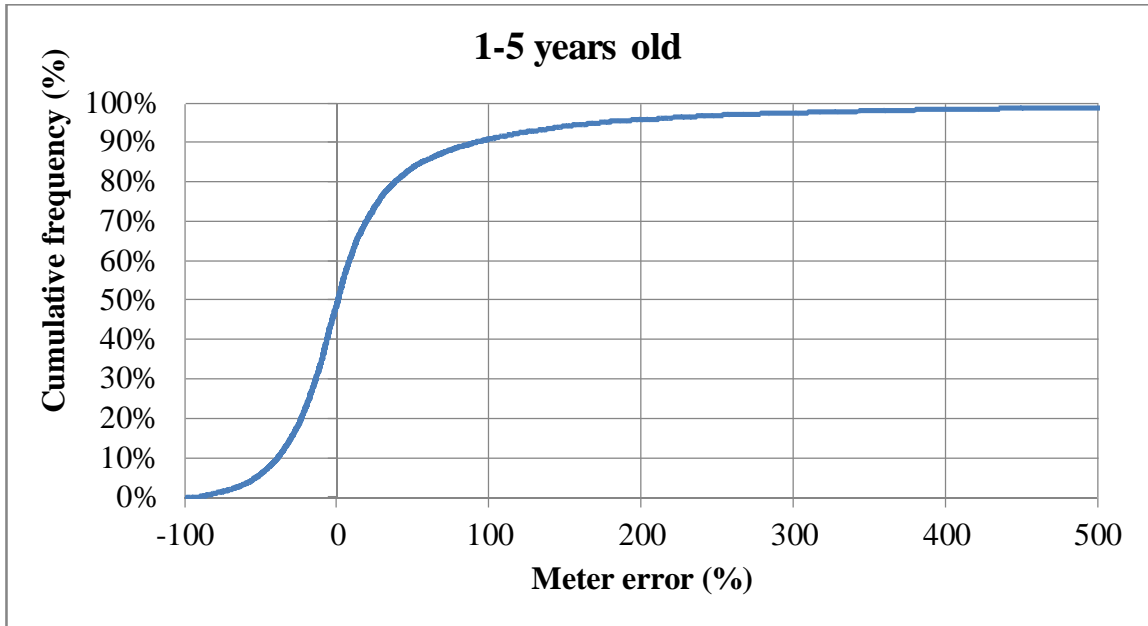


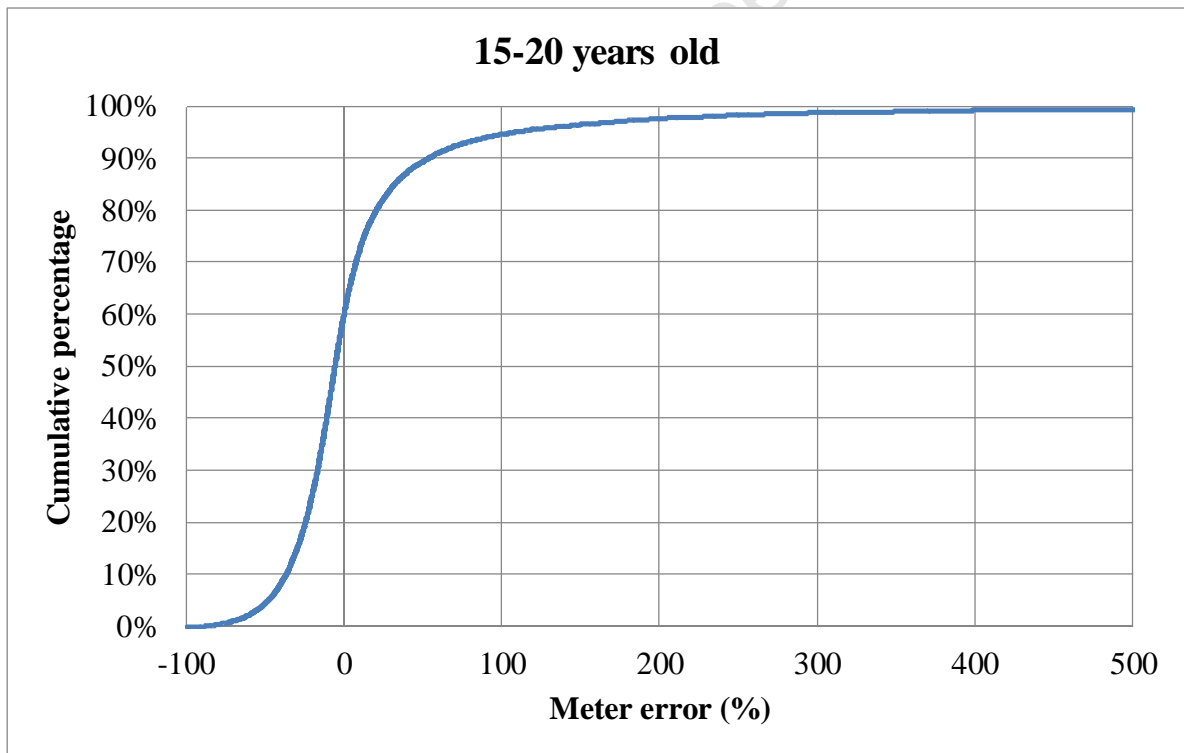


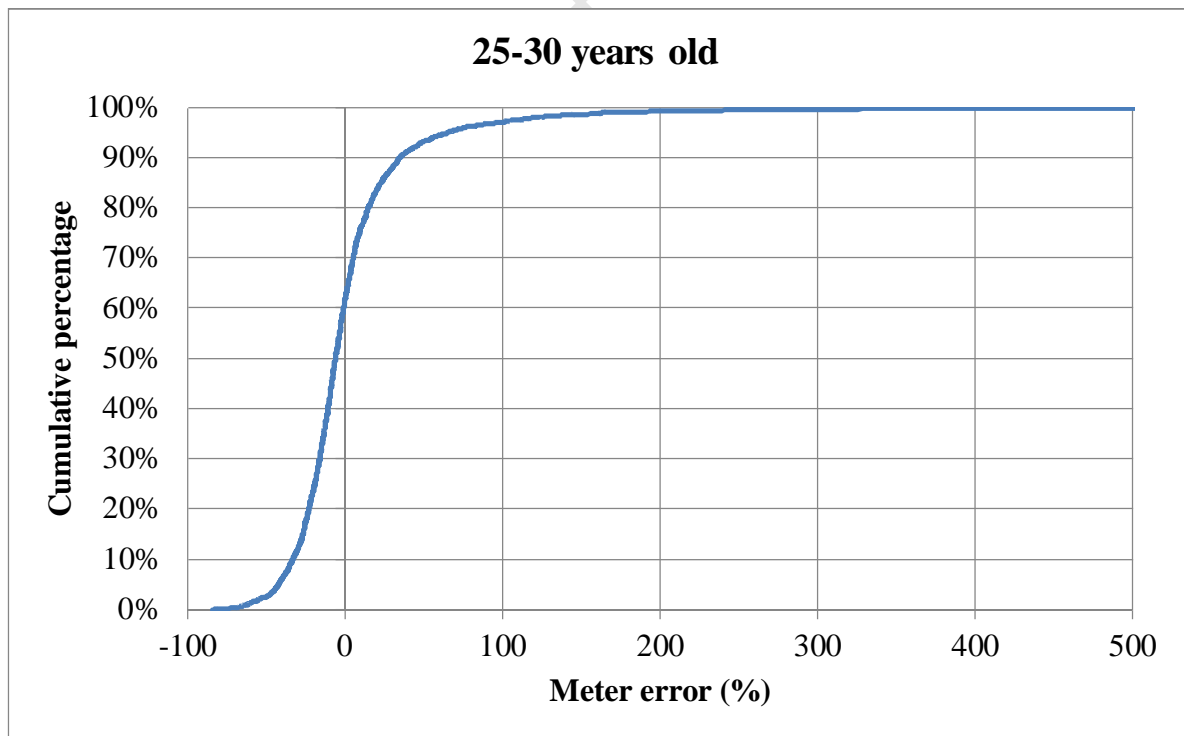


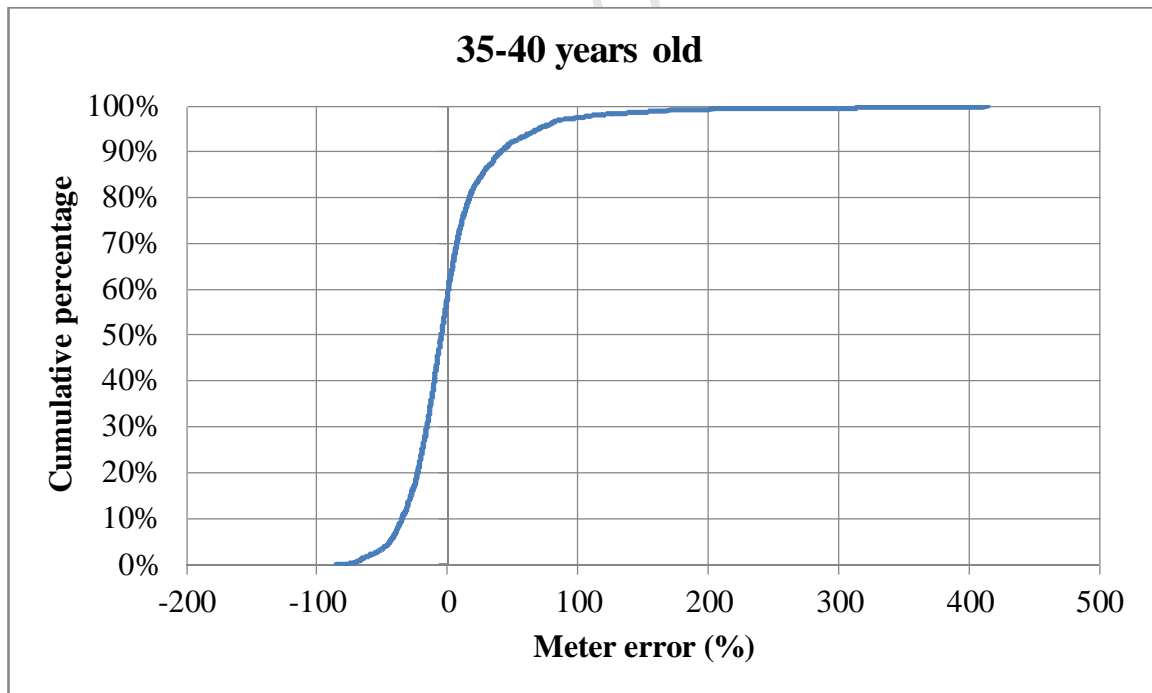
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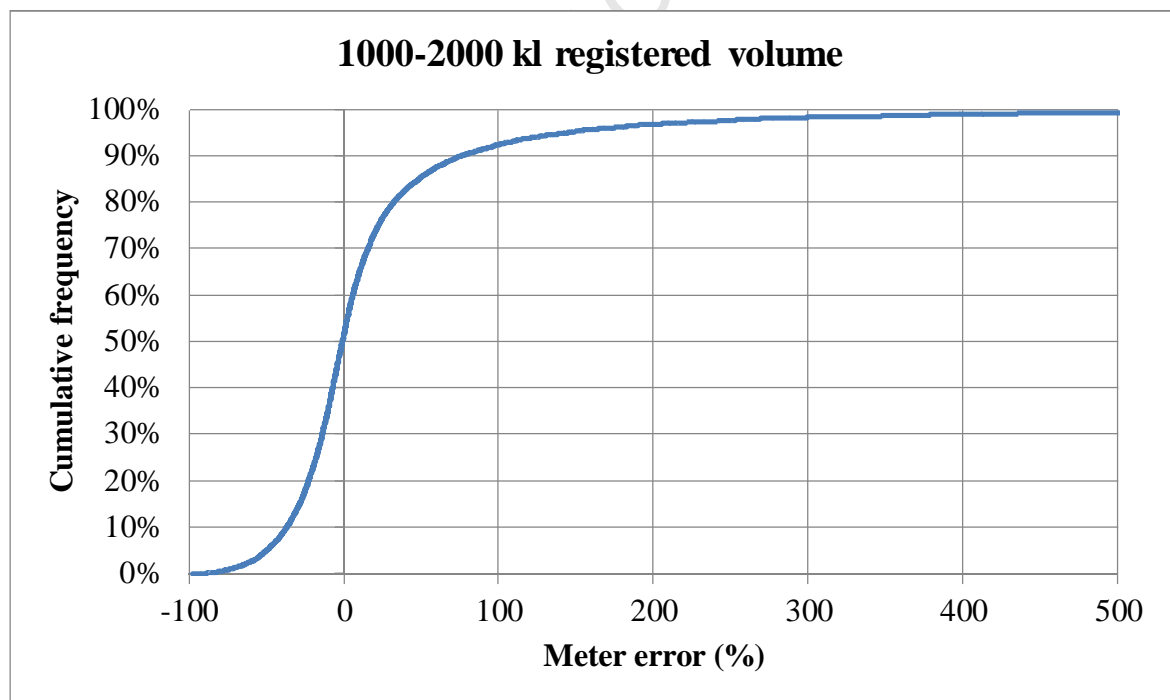
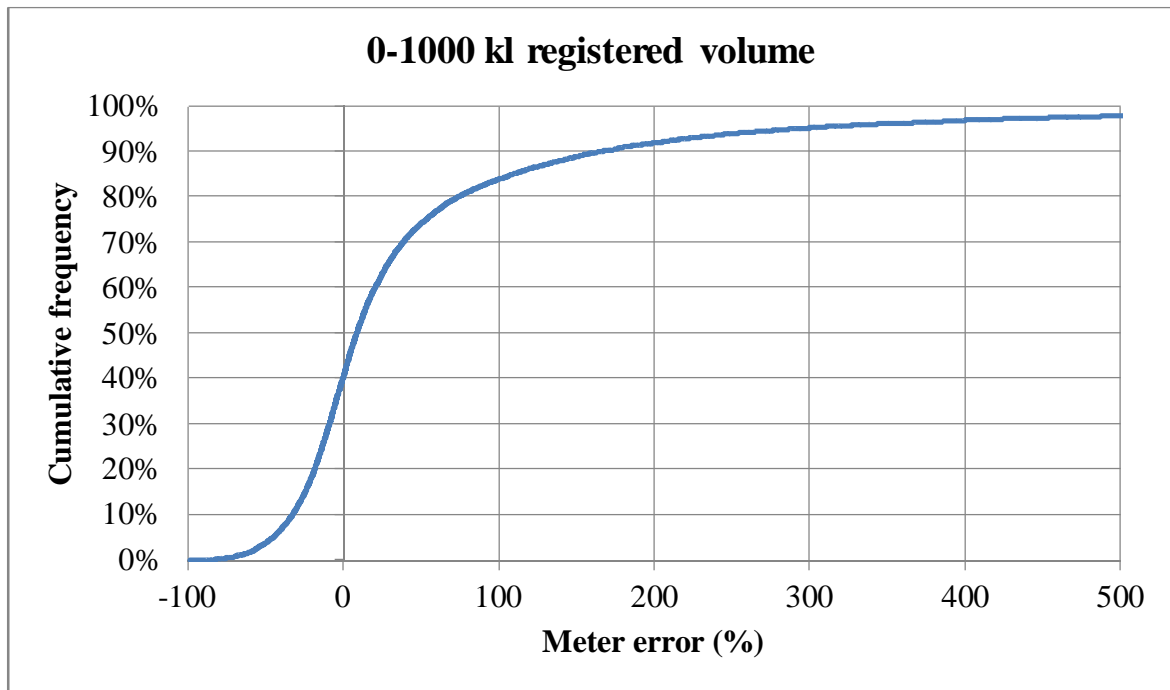
Appendix D: Database analysis cumulative percentage graphs

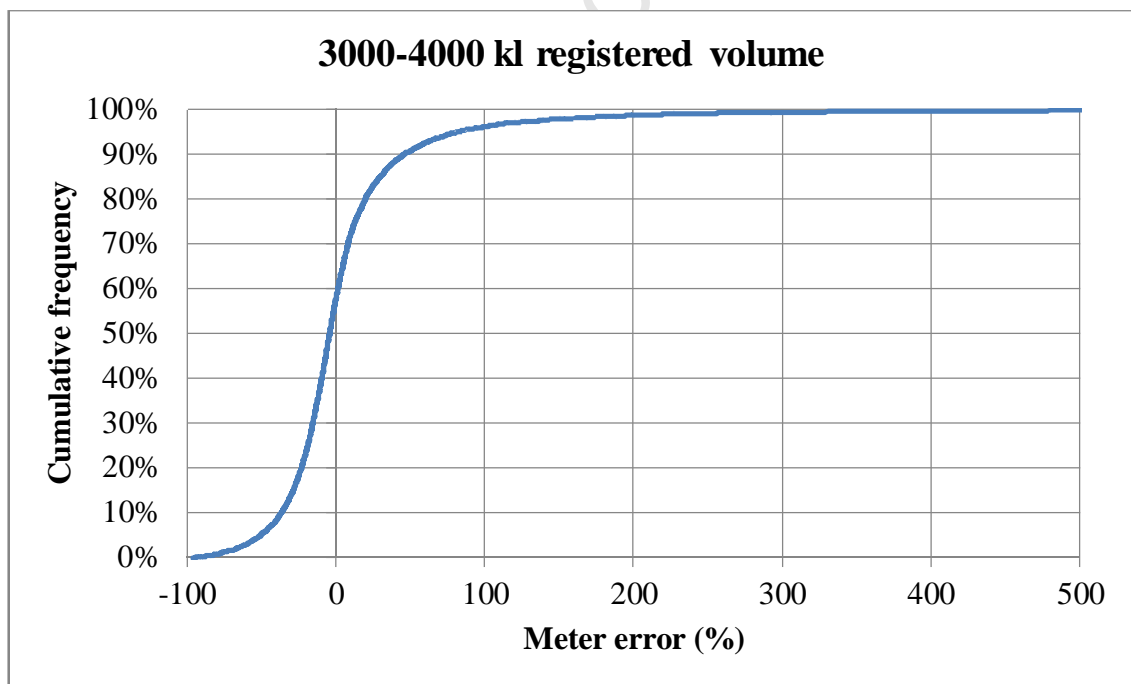
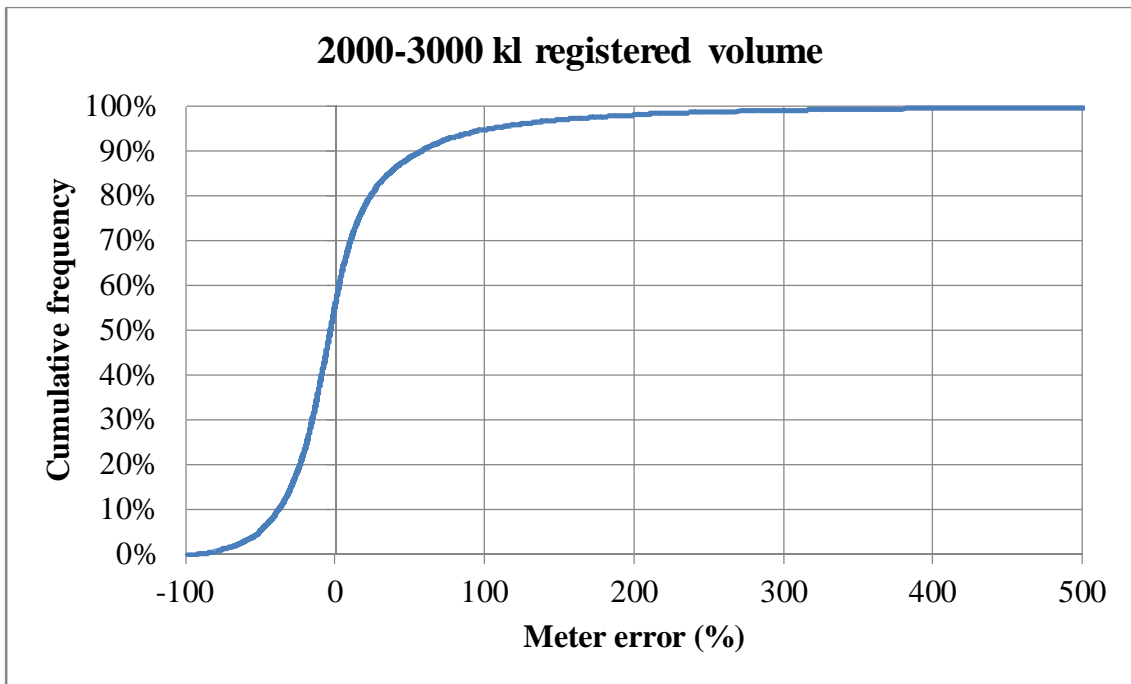


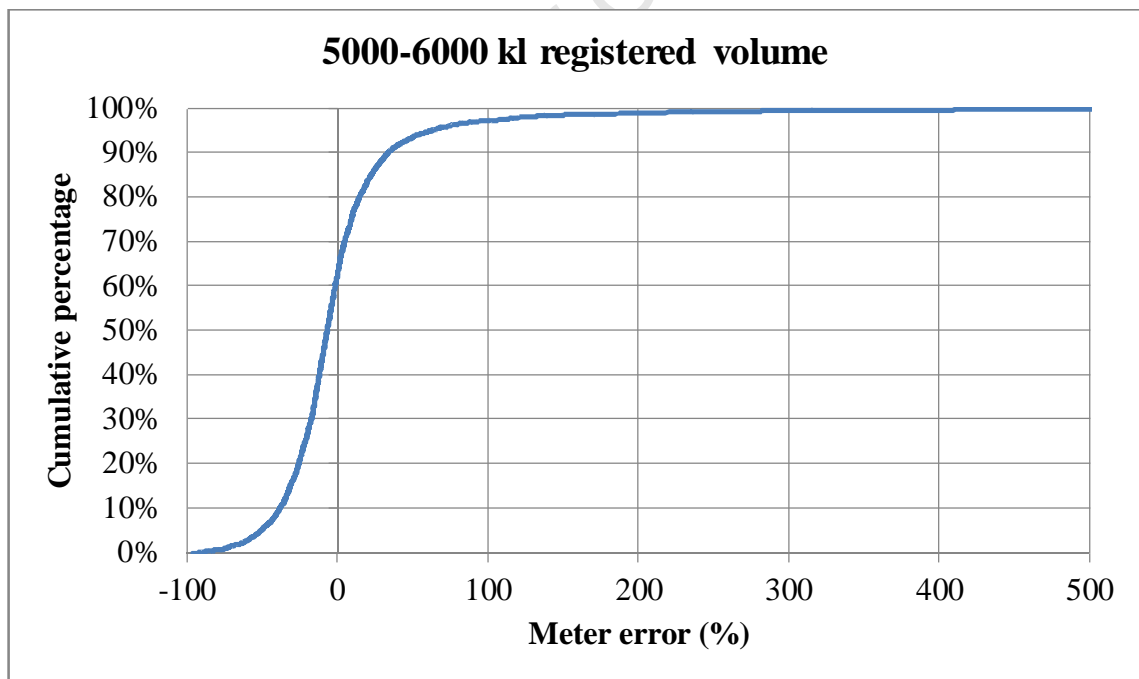
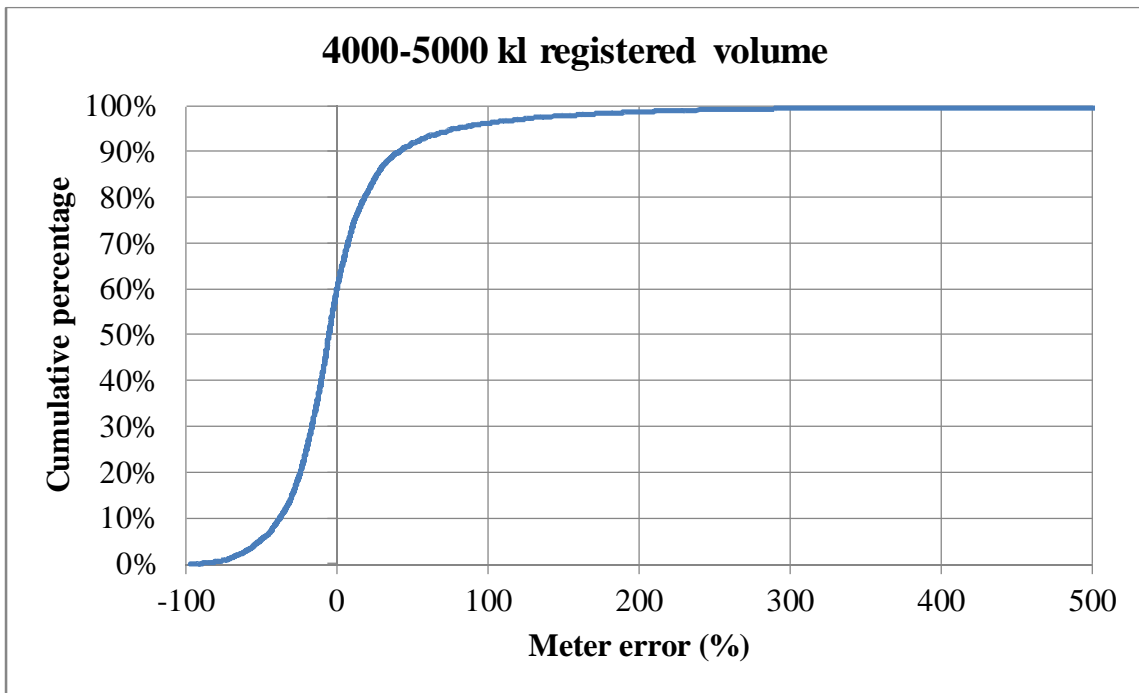


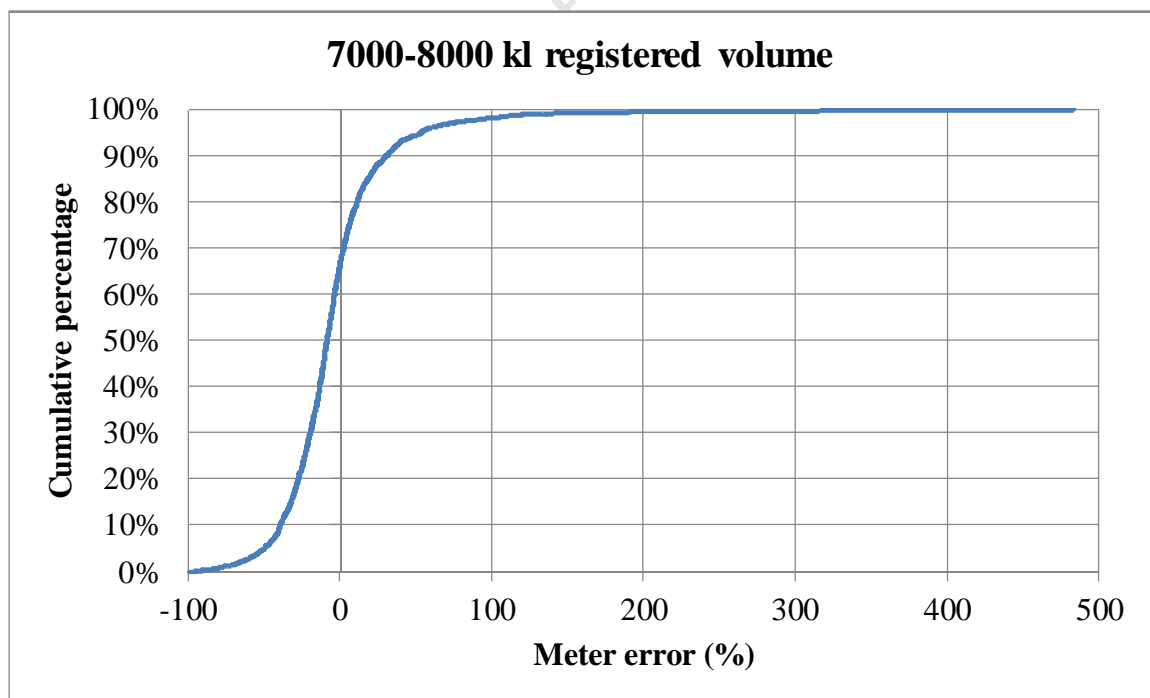
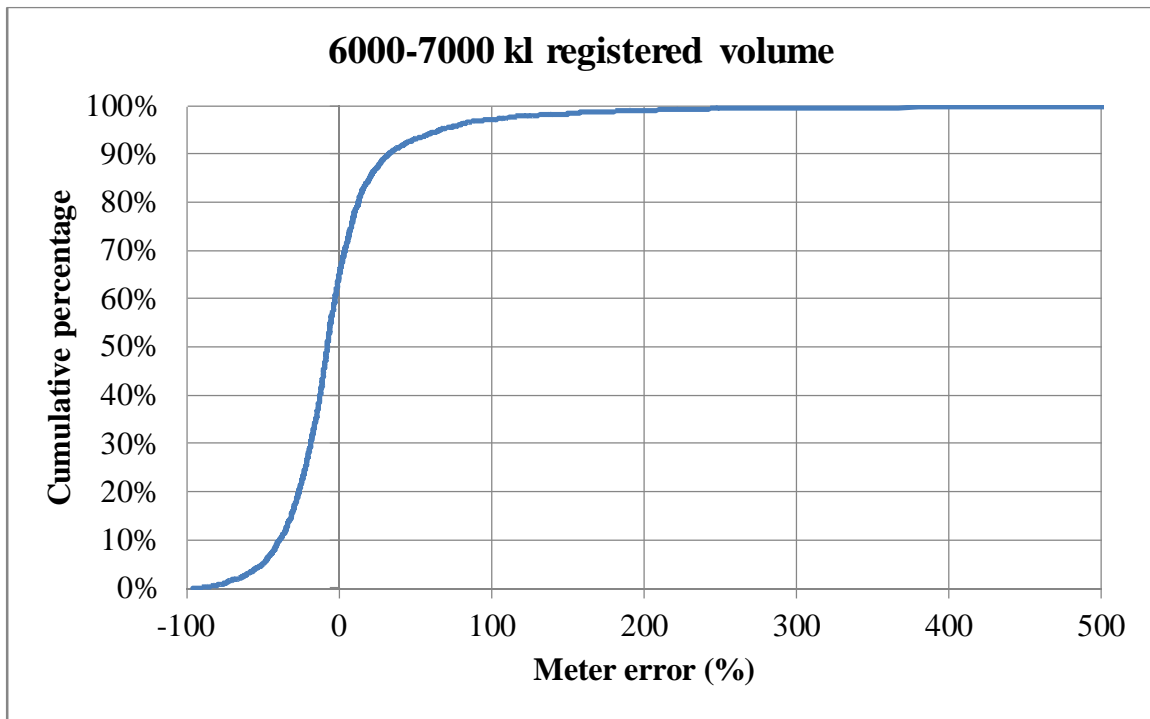


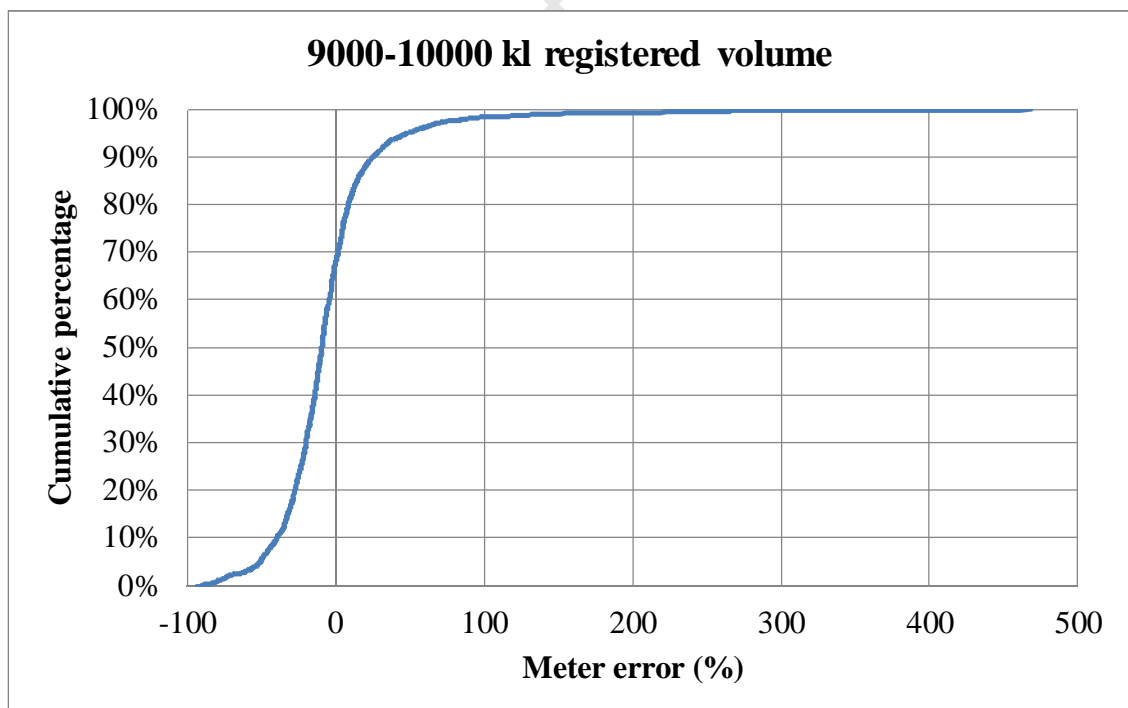
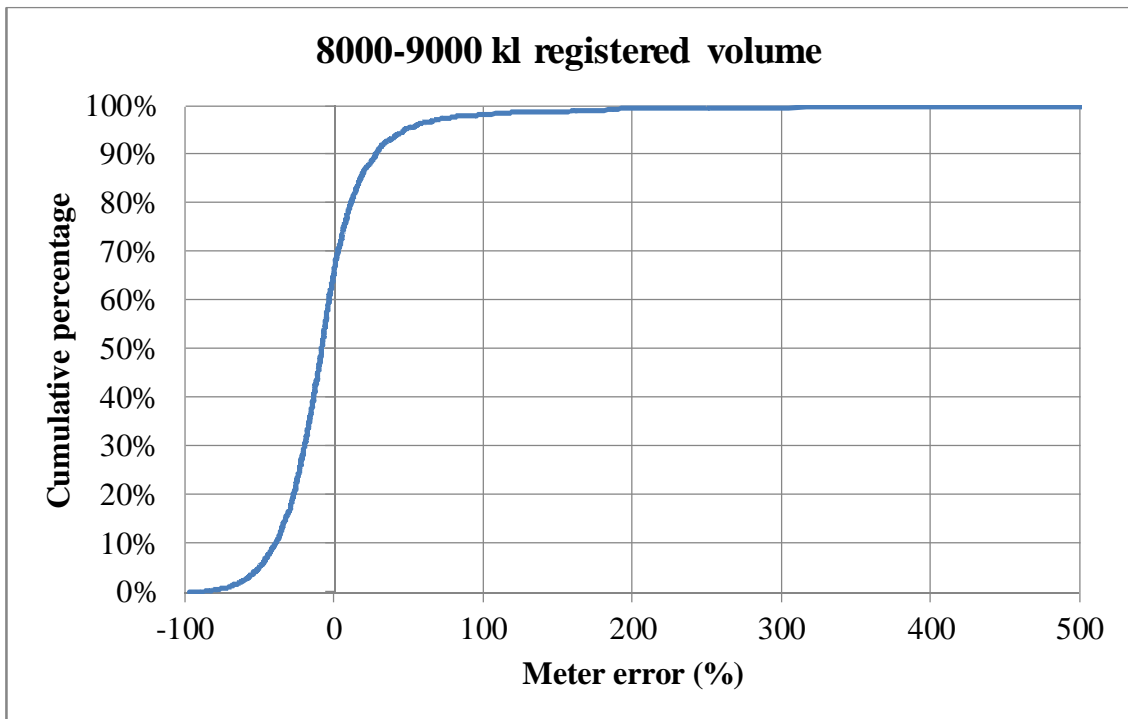


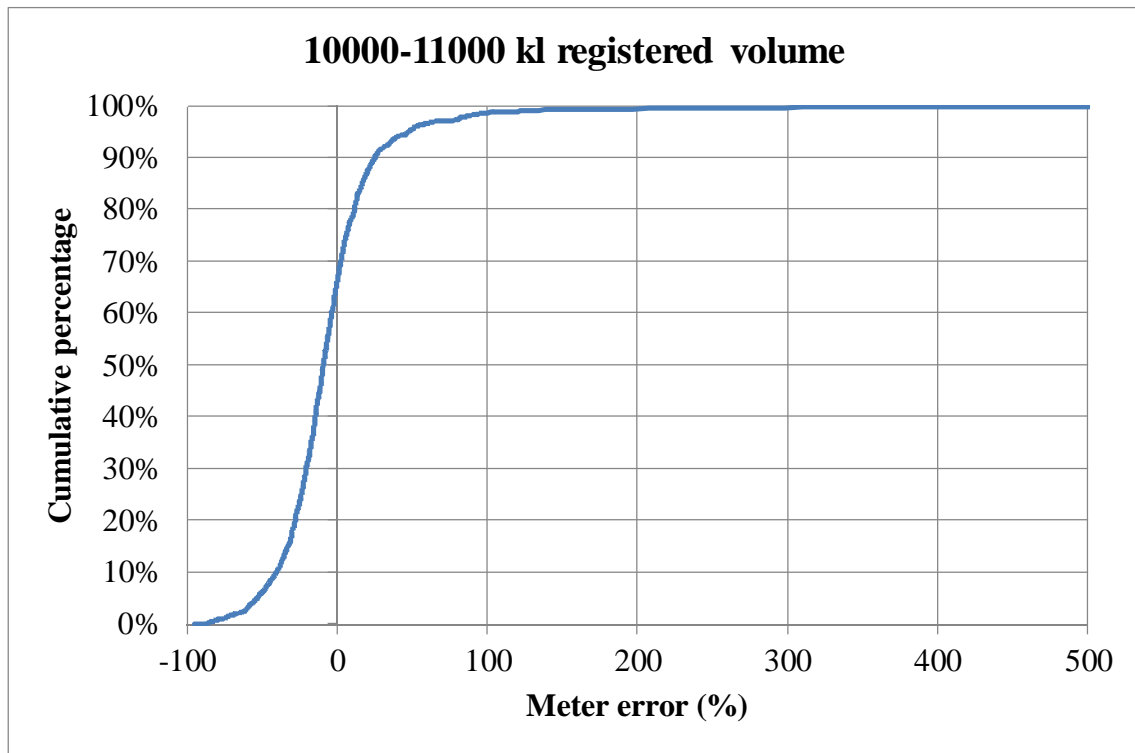






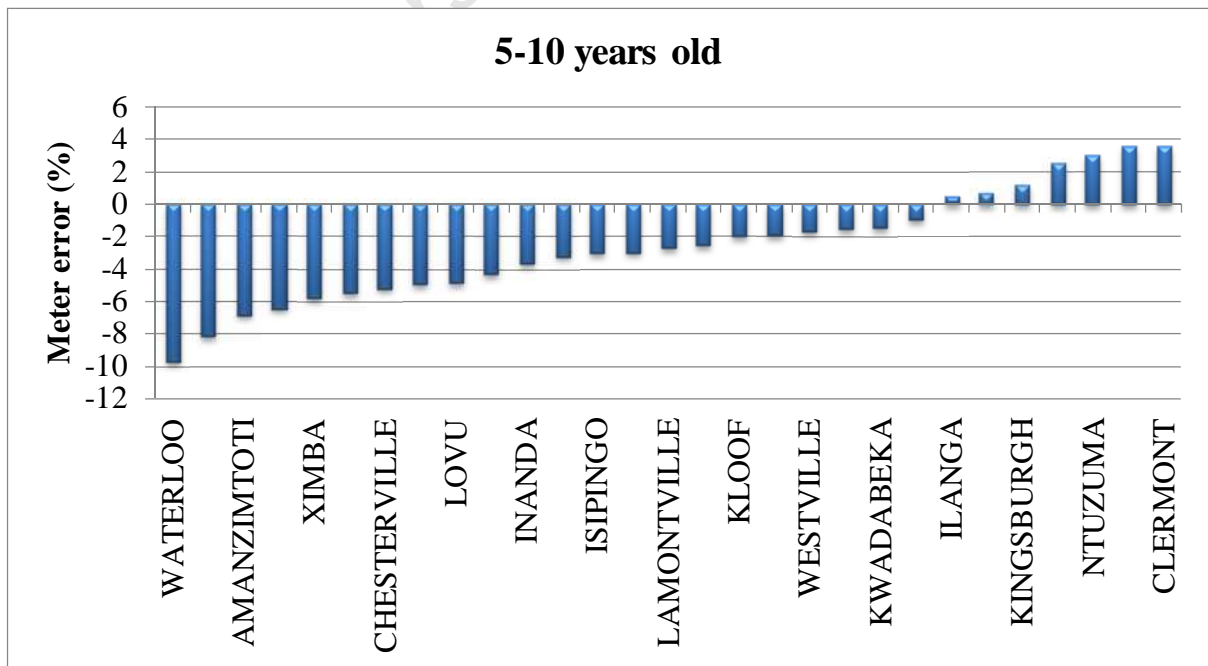
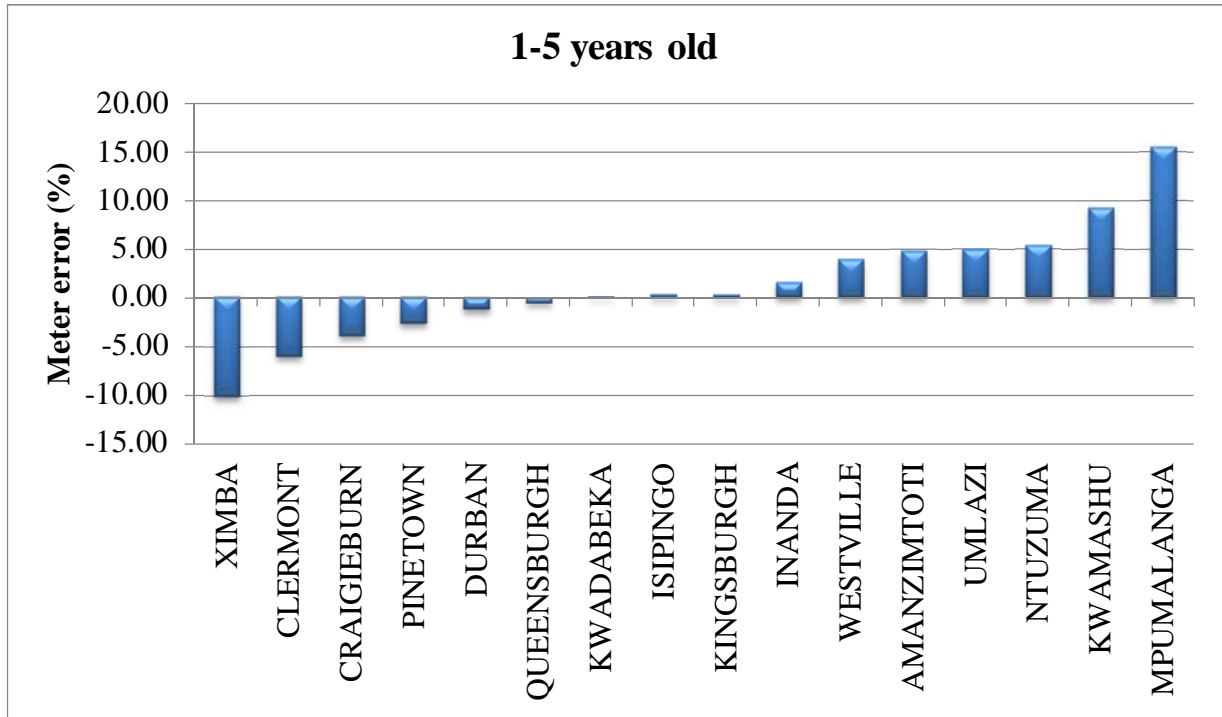


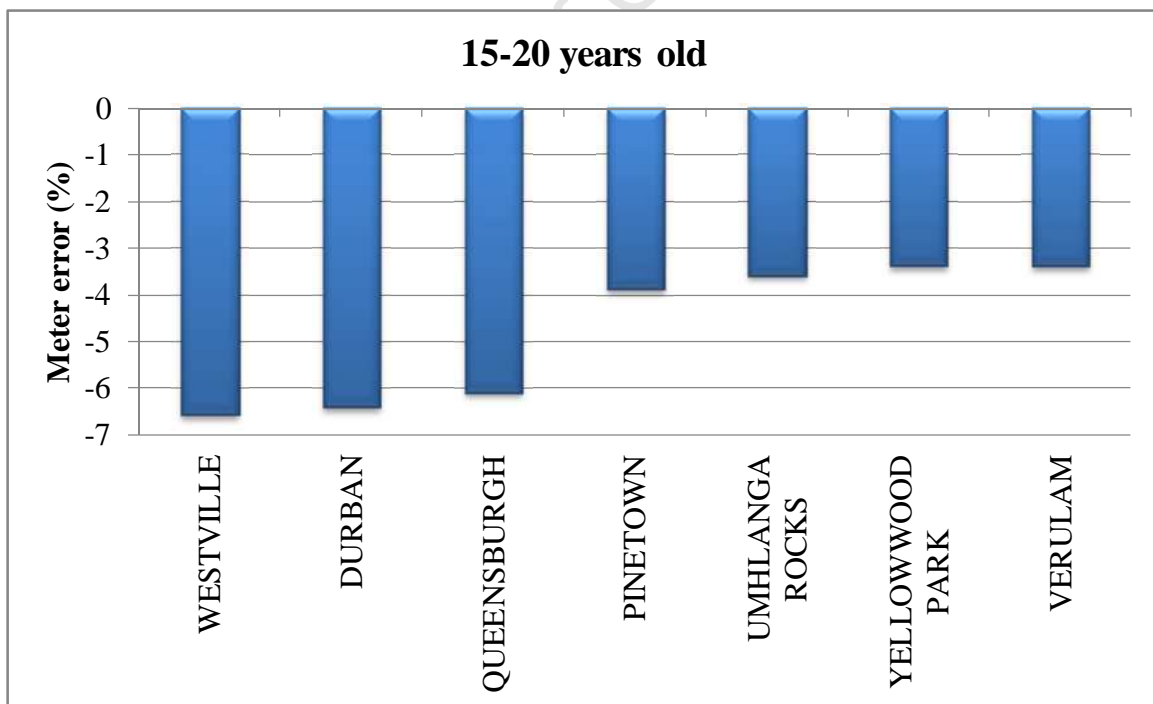
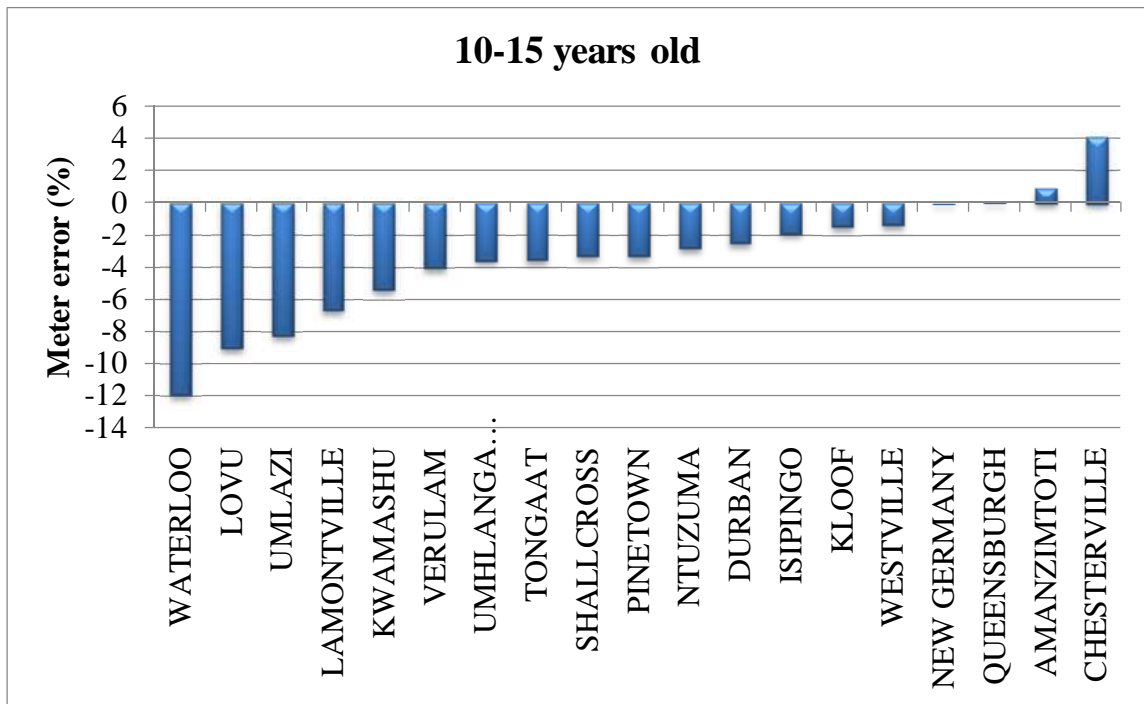


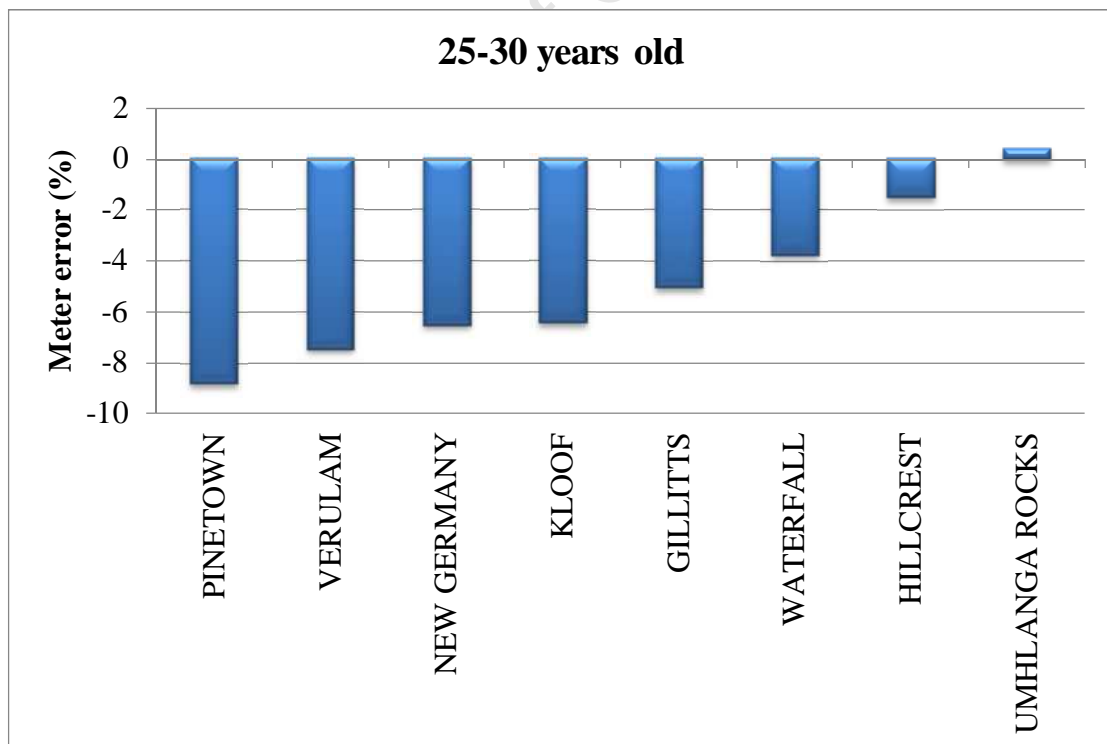
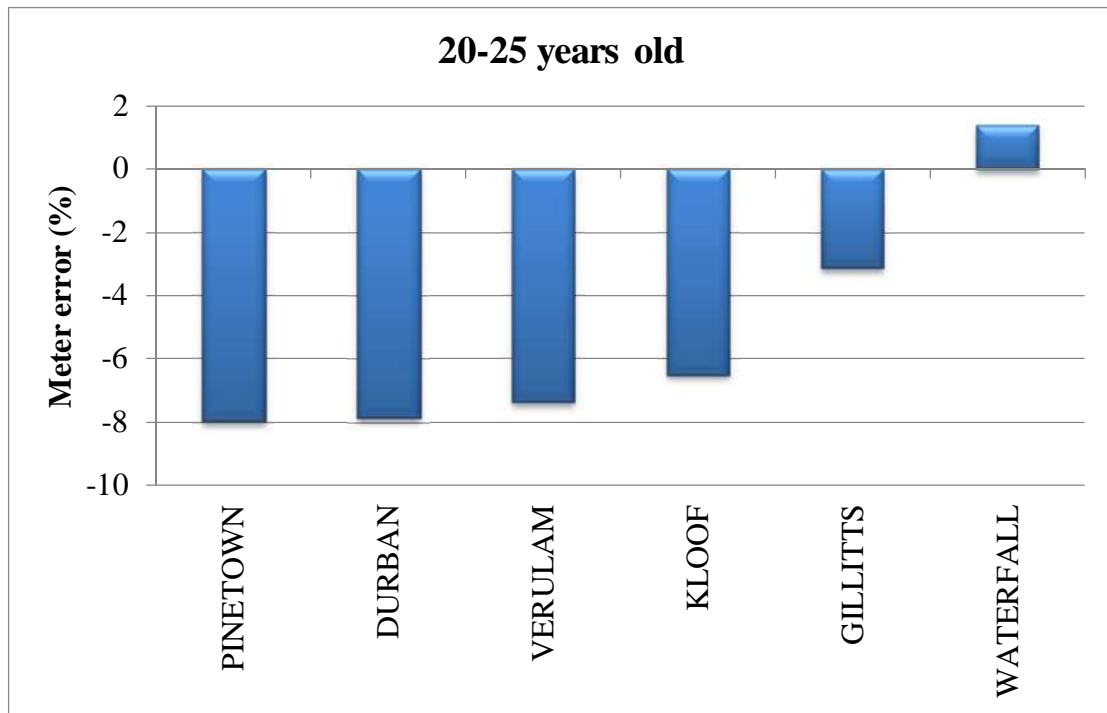


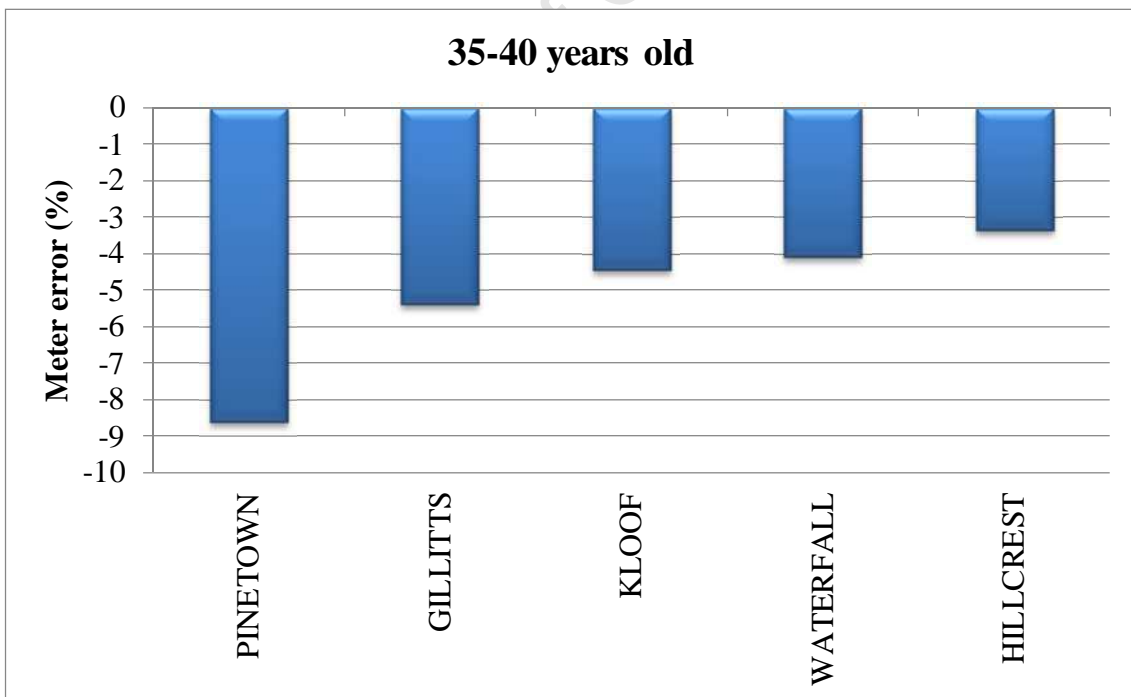
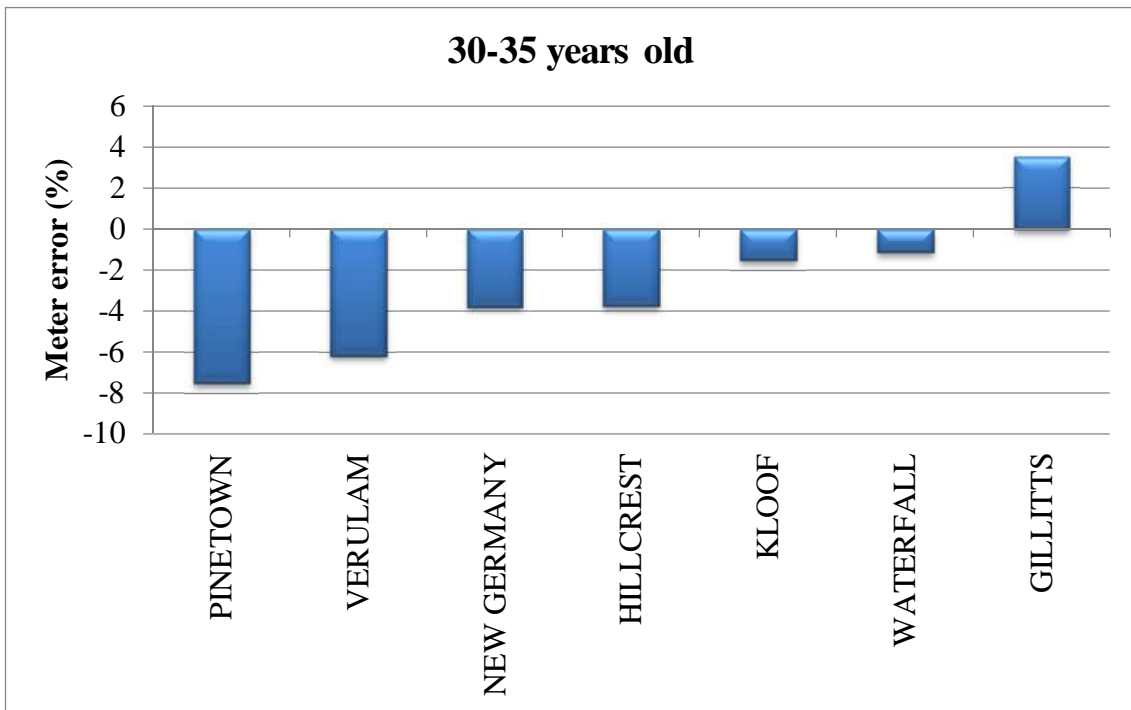
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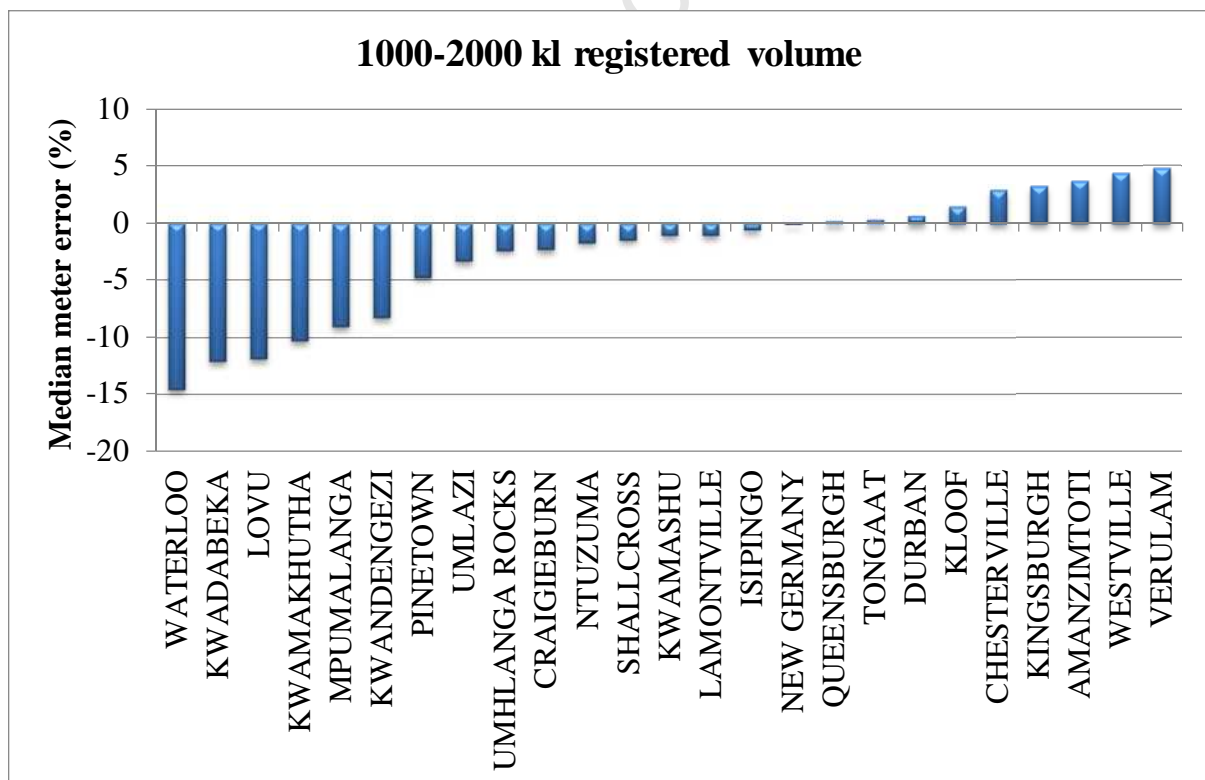
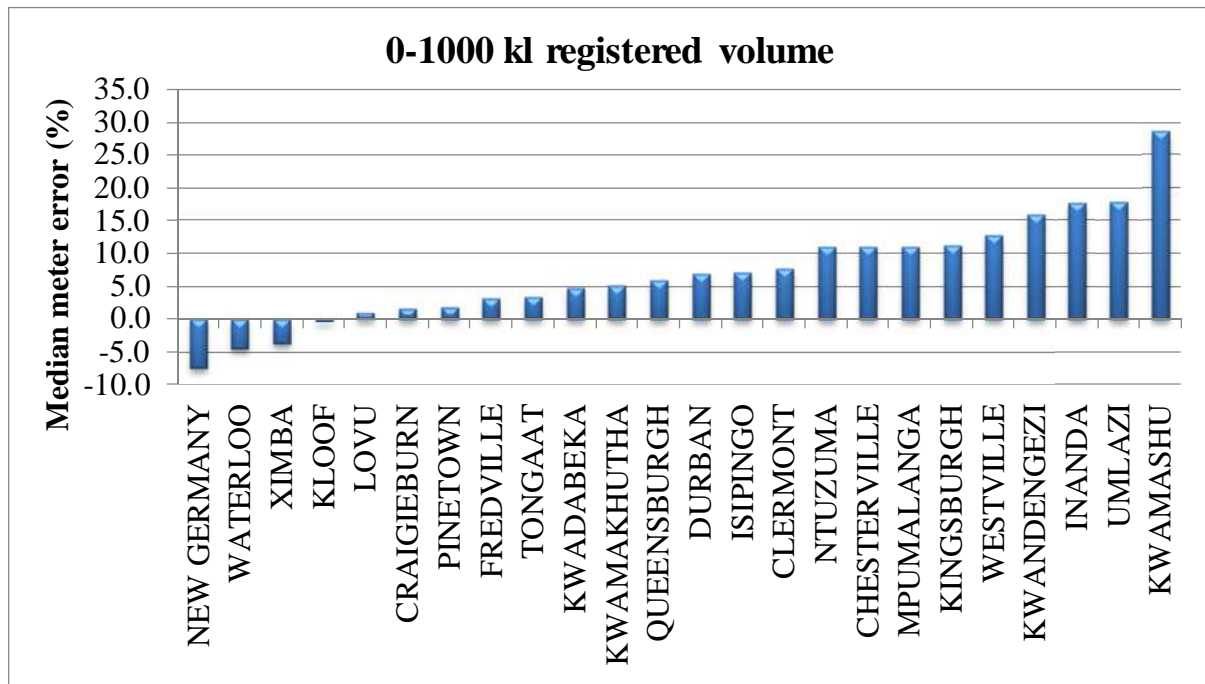
Appendix E: Meter error per Town charts

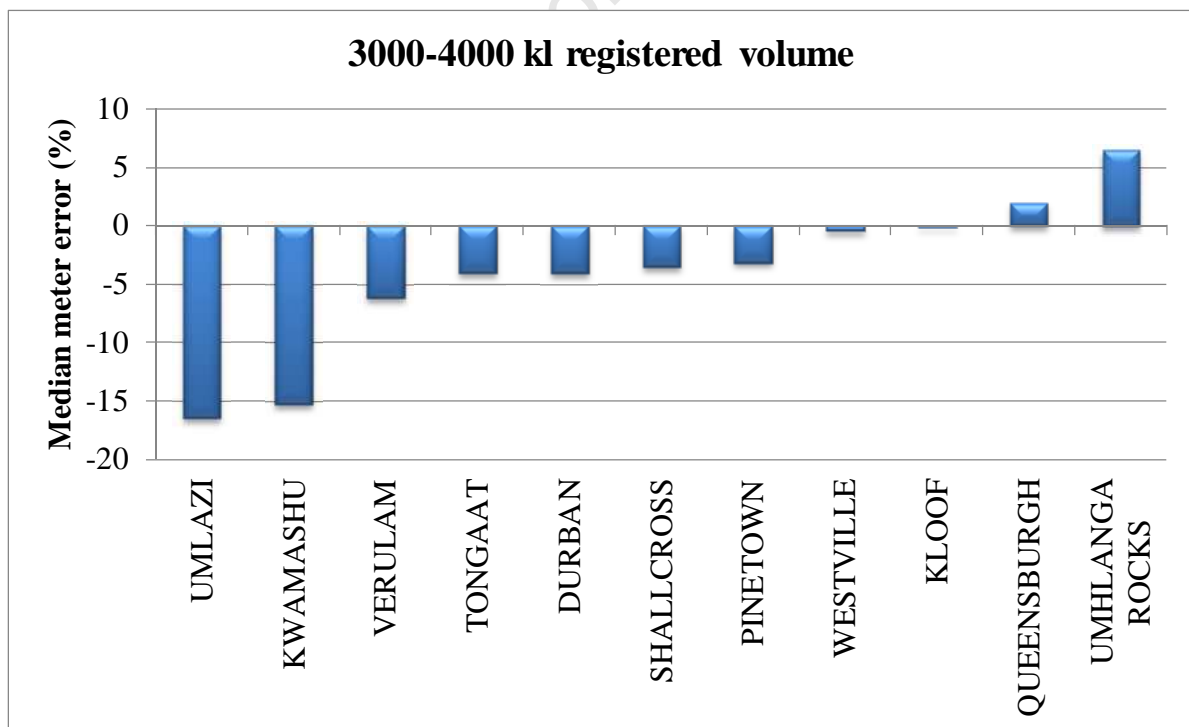
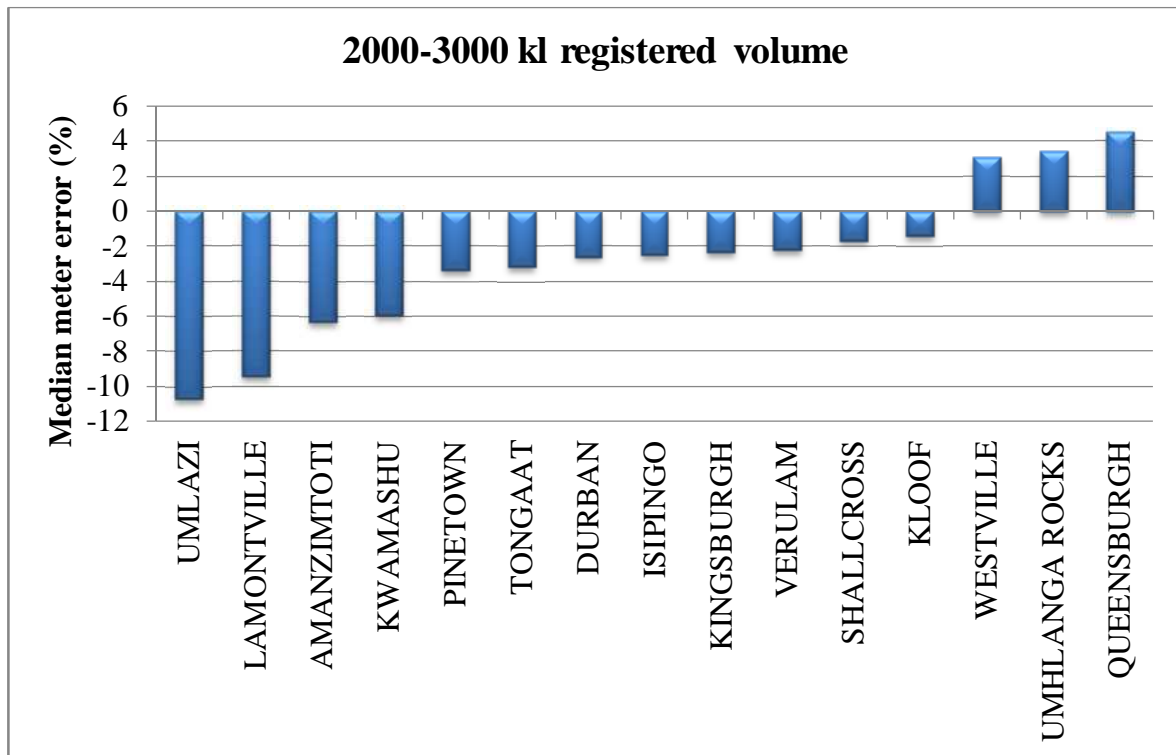


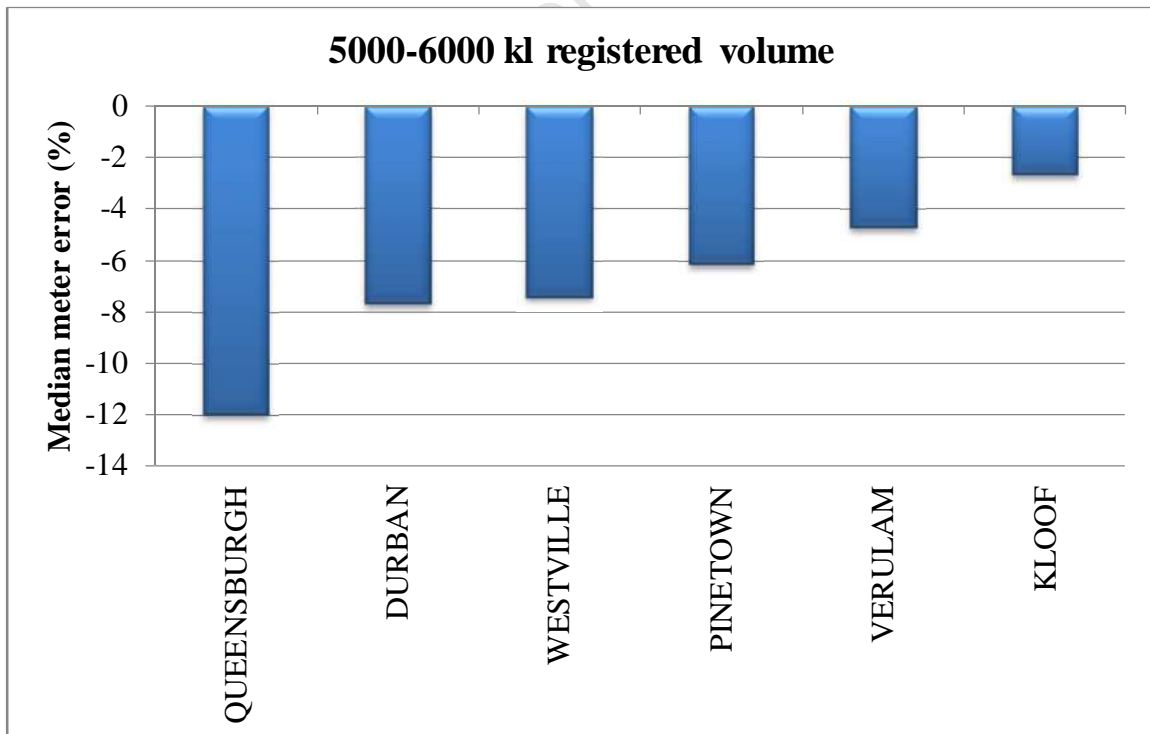
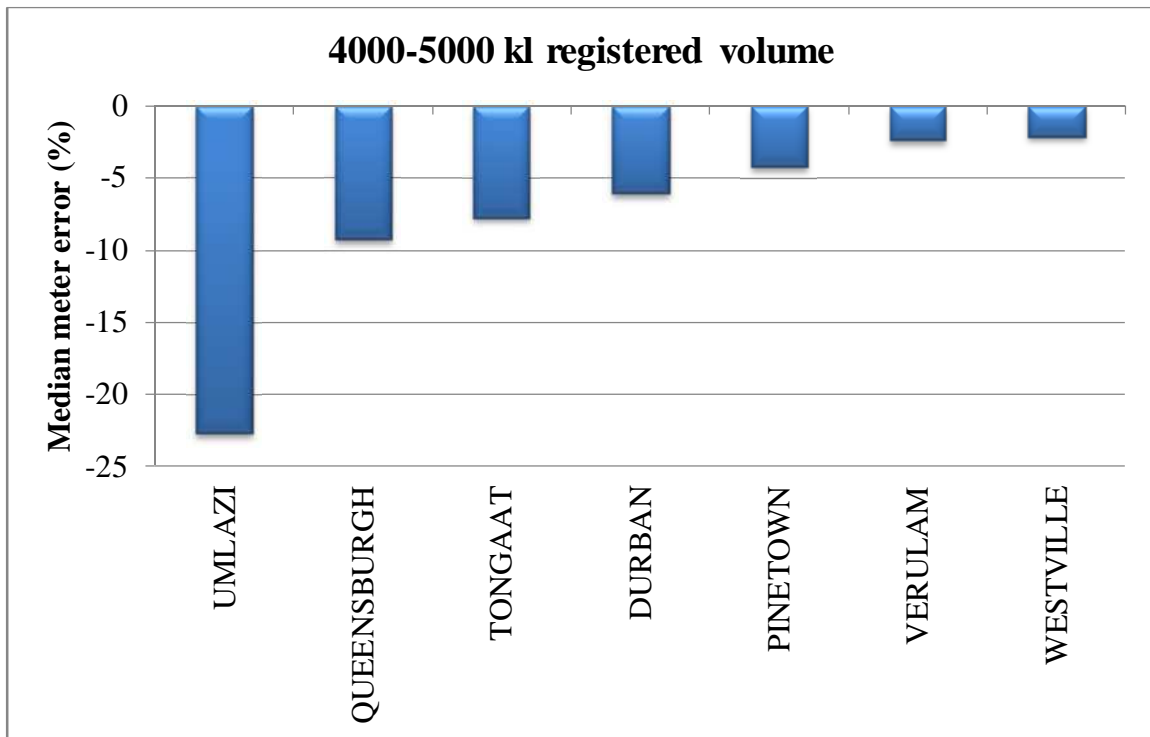


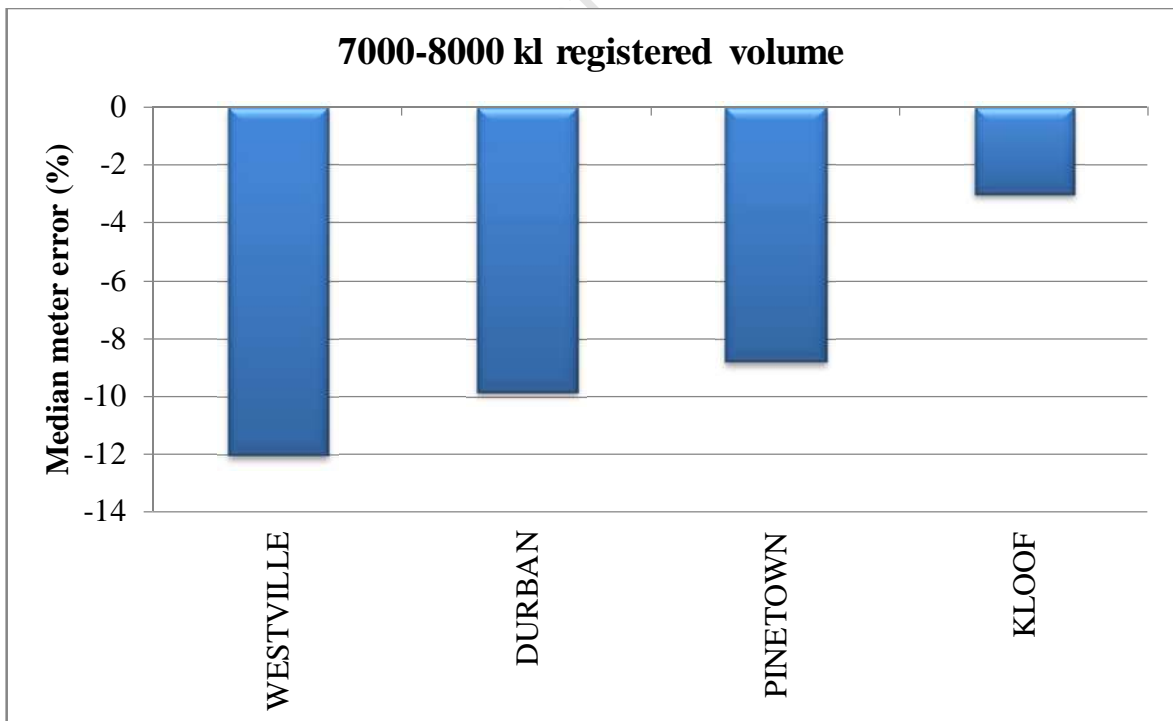
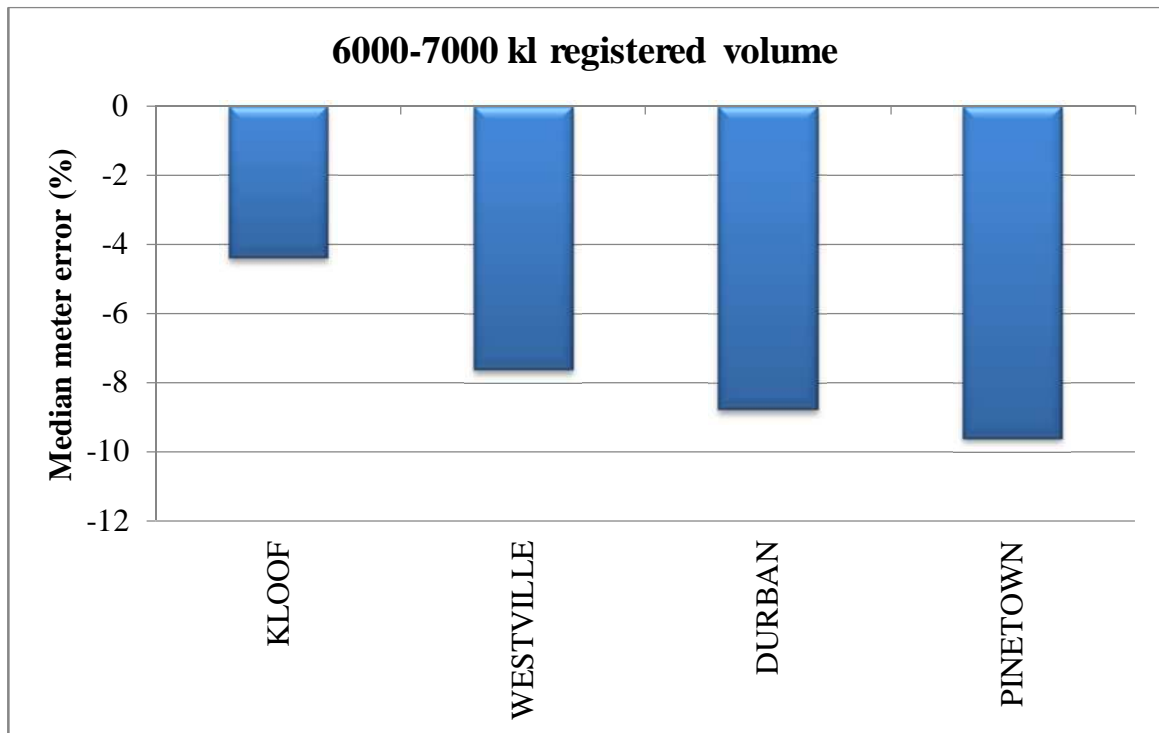


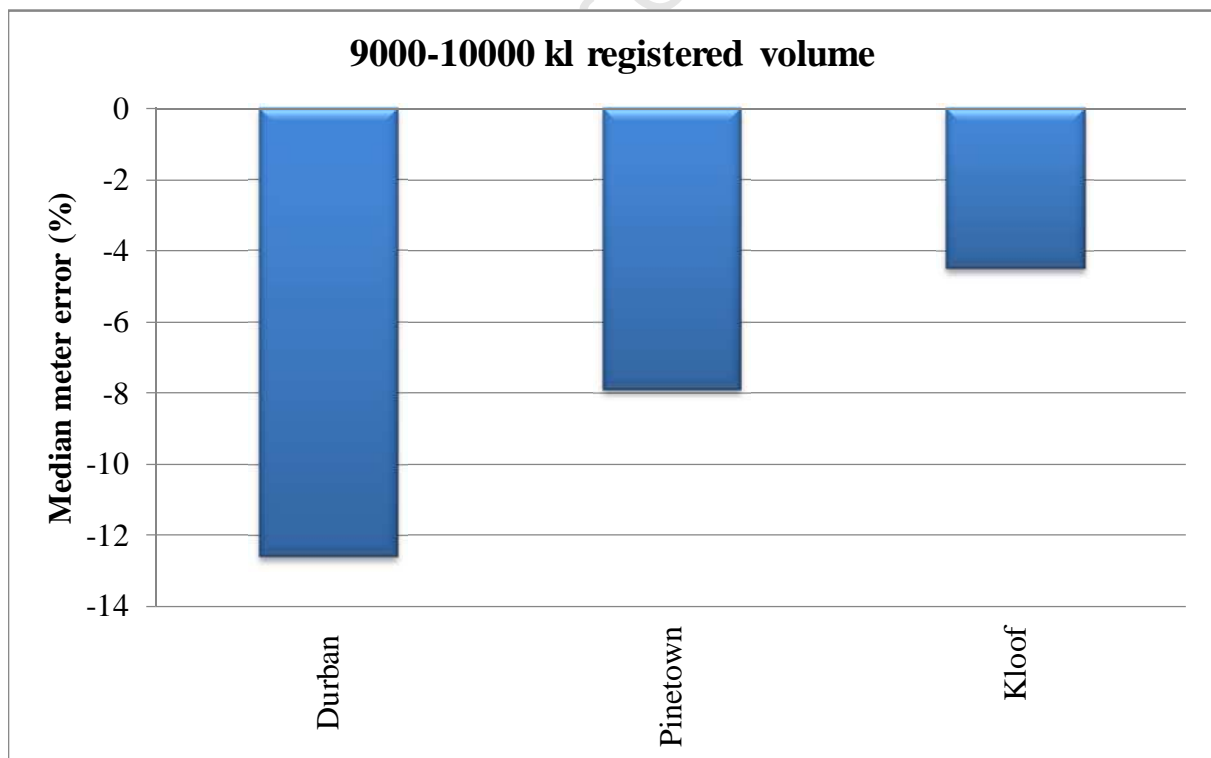
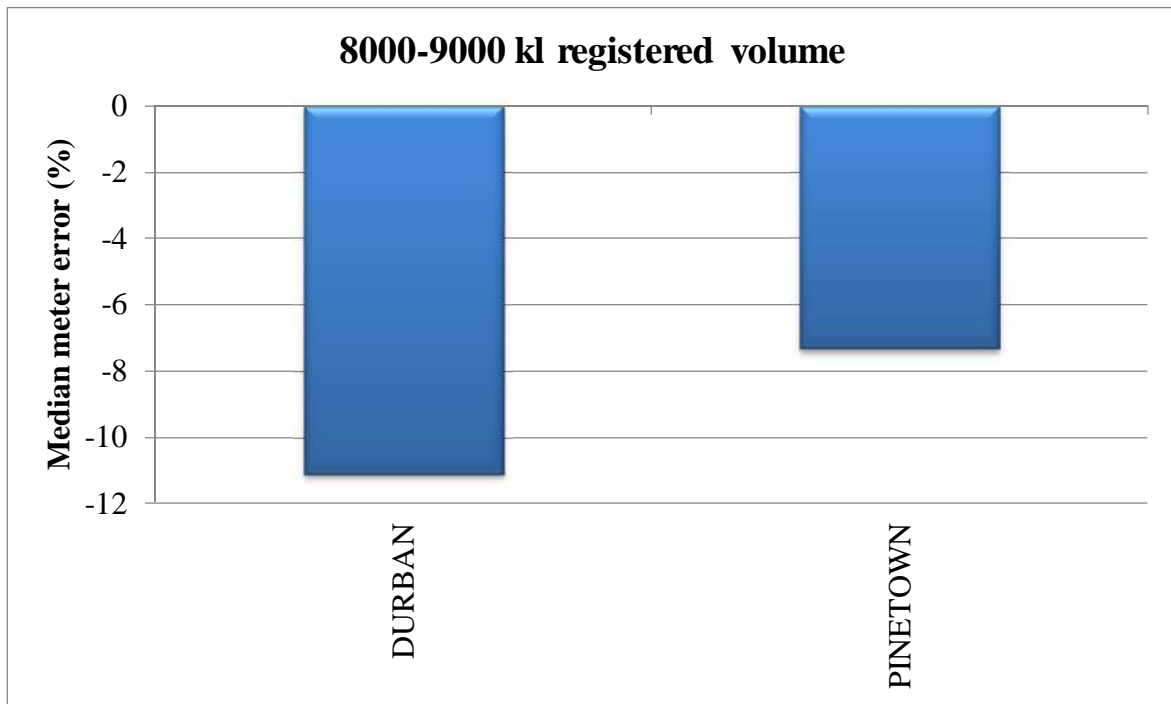


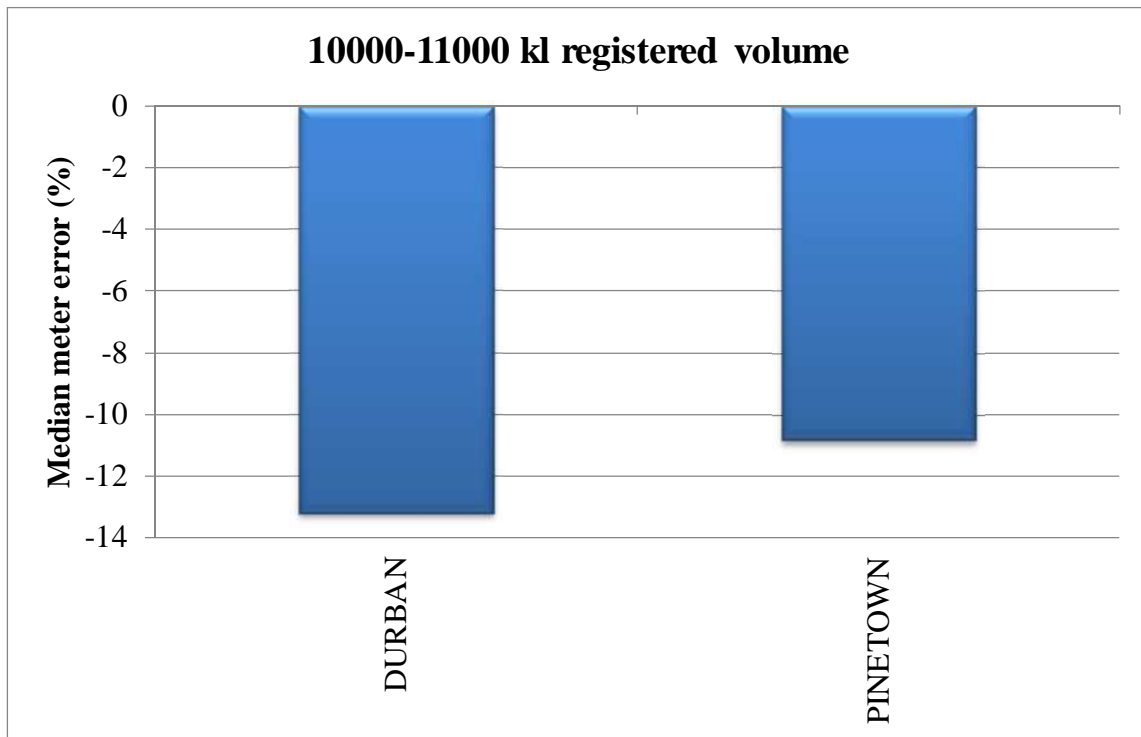












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Appendix F: Master meter error curves tested in the laboratory

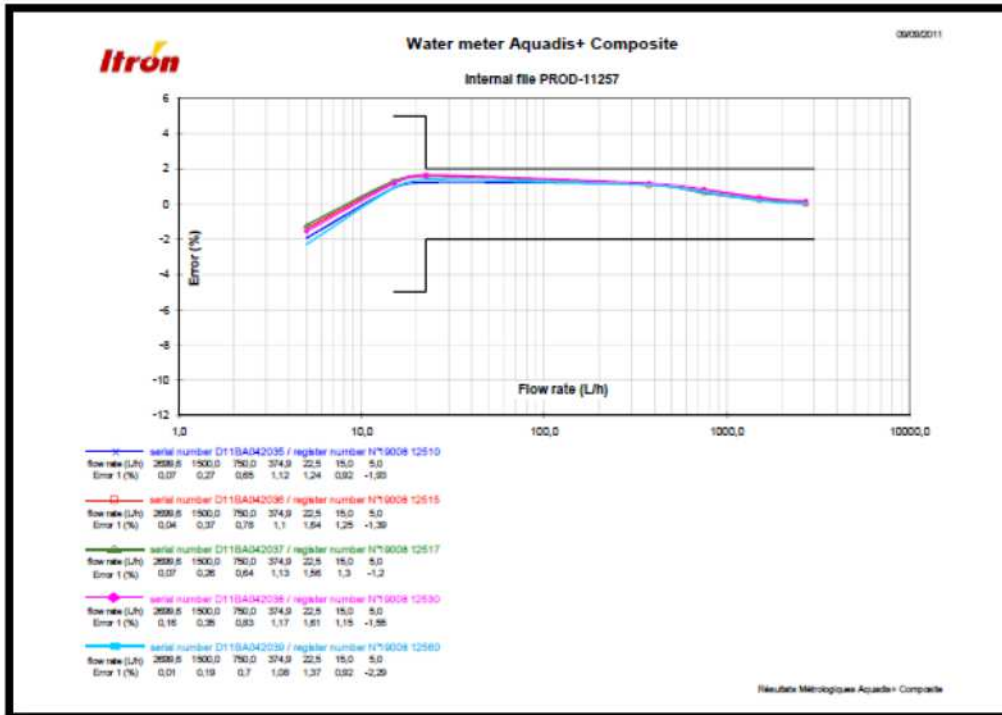


Figure 1: Meter error curves of master meters tested in the manufacturer's lab

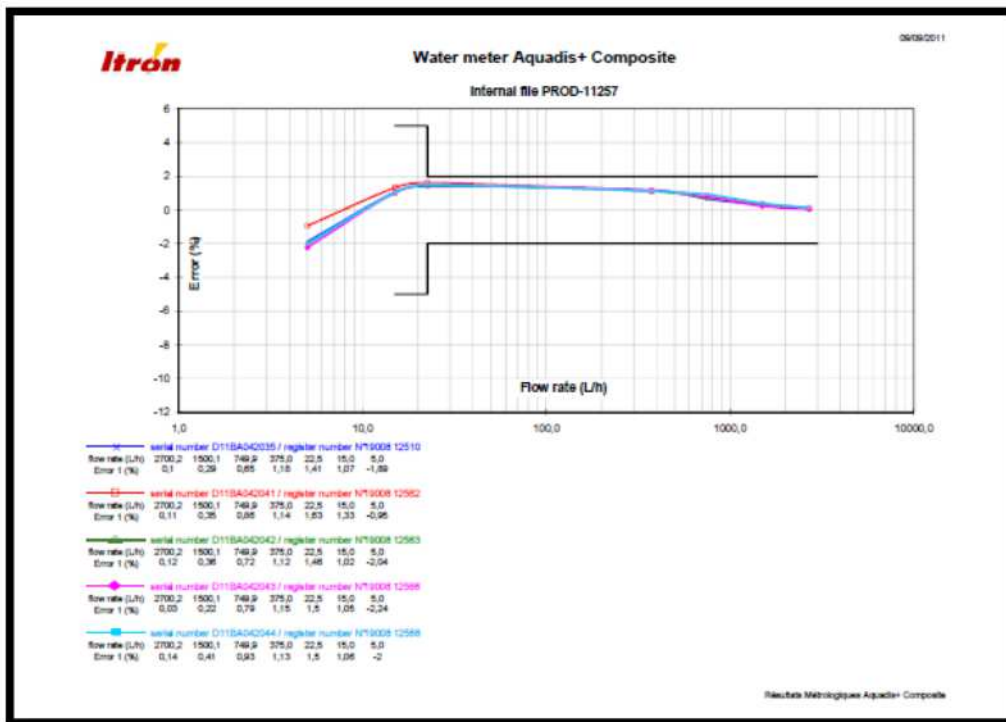


Figure 2: Meter error curves of master meters tested in the manufacturer's lab

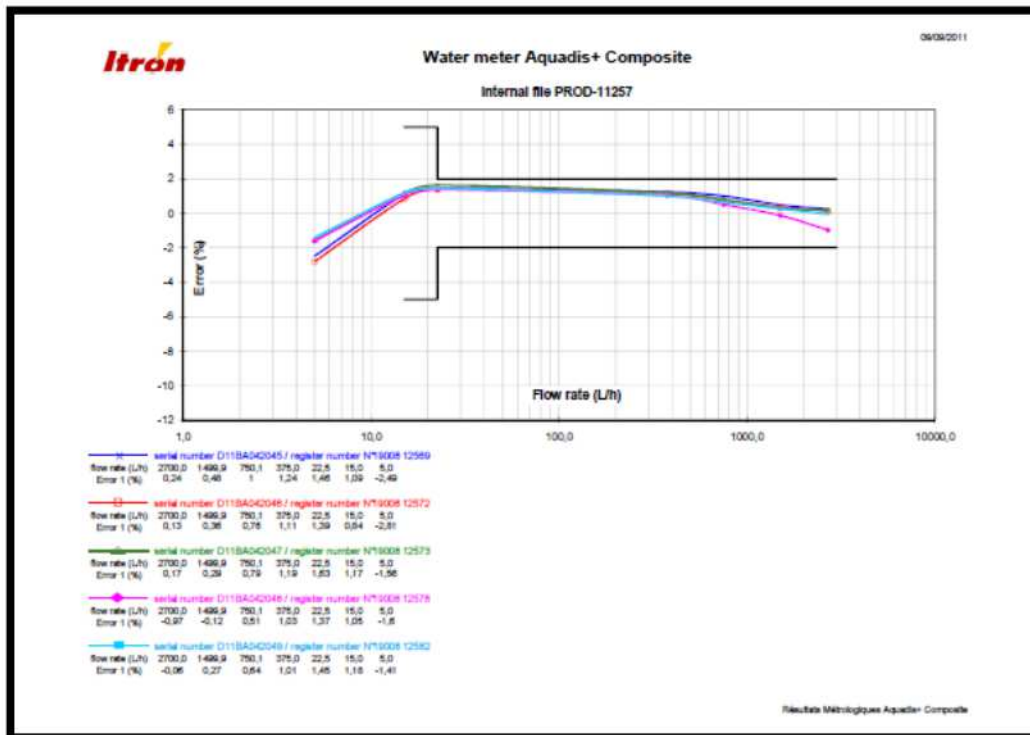
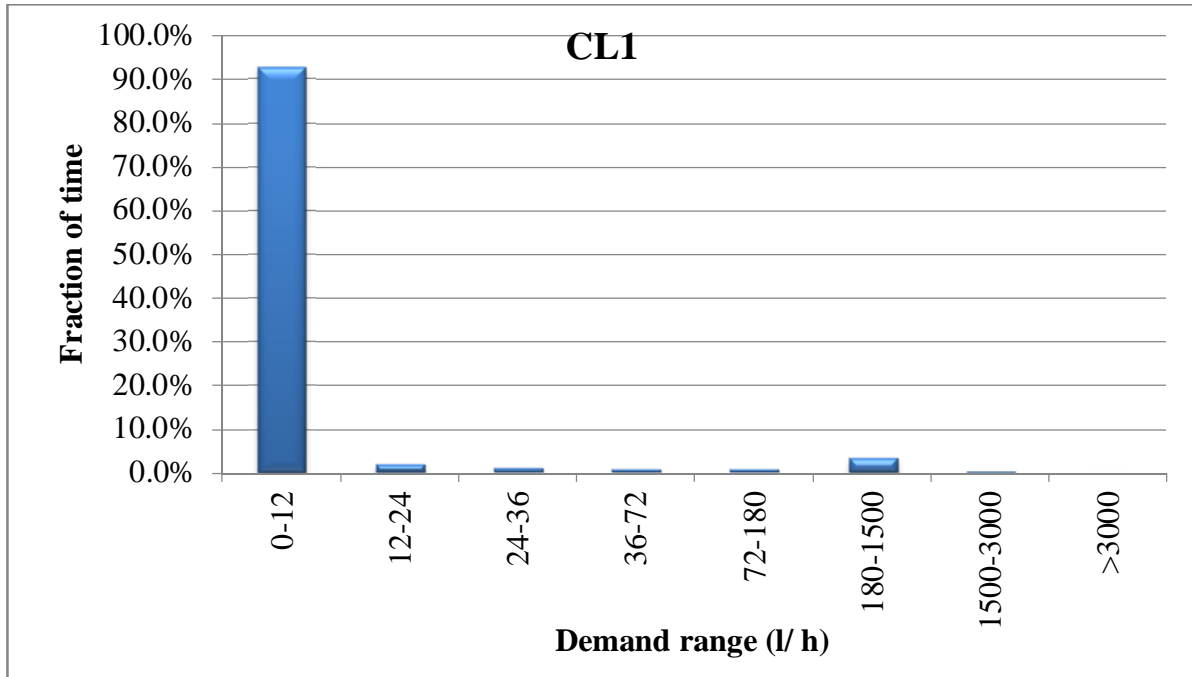
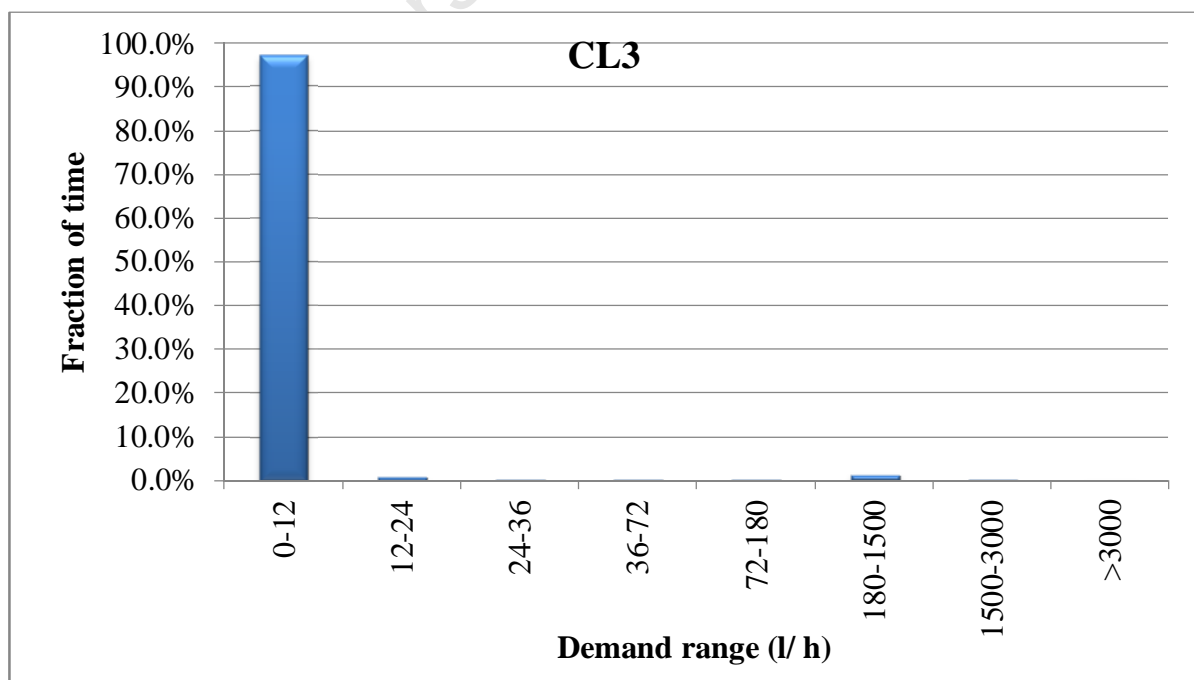
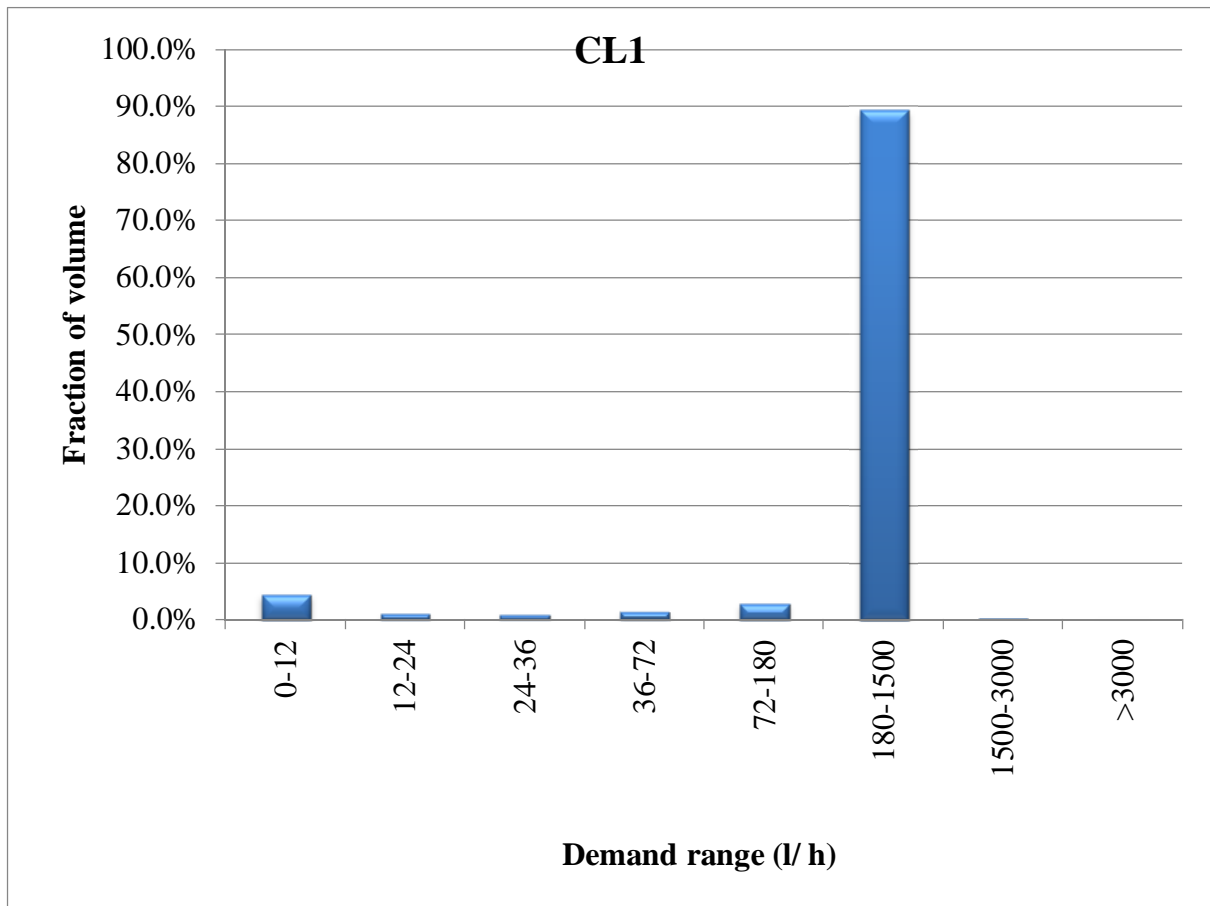


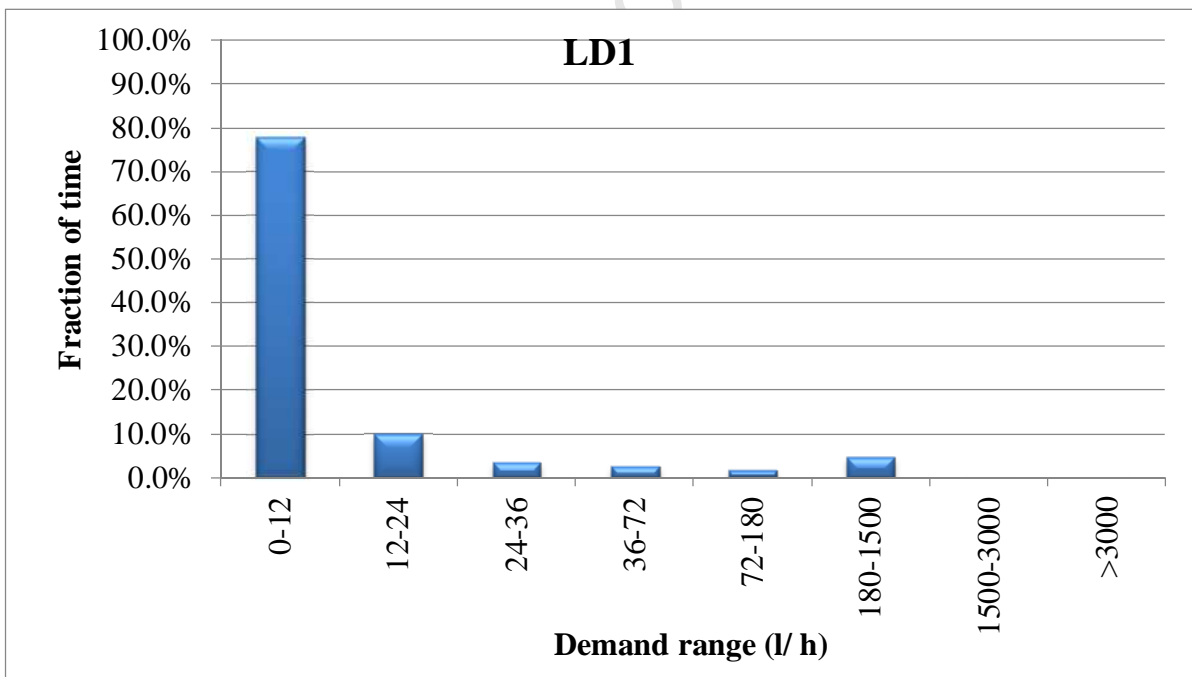
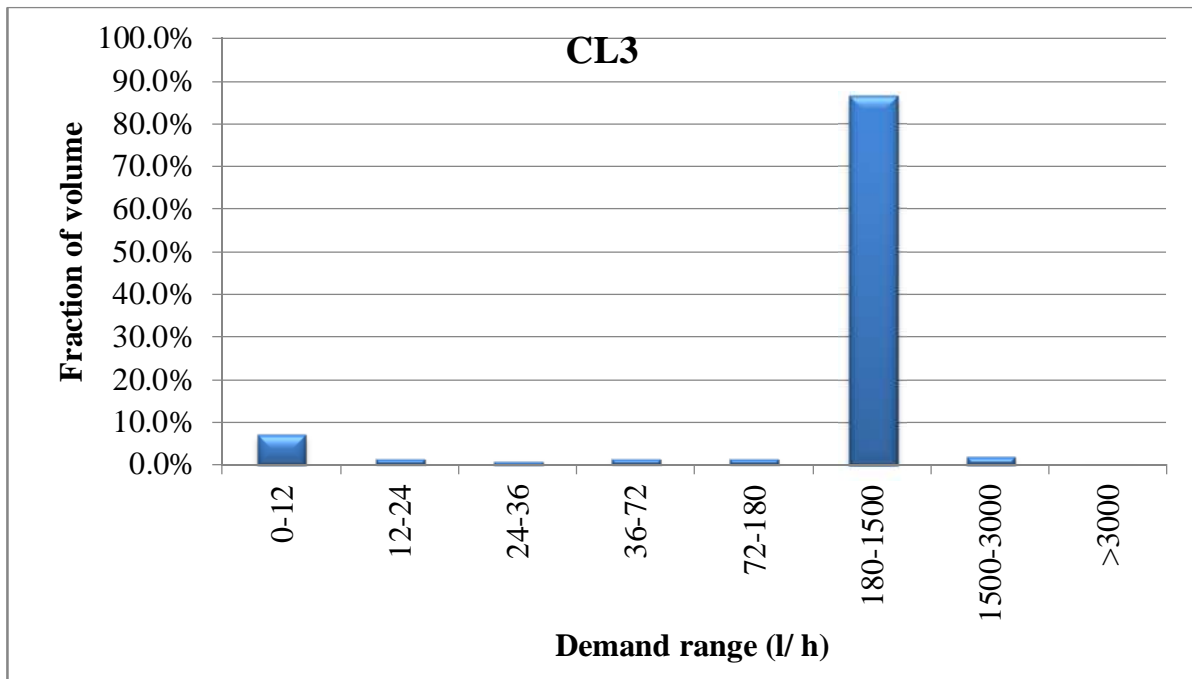
Figure 3: Meter error curves of master meters tested in the manufacturer's lab

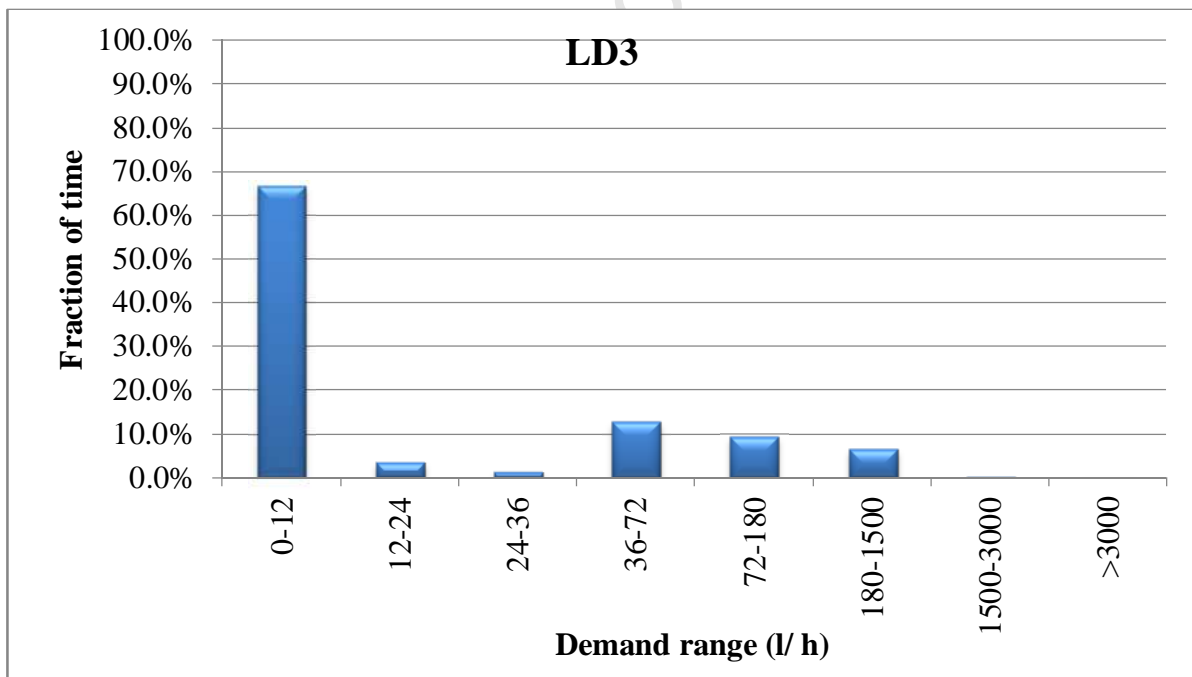
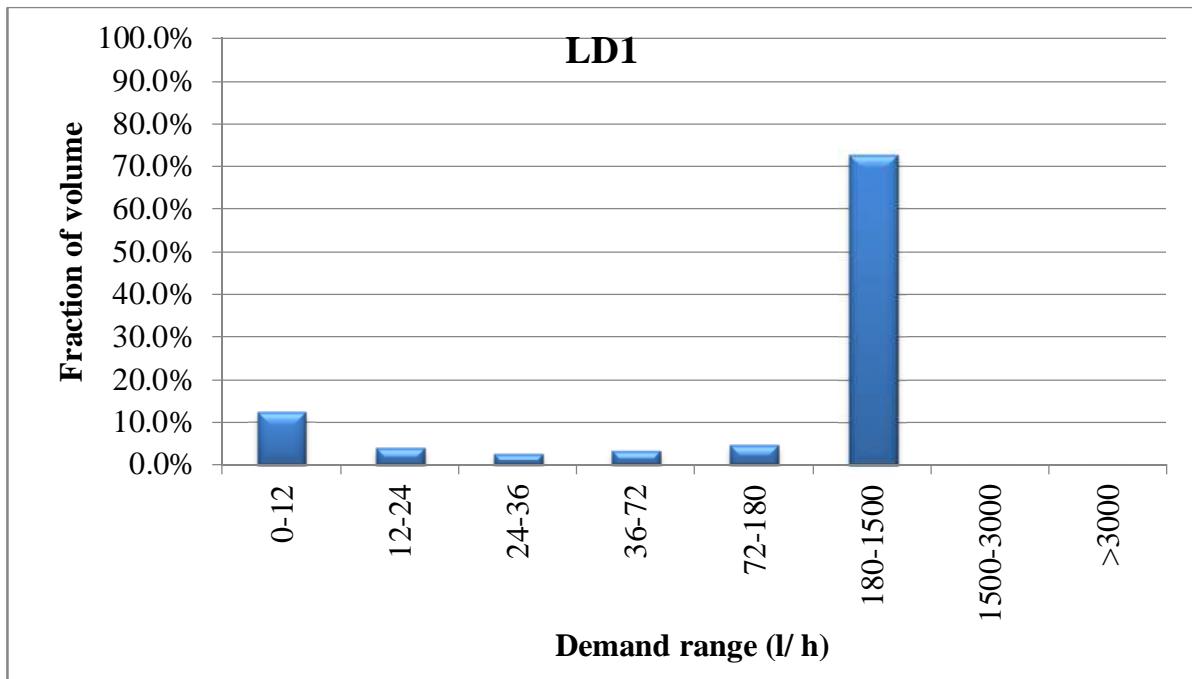
Appendix G: Histograms of logged domestic consumer meters

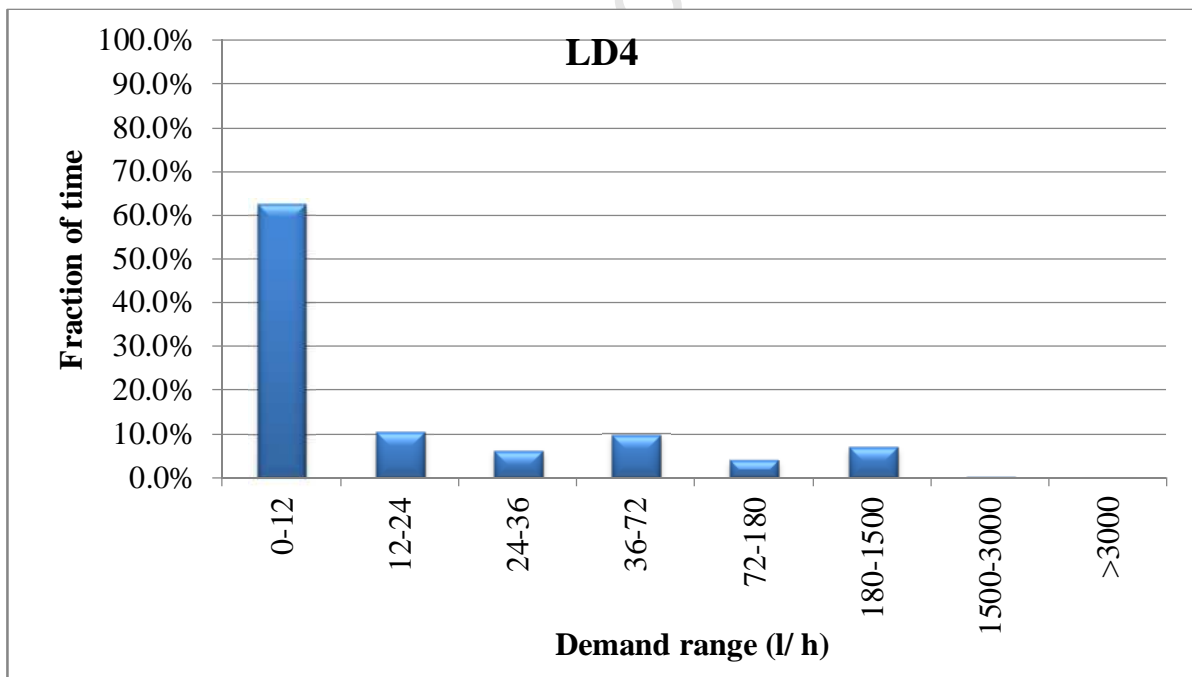
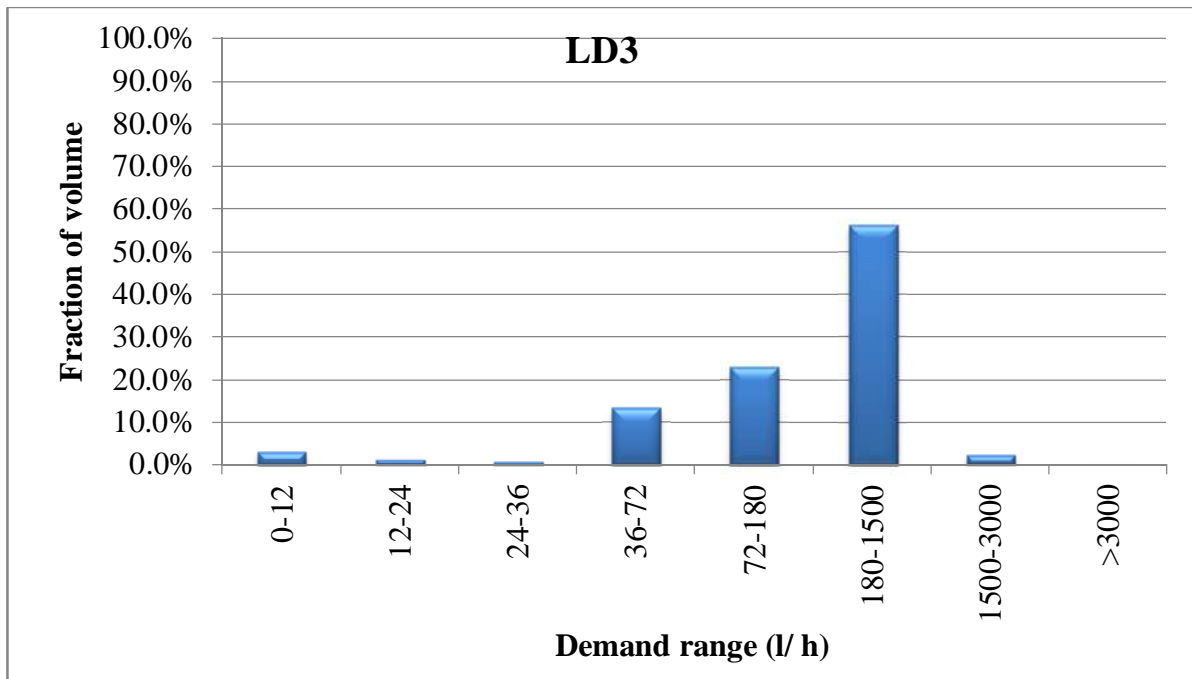


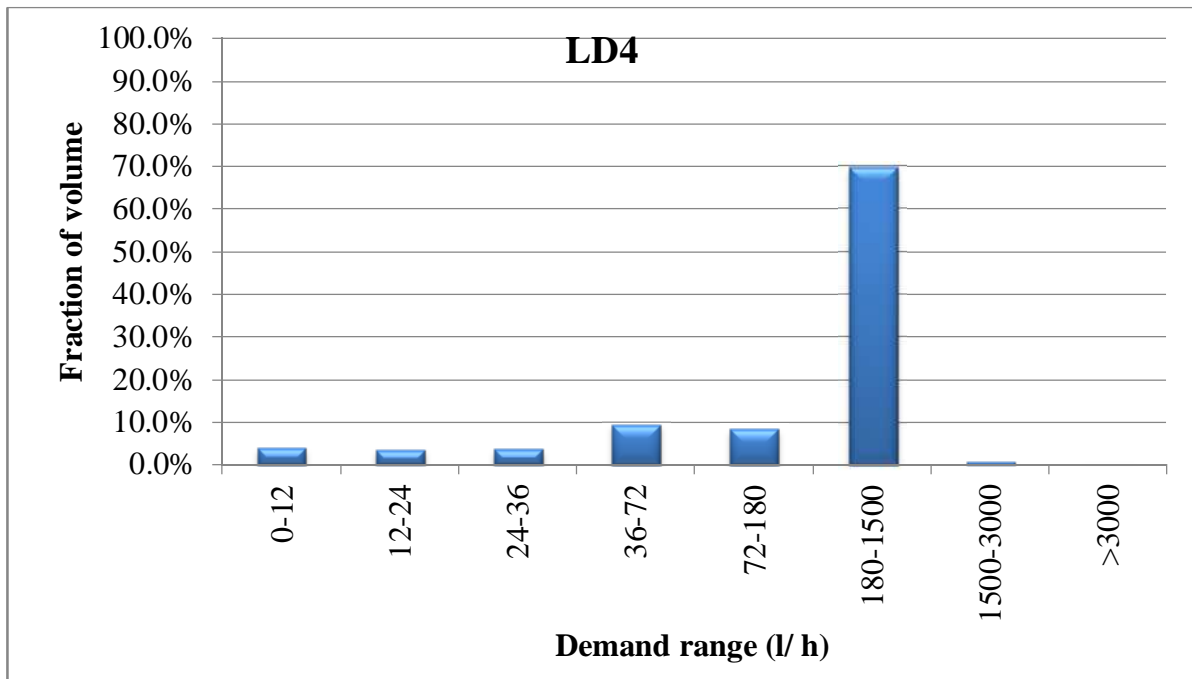
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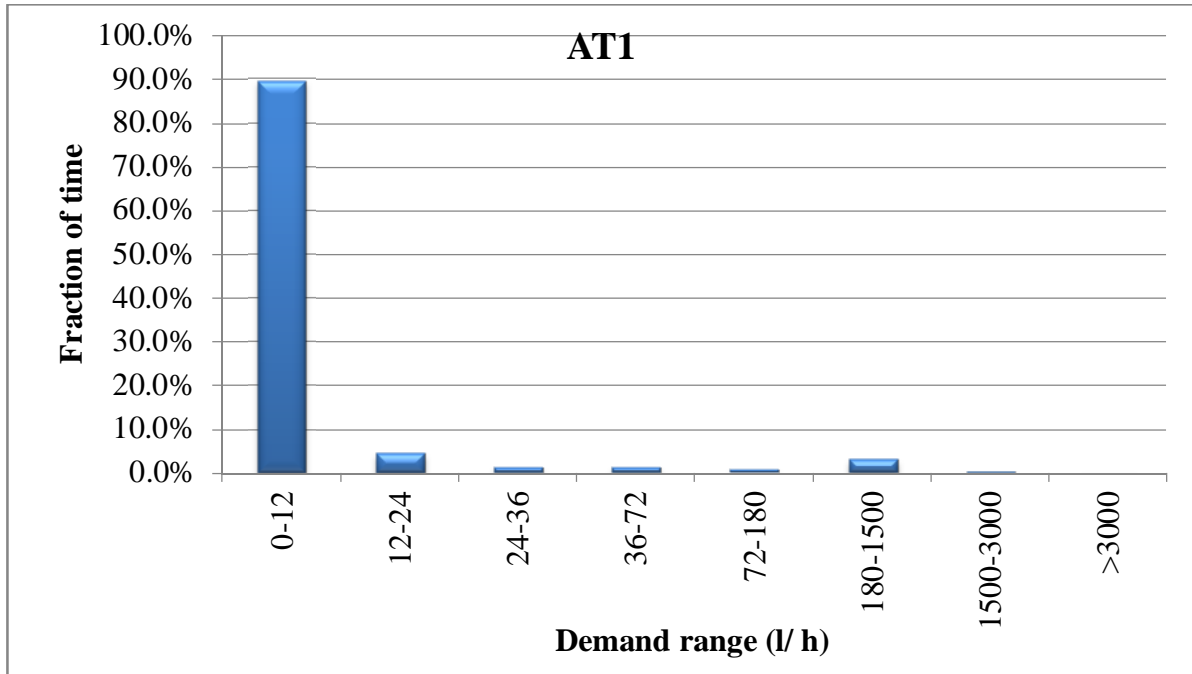




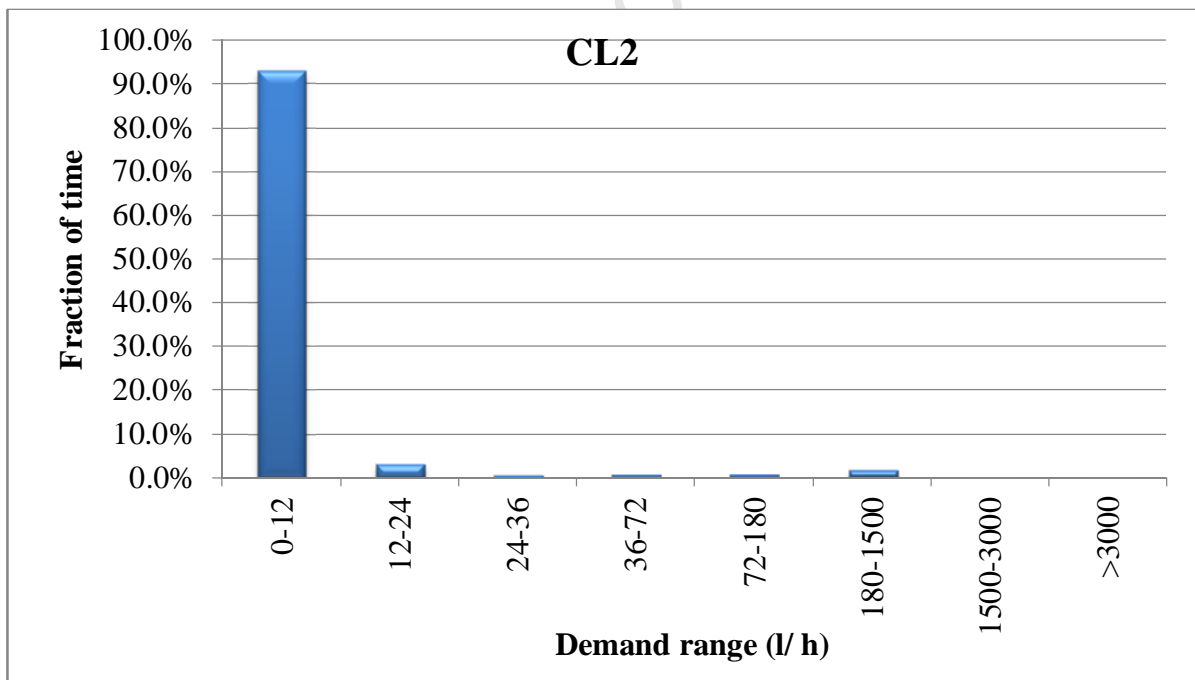
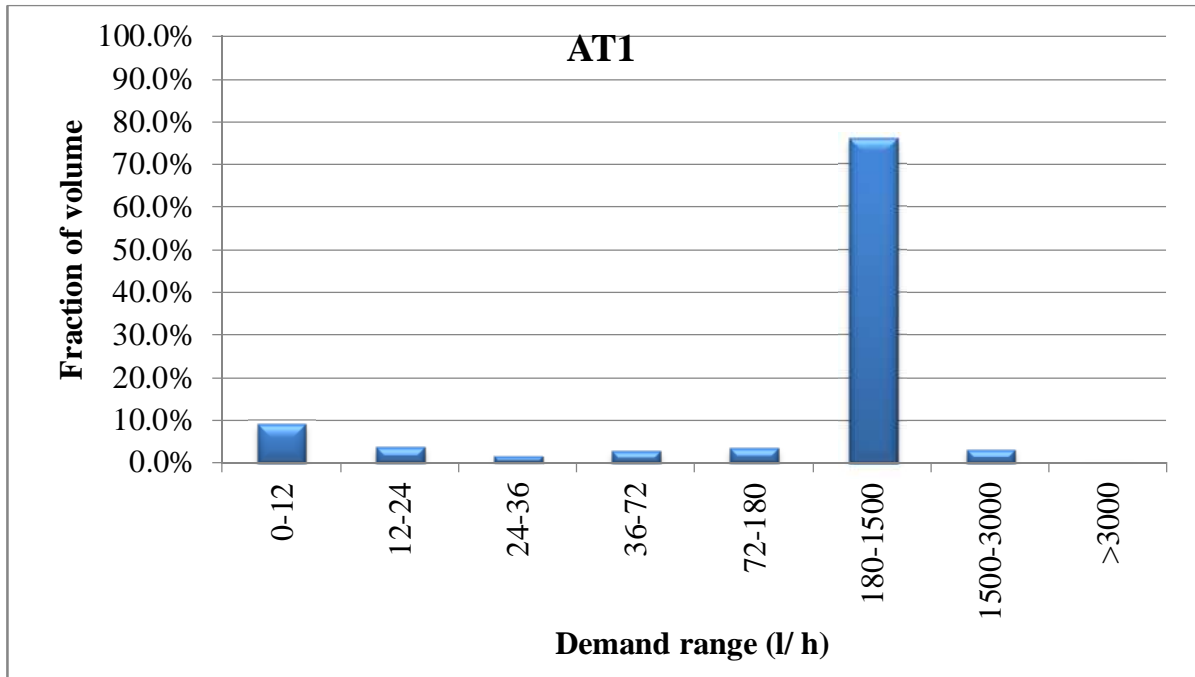


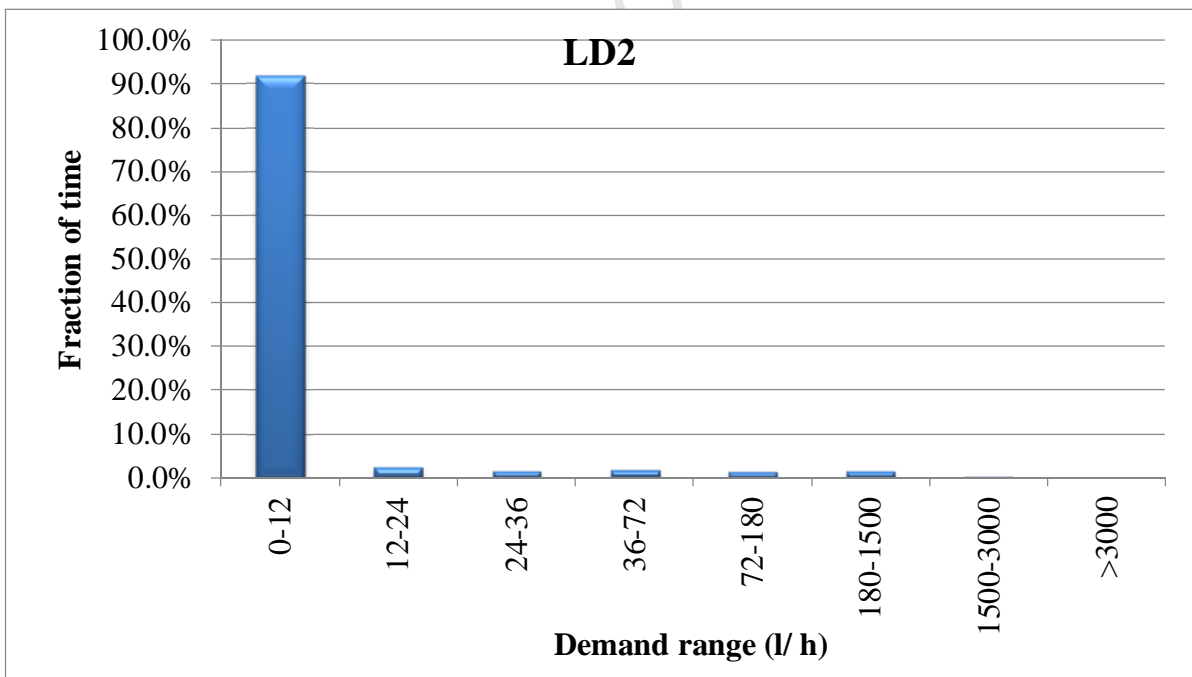
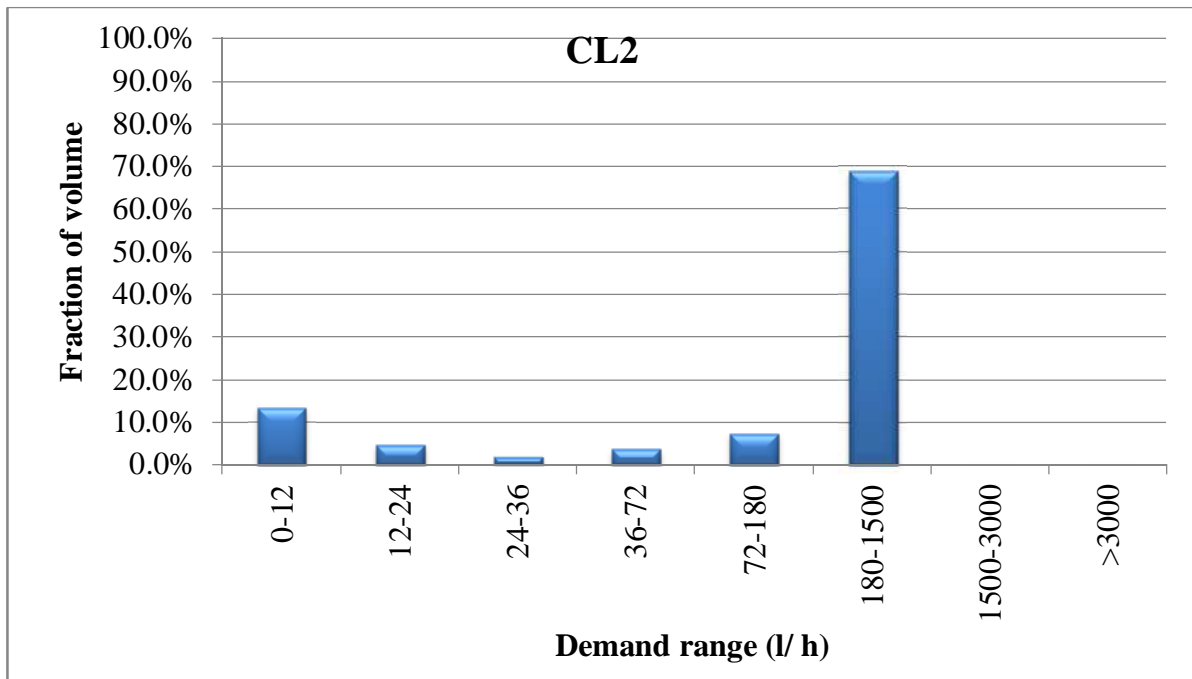
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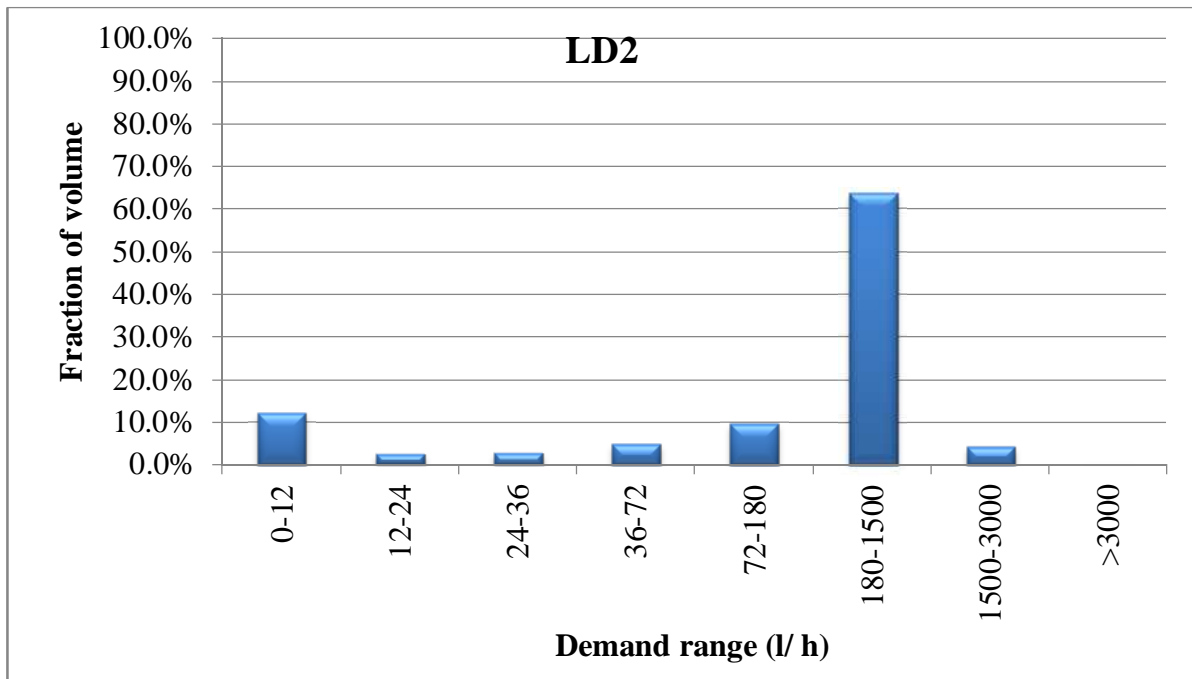
Appendix H: Histograms of logged domestic consumers with UFRs



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