WATER METER PERFORMANCE IN SOUTH AFRICA

Report to the
WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

Selecting the appropriate interventions for addressing the high non-revenue water (NRW) levels requires a detailed quantification and understanding of the various NRW components. In South Africa, the conventional approach to accounting for Apparent Losses (AL), the component of NRW that is the focus of this study, has not been from explicit quantification but rather through the reliance on rule of thumb estimations. The lack of explicit quantification of apparent losses may lead to sub-optimal or inappropriate interventions for managing NRW levels due to not being adequately informed.

Many South African municipalities carry out a variety of metering related activities such as the routine testing of water meters but without the express objective of quantifying apparent water losses. Such activities, although insignificant individually, become meaningful in combination with other tests, including those from similar municipalities. This Water Research Commission study seeks to leverage on these individual tests by collating water meter performance data from accredited laboratories into a freely available electronic database that will facilitate improved meter management in South Africa.

The project aims were to (i) undertake a literature review on meter performance evaluation, (ii) workshop with stakeholders (municipalities, water boards, meter manufacturers, NRCS, etc.) on key requirements, (iii) collate meter testing data from accredited laboratories, (iv) develop a database for water meter performance, and (v) evaluate the performance of new water meters in South Africa.

While a metering framework exists in South Africa, its main limitations are that it is outdated, has limited requirements for water meters when compared to other measuring instruments and offers no guidance on the testing and management of in-service water meters. This, therefore, hamstrings best practice in water meter management and the management of apparent water losses in general as standards define what is possible and permissible. On the other hand, the paucity of work on apparent losses also perpetuates the stagnation in standards development. Quantifying and understanding local specific reference values of apparent losses could potentially provide an impetus in the adoption of metering standard that minimises apparent water losses.

A review of the practices and methods of apparent losses estimation and management shows that several AL estimation approaches have been developed and applied in many locations.

However, the usefulness of the respective AL estimation approaches varies according to the extent to which assumptions underlying the methods lead to over-simplification. Cost is a key factor that heavily informs the choice of one approach over another. The reality is that the methods that have the most utility for comprehensive water meter management come at a prohibitive cost for most municipalities in the country. Key gaps identified in the review include:-

- The absence of explicit guidelines for on-going verification to identify defective meters for South African municipalities. The testing of in-service meters is often done at the behest of the consumer.
- With respect to unavoidable apparent losses, also referred to as the Reference Annual Apparent Losses (RAAL), most of the existing literature assign a default value which one has no way of telling if it considers local conditions. It is essential for the "default" values of RAAL to be determined in line with local metrological standards.
- There is no consensus on the optimal number of test flowrates as different studies reviewed relied on different test flow rates. It is therefore necessary that determination of the optimum number of test flowrates for the South African environment is done.

The study also sought stakeholders' expectations and their views on meter management in general and specifically on what they would like in a water meter performance database. The identified key stakeholders that were invited to a Stakeholders Engagement Workshop with subsequent one-on-one engagements included the following:

- South African Bureau of Standards (SABS)
- National Regulator for Compulsory Specifications (NRCS)
- Water Meter Manufacturers' Association
- Water Services Authorities and/or Water Services Providers (Municipalities and Water Boards)
- Academic/Research Institutions

The following is a summation of the key output from the Stakeholder Engagement Sessions conducted for the project: -

i. Inadequate regulations/standards/guidelines for in-service water meter testing.
ii. Meter testing is largely reactive and inadequate.
iii. Pervasive use of spreadsheets for meter testing data with limited analysis of the records.
iv. Meter testing according to SANS 1529 does not reflect field conditions.
v. Meter replacement periods are largely based on Rule-of-thumb estimates with no scientific basis.
vi. Inadequate funding allocations cited for limited meter replacements programmes, where such programmes exists.

vii. Availability of illicit metering products on the market.
viii. Ownership, custodian, and control of the database product was a concern and how users will be registered and use the database for only non-commercial and authorized uses.
ix. Structural sector issues such as the voluntary SABS Mark which manufacturers can opt out for thereby exempting them from quality control requirements of the mark.

A key aspect of the study was the collation and analysis of historical meter testing data from participating municipalities. While over 5,613 records were obtained from five municipalities, only 4,385 records from three municipalities could be used for analysis. Only one municipality has an accredited laboratory with the rest of the municipalities using one meter manufacturer's laboratories. The bulk of meter manufacturers also tend to only test their meters limits meter testing options.
The age of the meters tested could only be determined for 2,344 meters using the serial number logic as the age information is not included in the test results. The bulk of the meters had been in use for less than five year. On the other hand, the meter reading, which is available for all meters showed that a large proportion of the meters had registered well over 10,000 m^3. To put this in perspective, using an average domestic monthly consumption of 30 m^3/month, such a typical consumer meter will take over 27 years to reach that volume, which is excessive.

The probability of failure analysis showed degradation rate of 0.01-0.02% per 1,000 m^3 of volume registered with starting probability of failure for most meters being around 25% and up to 50% for one meter model. The degradation rate with of the probability of failure with age had much higher rates at 1%, 3%, and 6% per year for some models with starting probability of failure of 25%, 9.5% and 4% respectively. The high starting probabilities of failure is of concern and needs validation through the testing of new meters.

To determine the weighted accuracy of the meters that were historically tested, the consumption profile of Johannesburg was used together with the test results of each meter. The implicit assumption being that the consumption profile of Johannesburg is similar to that of other cities and towns. There was no meaningful relationship of the weighted meter error with registered volume for all the meters in the dataset. However, one meter model showed a strong relationship between weighted error and meter age where the error increased annually by 1.2% with a starting error of 8.7%. The high starting error is also of concern and will similarly need validation as the high initial probability of failure.

Despite the weakness of using data that could be of meters that were at the end of their useful life due to reactive meter testing, there are some clear informative trends that the sector can use to manage meters better. Better data collection and standardisation of the testing and test reports, together with more proactive testing would make such analysis even more useful. To counteract some of the challenges currently being experienced in the sector, a meter management database called the Meter Performance Monitor was developed as part of the research. The Monitor is able to handle activities ranging from capturing meter accreditation data, individual test reports, importing historical testing data, analysis and reporting all within a centralised platform that can consolidate data from different municipalities, flow laboratories and the NRCS.

To determine the initial weighted accuracy of new meters, the common meters that were being used and tested by the participating municipalities were reviewed to come up with the top meter models. Seven meter models were identified and these were purchased from the sales department of a manufacturer, or authorised sale representatives, as would be purchased by any customer. The purpose of the purchases was not disclosed to ensure that meters that would have been purchased by any member of the public were also offered to the project.

As a first step, it was important to determine the optimal number of test points for South Africa using two main local studies that had evaluated meter accuracy by testing at ten flowrates. In either case, using the raw data of each of the study, the weighted accuracy was recalculated for each of the test records by varying the number of test flowrates (3-10 flowrates) used to estimate the weighted error. The weighted meter accuracy increased with increasing number of flowrates, or conversely the error decreased with the increasing number of test flowrates. The best estimate of the meter accuracy was achieved at 10 flowrates, with 4.74% difference in weighted accuracy when calculated using three common flowrates (q_{min}, q_t, and q_p). The inadequacy of the common use of three test flowrates for the estimation of meter error and the weighted meter accuracy is clearly demonstrated in this case. Through various trials, the optimal number of test points was found to be seven test flowrates of *7, 15, 30, 60, 120, 1,500* and *3,000 ℓ/h* which only underestimated the weighted accuracy by 0.05%.

Using the adopted test flowrates, the project evaluated 101 new water meters of seven different models that are common in South Africa to determine their initial weighted accuracy and applicability for local conditions. Only about 40% of the meters tested were fully compliant with the SANS 1529 when evaluating their accuracy over the entire meter error envelope. This suggests that the values obtained from the probability of failure analysis are indeed plausible and therefore validated. While the meters would pass if only evaluated at the common three test points, this failure rate indicates that manufacturers may tend to calibrate the meters to pass at only those points but neglect the rest of the operational points. It was also shown that neither the meter class nor its technology are necessarily good predictors of the ability of a meter to pass or to have superior accuracy. Therefore, it is important to collect and collate meter performance data regularly to be able to evaluate and uncover such anomalies and be better informed in making meter management decisions.

The initial weighted accuracy of new meters in South Africa has been assessed, which is a first for South Africa and the African continent. This provides a better basis of determining the useful life of water meters and how they can be better managed to improve the management of apparent water losses. The average initial weighted accuracy of water meters in South Africa was determined to be 95.5% and is indicative of minimum apparent loss levels for a brand new meter. Current guidelines on possible apparent water losses need to be revised to reflect that a 4.5% initial apparent loss error is likely to be the best possible figure assuming an equal spread of the meters tested. A demonstration of the implication of the results has also been done that seems to indicate that based on the starting error of the common meters, and an average degradation rate of 0.7% per year, the average meter replacement period of local meters should be 10-11 years for a typical consumer who uses 360 kl per year.

Based on the findings of this project, together with a best practice from literature, water metering guidelines for South Africa have been developed. These cover the important aspects of consumer profiling, new water meter testing, in-service water meter testing, meter data analysis and overall meter management.

Key recommendations emanating from the study are (i) the establishing of Norms and Standards for water metering; (ii) updating the Legal Metrology Regulations aspects relating to Water Meters, ideally by incorporating them with (i); (iii) updating the SANS 1529 suite of standards, and; (iv) establishing mandatory meter and consumer audits

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1 INTRODUCTION

1.1 BACKGROUND

High levels of Non-Revenue Water (NRW) is a major challenge for municipalities and utilities worldwide, with estimates of NRW in South Africa having increased from 34.6% in 2013/14 to 41% in 2015/16 (Department of Water and Sanitation, 2017). This local increase in NRW is not only due to system attrition but also partly due to improved participation by rural municipalities, who previously did not participate in the implementation of water balance assessments that provide an indication of NRW levels (Ncube, 2019). For a water scarce country, these levels of NRW are unsustainable, particularly against the background of projected increases in water demands. Moreover, this has implications for the financial viability of many municipalities and therefore, appropriately addressing NRW challenges would be a key opportunity for many municipalities to unlock both resource and financial benefits (Green Cape, 2017).

However, to address the existing NRW challenges, it is imperative that the right interventions are identified, prioritised, and implemented. To support the identification of the right interventions, it is necessary to adequately understand the various components of NRW. One of the challenges associated with assessment of NRW is the reliability of the methods used for component analysis (Mutikanga, 2012). Apportioning water losses between physical (real) and commercial (apparent) losses is one contentious area. In South Africa, the conventional approach to accounting for Apparent Losses (AL), the component of NRW that is the focus of this study, has not been from explicit quantification but rather through the reliance on rule of thumb estimations. As an example, in a Water Research Commission (WRC) study, McKenzie, Siqalaba & Wegelin (2012) assume 20% of water losses to be apparent losses. Municipalities, with the support of the Department of Human Settlements, Water and Sanitation (DHSWS), generally adopt the approach detailed in the guidelines proposed in Seago, Bhagwan & McKenzie (2004). This method uses ratios based on the perceived rating of meter age and accuracy, water quality and data transfer to estimate apparent losses, with the maximum possible being 28% of water losses. The risk associated with such rule-of-thumb approaches is the reliance on simplifying assumptions that may render them inadequate in some contexts (AL-Washali, Sharma & Kennedy, 2016). Apparent losses comprise water that is not recorded correctly by a water meter but is likely consumed, including unauthorised consumption, as such a better measure is as a percentage of billed authorised consumption as opposed to a percentage of water losses proposed in Seago, Bhagwan & McKenzie (2004) and used in McKenzie, Siqalaba & Wegelin (2012). It can therefore be argued that without the explicit quantification of apparent losses, the interventions for managing NRW levels that are determined from the conventional approaches may not be adequately informed or optimum. Considering that apparent losses can reach up to 30% of total losses in terms of volume and 50% in terms of cost (Arregui, Cobacho et al., 2018), their estimation becomes paramount.

Assessment of apparent losses has mostly focused on metering errors (Allender, 1996; Arregui et al., 2010; Mutikanga, Sharma & Vairavamoorthy, 2011b,a; Arregui, Soriano & Gavara, 2012; Szilveszter, Beltran & Fuentes, 2015szter, Beltran & Fuentes, 2015) which have been found to be the highest contributor to apparent losses (Rizzo & Cilia, 2005). This is because mechanical meters, which historically have been and remain the dominant meter type in use, experience reduced efficiency with age and usage due to wear and tear, incorrect installation, water quality, incorrect meter sizing, demand profile, among other factors (Ncube, 2019). The weighted meter accuracy methodology outlined in Noss, Newman & Male (1987), Yee (1999) and Arregui et al., (2006) has internationally been adopted as best practice in the assessment of AL. It comprises the assessment of the metrological performance of a water meter at different flow rates in a flow laboratory and comparing this performance against the user demand temporal pattern from consumer audits through meter logging (Criminisi et al., 2009; Johnson, 2012). Meter testing and meter logging both involve varying levels of field and laboratory activities that are costly and require extensive amounts of time to do properly. As such, this best practice approach is not always realistic for many municipalities. While alternative methods exist, their usefulness without validation has been shown to be limited (Ncube & Taigbenu, 2019a) and in the case of validated methods, meter accuracy information remains a requirement as detailed in Ncube & Taigbenu (2019b).

Many South African municipalities do in fact carry out a variety of metering related activities without the express objective of quantifying and/or managing apparent water losses (Ncube & Taigbenu, 2018). These activities include the routine testing of water meters in response to consumer queries and complaints. Although the tests might not be significant individually, they become meaningful in combination with other tests, including those from similar municipalities. Ncube & Taigbenu (2015) and Ncube (2019) have shown that these random tests, when collated and analysed, offer valuable insight into the degradation of metering error and other meter management criteria. The determination of statistically significant results per meter model, which would otherwise be either difficult or expensive for a single utility or municipality, becomes within reach.

It is against this background that this WRC-supported study is being undertaken to collate existing water meter performance data from accredited laboratories, together with the generation of new meter testing data for the municipal water sector in the country. Through the creation of a freely accessible electronic database, the findings from the assessment of apparent water losses in South Africa will facilitate the improved management of apparent water losses.

1.2 PROJECT AIMS

The following are the aims of this project:

1. To undertake a literature review on meter performance evaluation and key indicators of water meter performance, with emphasis on domestic meters
2. To workshop with stakeholders (municipalities, water boards, meter manufacturers, NRCS, etc.) on key requirements and likely collaborations to deliver results that are beneficial and congruent with the broader sector requirements.
3. To request and collate meter testing data from municipalities and utilities that have used accredited laboratories.
4. To develop a database for water meter performance results for South African utilities and tools to evaluate meter performance of the populated data.
5. To evaluate the performance of new water meters in South Africa through the procurement and testing of 100 new at the accredited and independent lab of Johannesburg Water SOC.

1.3 STRUCTURE OF THE REPORT

This report is structured in keeping with the project aims above and the ensuring deliverables. Chapter 1 (this chapter) offers an introduction to the project and why it is necessary. Chapter 2 is a literature review of the state of the art in terms of water metering and broader apparent loss management with a focus on meter management, together with the best practice in the development of meter performance database and guidelines. Chapter 3 summarises the stakeholder engagement activities and the stakeholder requirements for a national meter performance database of meter. Chapter 4 summarises the analysis and metrics from the available meter data that has been incorporated into the developed meter performance database. Chapter 5 extends the meter database by incorporating the results of the testing of new meters that are available in the market. Lastly, Chapter 6 syntheses the lessons of prior chapters into a meter testing guideline manual for the South African market.

1.4 PARTICIPATING ORGANISATIONS

The organisations that have participated in this study, either by contributing meter test data or as part of the broader stakeholder engagement, include the following:

- Bernoulli
- City of Cape Town
- Ekurhuleni Metropolitan Municipality
- eThekwini Municipality
- Johannesburg Water
- Kamstrup Meters
- Khusela Amanzi
- Lesera-Teq Meters
- National Regulator for Compulsory Specifications (NRCS)
- Nelson Mandela Metropolitan Municipality
- Itron Meters
- Overstrand Municipality
- Precision Meters
- South African Bureau of Standards (SABS)
- Tshwane Metropolitan Municipality
- Water Meter Manufacturers Association
- WRP Engineers
- South African Local Government Association (SALGA)
- University of the Witwatersrand
- Rand Water
- Xylem Water Solutions
- Water Meter Manufacturers Association

The research team is especially grateful for the notable contribution of Johannesburg Water (SOC) Ltd, it's management and particularly the SANAS-accredited Flow Laboratory staff in the meter testing of the new water meters.

1.5 SCOPE AND LIMITATIONS

The two tenets of the weighted meter error methodology for determining apparent water losses are representative samples of water meter testing and consumer profiles. Neither of these were generated nor available for use in this study, apart from the consumer profiles for the City of Johannesburg. This study is limited to:

- Determining quasi-representative meter degradation curves of used meters that can then be applied to determine municipality specific apparent water losses if the meter age/volume and consumption patterns are known,
- Determining the initial error of new meters available in the South African market and adopting the City of Johannesburg consumption profile for illustrating the likely initial weighted meter error in the country.

No meter sampling nor consumption profiling work is included in this case nor is the express determination of apparent losses done for South Africa. The study is also focused on domestic water consumers and will be of relevance to smaller sized water meters in the size range of 15-25 mm.

2 LITERATURE REVIEW

A lot of work has been done as far as understanding and quantifying NRW in South Africa and internationally. The bulk of the local work has been supported by the Water Research Commission and includes the following four important national assessments of NRW in South Africa:

- 2002 – Development of a simple and pragmatic approach to benchmark real losses in potable water distribution systems in South Africa. WRC Report TT 159/01 by McKenzie and Lambert.
- 2005 – Benchmarking of Leakage from Water Reticulation Systems in South Africa. WRC Report TT 244/05 by McKenzie and Seago.
- 2007 – Non-Revenue Water in South Africa. WRC Report TT 300/07 by Seago and McKenzie.
- 2012 – The State of Non-Revenue Water in South Africa (2012). WRC Report No. TT 522/12 by McKenzie, Siqalaba & Wegelin.

These assessments progressively provided updated and more reliable information on municipal water use than the previous estimates (McKenzie, Siqalaba & Wegelin, 2012) and also included terminology, tools, and review of NRW best practice. The reader is referred to these reports and work such as that of AL-Washali, Sharma & Kennedy (2016) for a broader overview and review of NRW assessments and tools. The literature covered in this document focuses on the less covered areas of apparent loss component, meter testing and meter management.

2.1 METERING LEGAL FRAMEWORK

The Compulsory National Standards and Measures to Conserve Water (Regulation 509 of 2001) under the Water Services Act (Act 108 of 1997) prescribes the universal metering for all water connections. This therefore sets the basic requirement for water metering for all municipalities. In addition, regulation requires the reporting of information and calculations relating to water losses which implies active management of the metering systems.

Water meters effect and measure custody transfer of water from the service provider to the consumer, and as such, the verification of their accuracy throughout their lifecycle is the subject of legal scrutiny. In South Africa, the Legal Metrology Act (Act 9 of 2014), which replaced the Trade Metrology Act, 1973 (Act 77 of 1973), and its regulations form the basis of such scrutiny. It requires that all measuring instruments be subject to initial verification and subsequent verification in accordance with the relevant legal metrology technical regulation.

There are, however, very limited requirements for water meters in comparison to other measuring instruments in the regulations particularly on the on-going verification period. Referenced within the Legal Metrology Act is the South African National Standards (SANS) 1529 suite of standards which outline the performance characteristics, dimensions, type, approval requirements, etc. for all metering devices used for trade purposes. It currently consists of four parts:

- **Part 1:** Metrological characteristics of mechanical water meters of nominal bore not exceeding 100 mm. Last revised in 2019
- **Part 3:** Physical dimensions. Last revised in 2006
- **Part 4:** Mechanical meters of nominal bore exceeding 100 mm but not exceeding 800 mm. Last revised in 2004
- **Part 9:** Requirements for electronic indicators used with mechanical water meters, electronic water meters and electronic prepayment water measuring systems. Last revised in 2019

Of relevance to meter management and apparent losses, the SANS 1529 standards require that: -

- All water meters used for trade purposes must be type approved.
- The metrological class of a water meter describes the capacity of the meter to measure within prescribed tolerances of accuracy at prescribed flow rates which are expressed as ratios of the permanent flow rate as given in Table 1, with the overload flow rate being equal to 2 times the permanent flow rates.
- Only meters with metrological classes B, C and D may be used for trade purposes.
- Meter verification can only be carried out in accredited institutions by the accrediting authority (i.e. SANAS) and shall be carried out in terms of SANS 1529-1: Annex B.
- The Permissible Tolerance on indication, which is the difference between the indicated volume and actual volume, shall not exceed the values given in Table 2.
- All water meters must be the subject of on-going verification and the users of water meters for trade purposes are responsible for ensuring that the water meters under their control are subject to that on-going verification.
- If any water meter becomes defective or its accuracy is not within the specified tolerances, it shall immediately be withdrawn from service by its owner or user.

Table 1: Metrological Class of Meters (SANS 1529)

Class of Meter	***For q_p not exceeding 10 m^3/hr***		***For q_p exceeding 10 m^3/hr***	
	Minimum flow rate, q_{min}	Transitional flow rate, q_t	Minimum flow rate, q_{min}	Transitional flow rate, q_t
A	*0.04 q_p*	*0.10 q_p*	*0.08 q_p*	*0.08 q_p*
B	*0.02 q_p*	*0.08 q_p*	*0.03 q_p*	*0.03 q_p*
C	*0.01 q_p*	*0.015 q_p*	*0.006 q_p*	*0.006 q_p*
D	*0.0075 q_p*	*0.0115 q_p*	-	-

Table 2: Permissible Tolerance on Indication (SANS 1529)

Meter Status	***Flow Rates***	
	Less than q_t	***More than q_t***
New & Refurbished meters	*5%*	*2%*
Meters in use	*8%*	*3.5%*

Despite the requirement that all meters shall be the subject of on-going verification and that once defective, meters must be removed from service, there is currently no guidance on how such on-going verification to identify defective meters should be done locally. This is one area that South African standards and regulations fall short. For contrast, one can consider the Australian Standard AS 3565, for example, which includes Part 4 (2007) that focuses on in-service compliance testing. This is further supported by a voluntary Water Services Association of Australia WSA 11 Code of Practice dealing with the Compliance Testing of In-Service Water Meters. The American Water Works Association (AWWA) also provides Manual M6 on Water Meters – Selection, Installation, Testing, and Maintenance which provides guidance of the testing of in-service meters, among other issues. Despite the lack of standards locally, there is some work that could be formalised and/or codified to manage meters better. Johannesburg Water (2016) is a metering specification and guideline manual that articulates how they intend to proactively handle meter management, including the testing of water meters. Ncube (2019, chap. 7) also offers a guideline on how water meters may be best handled for the enhanced management of apparent water losses. Both documents are therefore instructive on how municipalities and utilities can also better handle integrated meter management

Practically, the requirement that municipalities check the compliance of their meter fleet and take corrective action is imbedded in the existing regulations. However, there is very limited insistence or enforcement that this is done, despite the high levels of NRW in many areas. Distilling such requirements into easy-to-follow steps and guidelines will therefore be useful for the sector.

Although SANS 1529: 1 2019 has been updated in 2019, it remains relatively outdated to metering standards internationally. It still is closely aligned to the ISO 4064:2005 version whose most current version is 2014. Fortunately, some meter manufacturers, particularly international ones, already comply with newer regulations such as the EN 14154 and ISO 4064 standards. Both these standards are very similar to the International Organization of Legal Metrology (IOML) model standard in the form of recommendation R49.

2.2 APPARENT WATER LOSSES

Thornton, Sturm & Kunkel (2008) define apparent losses as the non-physical losses that occur when water is successfully delivered to the customer but, for several reasons, is not measured or recorded accurately, thereby inducing a degree of error in the amount of customer consumption. The IWA Water Loss Specialist Group (WLSG), through the Apparent Loss Initiative, has proposed guidelines for the management of apparent losses in Vermersch et al. (2016). The main interacting components of apparent losses have been updated to comprise metering errors, unauthorised consumption, data acquisition errors and errors in the estimation of unmetered consumption. The last component of errors in the estimation of unmetered consumption is rather meaningless as it seeks to define errors in a quantity that is not quantified but is rather an educated guess. While the effort for a guideline is laudable, Vermersch et al. (2016) remains cumbersome to follow and appears to be more of a compilation of various papers by the contributing authors and team members of the task force over the years than what would be expected of an informative guideline. A more co-ordinated but very technical guideline in the determining the economic levels of apparent losses is provided by Arregui, Cobacho et al. (2018) and it divides the component of apparent losses into:

- **Intervention independent apparent losses,** which are the unavoidable level of losses in a system, no matter the number and frequency of the interventions regularly carried out. These losses could only be reduced if there is a substantial change in an essential element of the system (water metering technology, installation conditions of the meters, a variation of water meter suppliers' quality, etc.), but they would not be affected if, for example, customers' meters are replaced more frequently. A component of metering inaccuracies, illegal connections and data handling errors fall into this category.
- **Intervention dependent apparent losses** related to the amount of losses that depends on the intervention policies carried out by the water company and grows when interventions are delayed over time. On the contrary, more frequent interventions requiring greater investments by the utility lead to smaller volumes of apparent losses. This is largely made up of metering inaccuracies and unauthorised connections.

In concert, these levels define the unavoidable and economic levels of apparent losses. These levels are depicted graphically in Figure 30 and are contrasted to real losses terminology on the left.

The Current Annual Apparent Losses (CAAL) is the estimated value of apparent losses over a period of twelve months for the water supply system being evaluated. The Economic Level of Apparent Losses (ELAL, or the Economic Apparent Loss Level (EALL) in some literature) is defined as the magnitude of apparent losses for which the total costs, calculated as the sum of the control and reduction policies and the utility's cost of the water losses, reach a minimum (Arregui, Cobacho et al., 2018).

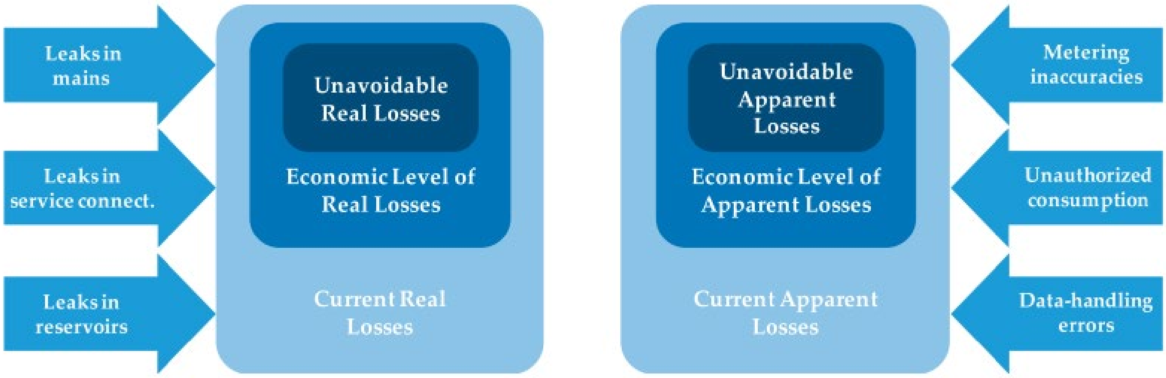

Figure 30: Levels of Water Losses
Source: Arregui, Cobacho et al. (2018)

This minimum is at a point at which the financial savings gained from implementing a specific apparent loss reduction project equals the financial expenses incurred for the same project. The unavoidable apparent losses, also referred to as the Reference Annual Apparent Losses (RAAL) is the estimate of a reference target of apparent losses for a water supply system. Authors such as Vermersch et al. (2016) provide a default value for RAAL as 5% of billed authorized consumption. However, as pointed out in Ncube (2019), while such a value may be reasonable and coincides with output from research such as Arregui, Balaguer & Soriano (2017) that found new meters to have errors ranging from -1% to -6% depending on the meters used and the consumption profiles, it is important that the "default" values of RAAL be determined in line with local metrological standards. Such standards define what is possible and permissible from a metering perspective, as well as the prevalent consumption characteristics when superimposed on the metering accuracy. Quantifying and understanding of a locale specific reference value, which is currently not prevalent, could also provide an impetus in the adoption of metering standard that minimises apparent losses. Because of this gap, Arregui, Cobacho et al. (2018) proposes the use of Intervention Independent Annual Apparent Losses (IIAAL) as the reference value but estimated based on the intrinsic meter errors and meter failures of a utility, the level of unavoidable illegal consumption and losses due to systemic data errors.

This study is concerned with making contributions towards the determination of both the intervention dependent and intervention independent components of apparent losses but only focusing on the parts on metering inaccuracies.

2.2.1 Data Acquisition Errors

Data acquisition errors are directly related to water utility management capability (Criminisi, et. al., 2009) and are a result of manipulation of meter reading data as municipalities validate it for billing purposes. For well managed utilities, such errors are expected to be lower and, in any case, the solution is heavily reliant on changing system operations and management actions. The South African experience is that management deficiency is prevalent with several municipalities and cities being in the press in recent years for various billing related challenges (Ncube, 2019). In Mazibuko (2013), incorrect and inaccurate municipal billing is revealed to be pervasive in the country's major cities. The consequent reduced collection of revenue in turn has implications for the financial viability of the municipalities (Manyaka, 2014). Arregui, Cobacho et al. (2018) considers this component to be intervention independent as the magnitude of this error will remain approximately constant over time and be independent of the frequency of intervention activities unless policies and procedures are changed.

To estimate these errors a simple methodology of using sampled field and database information is proposed by Mutikanga, Sharma & Vairavamoorthy (2011a) and Thornton, Sturm & Kunkel (2008). However, Ncube (2019) notes that in cases with pervasive billing problems, such as those described in Mazibuko (2013), the evaluation of this component of AL will be difficult, if not impossible, to implement.

2.2.2 Unauthorised Consumption

Unauthorized consumption is prevalent in the developing world Mutikanga (2012). While some authors such as Criminisi et al. (2009) view this component as also directly related to water utility management, there are some aspects of this component that are neither technical nor managerial but rather social and are reflective of the prevailing socio-economic and cultural conditions (Ncube, 2019). It is for this reason that Arregui, Cobacho et al. (2018) considers these errors as falling within both the intervention-dependent and intervention-independent components. The dependent portion can be minimized by increasing the frequency of inspections of customer connections.

One approach of estimating this component includes the use of field surveys of sampled data, described in Thornton, Sturm & Kunkel (2008), to assess the prevalence of unauthorised consumption and quantify its contribution to apparent losses.

2.2.3 Metering Inaccuracies

Water meter inaccuracies are probably the most intricate and important of apparent losses, but unfortunately have not received as much attention from an evaluation perspective. Importantly, even in the best-case scenario of brand-new meters, there is an unavoidable measuring error that is dependent of the meter technology, meter model and the consumption profile of users. This forms part of the intervention-independent component of metering errors. Several studies that explored these initial metering errors include Arregui et al. (2014); Arregui, Balaguer & Soriano (2017); Mantilla-Peña, Widdowson & Boardman (2019). A summary of errors from varying technology of meters are shown in Table 3.

Table 3: Typical Weighted Initial Error (Arregui, Cobacho et al., 2018)

Meter Type	Worst Case (%)	Best Case (%)
Single jet	-5	-2
Oscillating Piston	-1	+0
AWWA Single-jet	-7	-3
AWWA Multi-jet	-7	-3
Fluidic	-7	-5
Multi-jet	-6	-2
AWWA Nutating Disc	-3	-1

It is clear from Table 3 that the choice of metering technology will have a considerable impact on the initial level of unavoidable apparent losses due to metering errors. As such, their estimation can prove valuable for municipalities hence the inclusion of the testing of new meters in this study. The estimate of these Unavoidable Annual Unmeasured Volume (UAUV) can be estimated for each system as Arregui, Cobacho et al. (2018);

$$UAUV = (-1) \times \sum_{i} \varepsilon_i(0) \times ACV_i$$

Equation 1: Unavoidable Annual Unmeasured Volume

where sub-index i refers to each specific meter type in the utility, $\varepsilon_i(0)$ is the average initial weighted error (Arregui, Cabrera Jr. & Cobacho, 2006) of a meter type i, and ACV_i (m^3/year) is the Annual Consumption Volume of all the customers using this meter type. Because it is known that the volume obtained from a meter reading at any time, the Annual Registered

Volume (ARV, in m^3/year) excludes metering errors and is therefore not equal to ACV. The term ACV can therefore be estimated as (Arregui, Cobacho et al., 2018);

$$ACV_i = \frac{ARV_i}{1 - \varepsilon_i(t)}$$

Equation 2: Annual Registered vs Consumption Volume

where $\varepsilon_i(t)$ is the average weighted error of type i meters t years after installation.

Other than the initial error, as meters age and their mechanical parts wear out, their metrological characteristics degrade and measuring inaccuracies increase (Arregui, Gavara et al., 2018). The rate at which the meters degrade, and generally under-register volume passing through, is a function of the meter quality, technology, and the consumption profile of the consumer, among other environmental factors. Many authors have followed a rigorous approach in estimating apparent losses due to metering errors, and in turn the meter degradation rate, and they include ,Noss, Newman & Male (1987), Yee (1999), Arregui et al. (2006, 2013), Arregui, Cabrera Jr. & Cobacho (2006), Mutikanga, Sharma & Vairavamoorthy (2011a) and Ncube & Taigbenu (2019a,b). All these studies use a methodology that measures both the accuracy of a meter and the effectiveness of that meter in measuring a particular consumption pattern (Ferréol, 2005). These are collectively known as determining the weighted accuracy of a meter and conversely determining the amount of water that is not registered for every 100 litres of water consumed in relation to the water consumption pattern of the user (Arregui et al., 2006). Ultimately, the Intervention Dependent Annual Apparent Losses (IDAAL) due to meter inaccuracies can be estimated by (Arregui, Cobacho et al., 2018)

$$IDAAL_i(t) = ADR_i/100 \times ACV_i$$

Equation 3: Intervention Dependent Annual Apparent Losses

Where ADR_i (%/year) represents the Annual Degradation Rate of the weighted error of meters of type i. The annual degradation rate links the initial weighted error to the current weighted error in the form of

$$\varepsilon_i(t) = \varepsilon_i(0) - ADR_i \times t$$

Equation 4: Weighted Error Evolution

As can be observed from Equation 4, the progression of meter inaccuracy generally tends to follow a linear curve and get worse with time. Part of this study is dedicated to evaluating historical meter testing data to extract meter accuracy at various meter ages and registered volumes to be able to determine the relationship described by Equation 4.

While there is no known study of a comprehensive and national meter testing database, particularly of reactive data, Arregui, Gavara et al. (2018) evaluates over 4972 used and new meters of two types from a single utility (FACSA, in Spain) to better understand the progression of the weighted meter error. One key finding of the study was that all meter types need to be tested and analysed as two meter types can behave completely different in a specific water system and the same meter type can present dissimilar ageing processes in two different water systems. Careful consideration therefore will be taken in this study to take care of different water systems particularly where the supply source is different.

From a database perspective, Arregui et al. (2009) describes a software tool designed to improve water meter management through the standardization of how the weighted error calculation is done, together with the storage of the data in one centralised place. The study also proposes minimum field that must be contained in the database, and they include:

1. **Details of the testing procedure**, with information such as the theoretical flow rates, reference volume and/or weight, water density, order of tests, allowable flowrate tolerance and number of repetitions at each flow rate.
2. **Verification officer details** (i.e. person in charge of the tests), including the date and time of test.
3. **Test results information** with the test duration, meter readings (with enough resolution) and the starting flowrate of the meter
4. **Meter information**
    a. Serial number
    b. Meter model and manufacturer
    c. Length, nominal diameter, and nominal flow rate
    d. Reason for testing. Where the meter comes from?
        i. Has it been taken randomly from the field or from a procured lot?
        ii. Was it selected from a specific user?
        iii. Was it suspicious of having under or over registration?
        iv. Does it come from a customer complaint, etc.?
    e. User ID when the meters are taken from the field, with address and installation date.
    f. Short characterization of the user:
        i. Type of user: domestic, commercial, industrial, services, considering subgroups of each type it is also advisable.
        ii. Type of user facility: direct connection, private tank, ...
    g. Field and Test Installation Positions

h. Comments text field
i. Pictures of the meter that allow in the future the identification of any problem in the meter design or behaviour.

Most of the information above is generally contained in well-designed test reports, which currently most municipalities use only for the purposes of reporting back on the reason for the test. Only when such data is stored in a proper format can it be meaningfully used to inform decision making.

2.3 WEIGHTED METER ACCURACY

The weighted meter accuracy methodology is an empirical method which is currently the gold standard for the assessment of apparent water losses (Ncube, 2019). Figure 31 is an outline illustrating the methodology and it involves the evaluation of samples of meters and consumers to determine meter accuracy and consumption patterns, respectively.

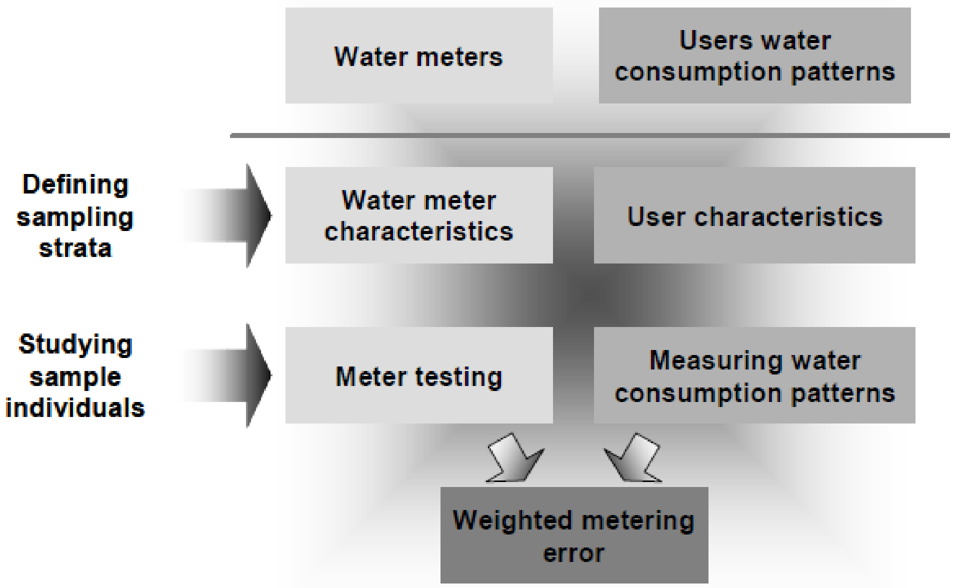

Figure 31: Methodology for determining weighted meter accuracy.
Source: Arregui et al. (2006)

The general practice is to use of statistical tools and extrapolate results obtained from a representative sample to the rest of the meters and consumers (Arregui et al., 2006). As such, homogenous groupings of meters and consumers are identified, sampled and the results used to compute the weighted meter accuracy. In the case of industrial and commercial users, it is preferred to deal with them on an individual basis as they tend to be unique. While the use of representative samples reduces the need to evaluate all meters, statistical significance still requires that a meaningful number of meters and consumers be evaluated. For example, to obtain a representative sample at a 95% confidence level within ±5% margin of error, you require a sample size of about 380 for a population of 40,000 consumers/meters. This leads to the main drawback of the method as being labour-intensive and expensive to implement despite providing the best estimate of apparent water losses (Ncube, 2019).

Mathematically, the weighted meter accuracy for each homogeneous meter-consumer grouping is given by (Ncube, 2019)

$$\bar{\varepsilon}_w = \sum_{q=1}^{n} PTC_q * 0.5(GAAL_q + GAAL_{q_{-1}}) \quad \textbf{(1)}$$

Equation 5: Weighted Meter Accuracy

Where:

- q refers to a key flow rate at which the meter is tested.
- n is the number of key flow rates used in the testing
- PTC_q is the consumption percentage at each specific flow rate from 1 to n.
- $GAAL_q$ is the average accuracy of the meter at each specific flow rate from 1 to n.
- $GAAL_0$ is the meter accuracy flow at a flow rate of 0, where it is assumed that the meter is not turning, and therefore, the meter accuracy is assumed to be -100%.

The meter testing must be done as sufficient test flowrates to mimic the actual meter error curve.

There has been some meaningful work done in determining the weighted meter error in various parts of the world, but much less so in the developing world, as summarised in Ncube (2019). Arregui et al. (2014) measured the weighted error of 330 new and used meters and monitored the consumption of 200 domestic users over a week. The results showed that new Class B velocity meters (single jet) have an initial error of -3.45% to -6.37 while Class C meters have a narrow range of -2.14% up to -3.5%. Positive displacement meters have an even better initial error of -0.76% up to -1.04%. For used meters, the average weighted error was about -10%, with the actual degradation best represented by both age and accumulated volume, although with the accumulated volume only having an impact after 2500 m^3. In a related study, Arregui, Balaguer & Soriano (2017) investigated the performance of 11 new meters, considering different consumer patterns and metrology standards (ISO and American Water Works Association (AWWA)) and found that the ISO velocity meters under ideal conditions have an error range of -0.71% to -3.87%. On the other hand, ISO oscillating piston meters showed errors of between 0% and -1% independent of the type of user while AWWA oscillating piston meters were much worse with errors of up to -11.37%. In another study, (Barfuss, Johnson & Neilsen, 2011) tested AWWA single-jet meters registered an error of +4.56% while the AWWA multi-jet meters registered an error of -4.46%. (Szilveszter, Beltran & Fuentes, 2015) compared the weighted error for 384 meters in Ecuador using two consumption

patterns, both of which were from different locales to the study area and found global errors of -9.95% and -10.9%. While the results are indicative, the use of consumption profiles that are not from Ecuador is problematic as the local consumer characteristics are likely different (Ncube, 2019). Mutikanga, Sharma & Vairavamoorthy (2011a) similarly found a weighted error of -22% (due to the prevalence of storage tanks) in Uganda from the meter logging of 90 properties and the testing of 250 meters. Locally, Ncube & Taigbenu (2019a) tested 123 meters and logged 408 properties and found an average weighted error of -12% of the billed volume, with a range from -9.4% to -14.6% depending on meter size ratios.
These results show that metering standards have an impact on the level of metering accuracy and the meter testing regime. It is also clear that the user consumption patterns, and both the accumulated volume and age are key factors affecting the degradation of the weighted error.

This study is not directly evaluating either component of the weighted error methodology but rather, due to the lack of sampled meter testing data of adequate quantities, it is attempting to build up a database of general meter characteristics and performance that can be applied by municipalities and utilities for their population of meters.

2.4 METER TESTING

The metrological control of water meters is a foundational imperative for meter management as it forms the basis for all meter accuracy estimation through meter testing (Arregui, Cabrera Jr. & Cobacho, 2006). Meter testing in a utility could be done for a variety of reasons that include suspicion of meter failure (e.g. meter that does not turn), customer requests/complaints, routine testing (Noss, Newman & Male, 1987), among others. Results from such meter testing programs are valuable for a variety of reasons such as determining meter failure rates and probabilities, the degradation of meter accuracy for the standard flow rates as demonstrated in Noss, Newman & Male (1987) and Ncube & Taigbenu (2015). These may also be a means of satisfying local metrological standards with respect to both initial and ongoing meter verification requirements, as is the case in South Africa with SANS 1529-1:2006 Standard (SANS, 2006).

Various authors have been involved in evaluating meter performance through meter testing in a laboratory environment, as summarised in Ncube (2019). Bowen et al. (1991) evaluated 200 meters of twenty distinct types and found that meters which receive pulsed-flow (of which intermittent supply is a type) experienced greater meter accuracy degradation than those with constant flow, and that at flows above 3.8 ℓ/s polymer body meters were less accurate than brass meters. In addition, meter chamber size and rotating element also influenced the degree of accuracy. Barfuss, Johnson & Neilsen (2011) investigated 450 new meters and 595 pulled meters and found that a higher-than-expected number of new meters did not meet the AWWA standards and that degradation rates for the new meters tested for endurance were higher and more apparent at low flows. There was obviously variation amongst different meter manufacturers. The pulled meters showed that meter accuracy was affected by suspended solids in the water than the other water quality factors and that the degradation rates correlated well with results from the endurance testing of new meters. These studies, both of which are from the United States of America and therefore done in line with AWWA standard, reveal some of the numerous variations that need to be considered in evaluating meter accuracy, and such variations do tend to be location specific. Also important is how the particular meter testing is done by the respective utility as failure to follow testing protocol gives rise to inaccurate results and increases uncertainty as pointed out by Shields et al. (2013). Locally, Fourie (2019) investigated the performance of 200 used meters from the same manufacturer but of two technologies (volumetric and velocity meter) to evaluate meter degradation in Gauteng. He found no definitive relationship with either meter type with respect to age of the meter, and the relation with volume had a poor relationship. It is important to note that a challenge that persist with research such as Ncube & Taigbenu (2015) and Fourie (2019) is that for each meter types evaluated, there is insufficient data per age/volume ordinate to derive a true meaningful relation. This is part of the reason why consolidating meter data makes sense so that there are adequate groupings of meters to derive meaningful relationships.

One exacting demand of meter testing for the purposes of AL assessment is that there is a requirement to reproduce, as best as possible, the meter error curve. This requires the testing of a single meter at several selected flow rates to reconstruct a representative error curve. This requires more than the four flowrates (Q1, Q2, Q3, Q4) referred to in standards aligned with ISO 4064-1:2005, (q_{min}, q_t, q_p, and q_p) such as the South African SANS 1529-1:2006, or the three flowrates (minimum, intermediate, maximum) in the AWWA's Manual M6. This is where a few studies (Allender, 1996; Yee, 1999; Mutikanga, Sharma & Vairavamoorthy, 2011a) which evaluated AL fell short by using only three points to reconstruct the meter curve. The pitfalls in doing this are demonstrated in Arregui et al. (2009) where substantial errors in the estimation of the metering accuracy become the inevitable result. Johnson (2019) aptly demonstrates the impact of the choice of number of test flowrates as per different guidelines and standards on the weighted error, reproduced as Figure 32.

It becomes clear that the choice of number of tests for the purposes of determining meter accuracy is not trivial. Arregui et al. (2013) proposes test flow rates for meters of different permanent flow rates, based on the testing of several meter models at 20 different flow rates to determine the optimum number of required test flow rate. The optimum number of test points was one that minimised the meter error and was found to be eight test points as shown in Table 4 for the permanent flowrates considered.

The additional investment has merit particularly when considering the prevalence of low flow onsite leaks in consumer properties, such as the dripping taps and leaking toilet cisterns (Mayer et al., 1999; Lugoma, Van Zyl & Ilemobade, 2012; Ncube & Taigbenu, 2016). It should be noted though that SANS 1529-1:2019 only requires the verification (testing) of used meters at only three flowrates and this is generally what most municipalities and flow labs do for the purposes of determining the suitability of a meter. If such data is to be used for informing the management of meters and quantifying apparent losses, there is value in increasing the number of test flowrates.

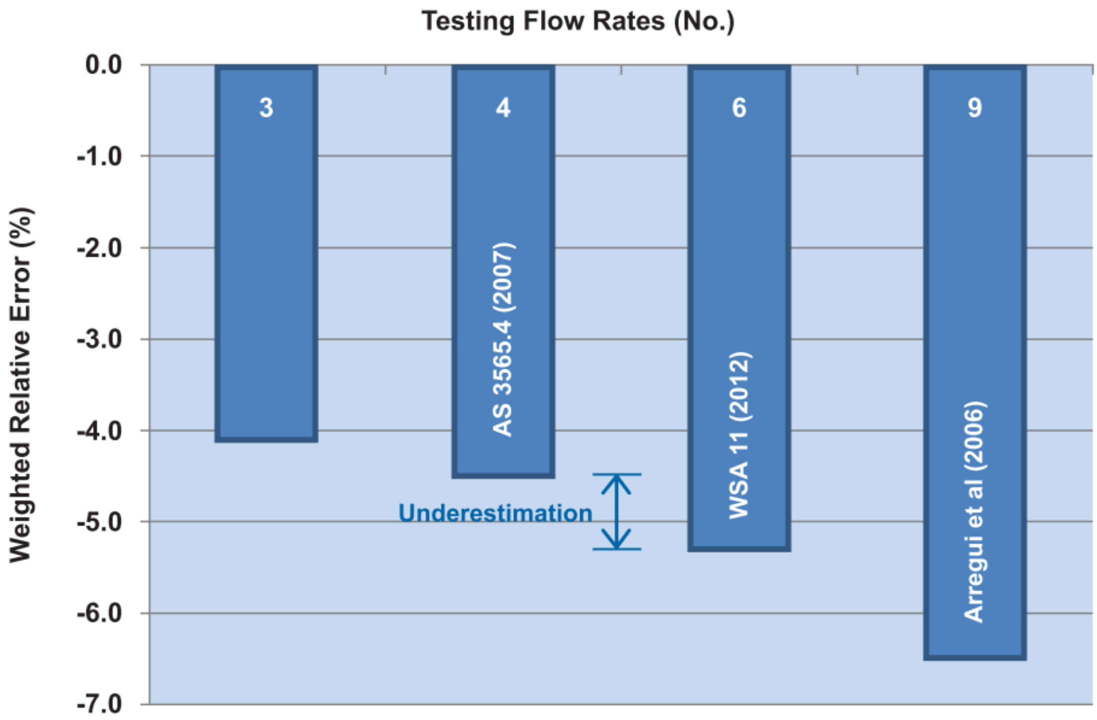

Figure 32: Influence of the Number of Test Flowrate on Weighted Error

Source: Johnson (2019)

Table 4: Proposed Test Flow Rates for Different Permanent Flowrates

Permanent flow rate (ℓ/h)	Q_{T1}	Q_{T2}	Q_{T3}	Q_{T4}	Q_{T5}	Q_{T6}	Q_{T7}	Q_{T8}
1,600	8	16	32	64	128	800	1,600	2,000
2,500	13	25	50	100	200	1,250	2,500	3,125
4,000	20	40	80	160	320	2,000	4,000	5,000
6,300	32	63	126	252	504	3,150	6,300	7,875
10,000	50	100	200	400	800	5,000	10,000	12,500
16,000	80	160	320	640	1,280	8,000	16,000	20,000
25,000	125	250	500	1,000	2,000	12,500	25,000	31,250

Permanent flow rate (ℓ/h)	Q_{T1}	Q_{T2}	Q_{T3}	Q_{T4}	Q_{T5}	Q_{T6}	Q_{T7}	Q_{T8}
40,000	200	400	800	1,600	3,200	20,000	40,000	50,000
63,000	315	630	1,260	2,520	5,040	31,500	63,000	78,750
100,000	500	1,000	2,000	4,000	8,000	50,000	100,000	125,000

It is therefore an integral part of this study to determine the optimum number of test flowrates for the South African environment, considering best practice and what is possible for municipalities.

2.5 INTEGRATED METER MANAGEMENT

Integrated meter management is what brings together everything discussed in the preceding sections. It is necessitated by the overarching need to protect both the consumers and water services providers and is underpinned by the regulations and standards that inform measurements and the instrumentation (Ncube, 2019). This allows for a consolidated approach required for the management of apparent losses, which is not always clearly articulated in both literature and practice (Ncube & Taigbenu, 2018). Arregui, Cabrera Jr. & Cobacho (2006) provides a comprehensive overview on the requirements for integrated management with the key components summarised in Figure 33.

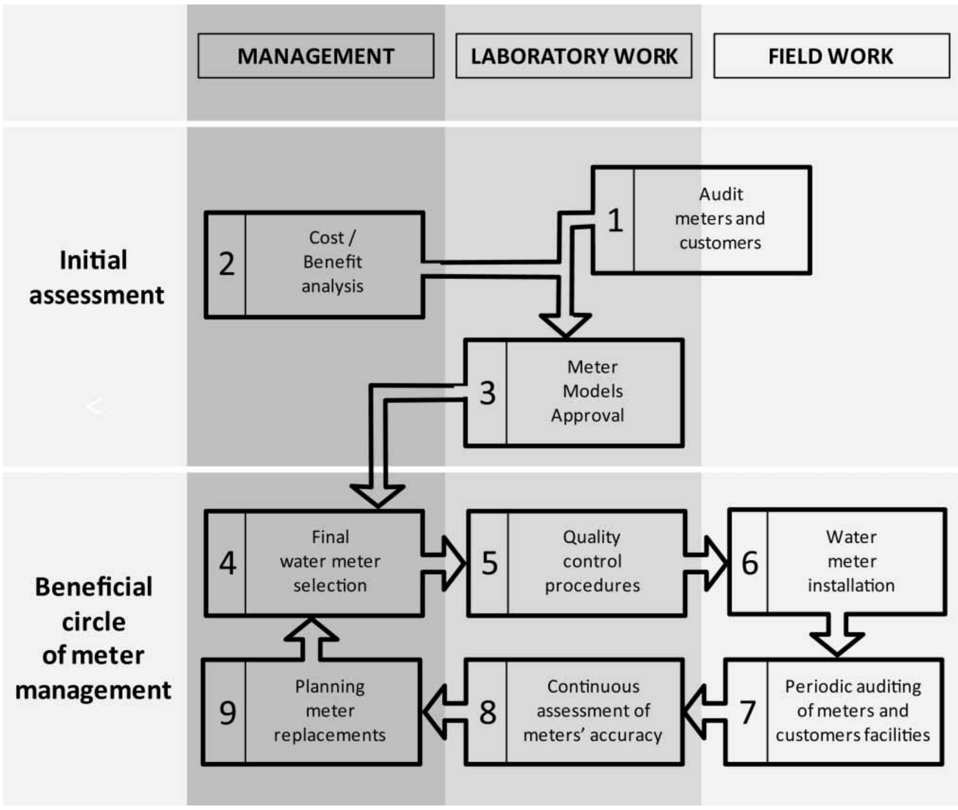

Figure 33: Nine Steps towards Integrated Meter Management
Source: (Arregui et al., 2006)

Van Zyl (2011) provides an alternative view (Figure 34), with a South African specific context, that clearly puts meter management databases at the core but without components such as consumer auditing for the determination of consumption profiles. Both frameworks clearly depict the cyclic and integrated requirements in the management of meters, with a combination of management/back office, laboratory, and fieldwork. The unintended consequence of these frameworks is that they may communicate to a novice that the steps should be done sequentially, without breaking the chain, which is further from the truth (Ncube & Taigbenu, 2018).

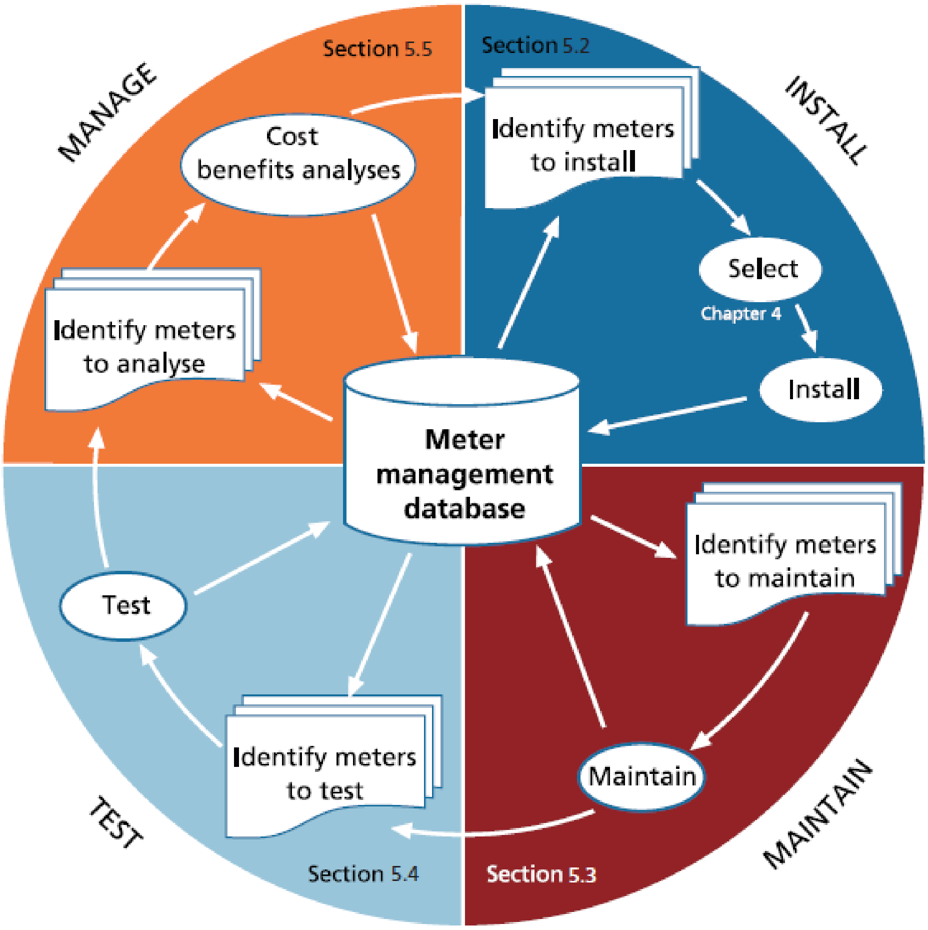

Figure 34: The Meter Management Process
Source: (van Zyl, 2011)

The context for many municipalities is that they do implement some of the activities in Figure 33 and Figure 34, albeit for reasons other than to quantify apparent water losses. There is therefore a need for adequate recognition of such individual activities, their collective interdependence and how they can be leveraged to achieve a better whole. Ncube & Taigbenu (2018) proposed an improved framework (the SAAM framework) that corresponds with management component, fieldwork and laboratory work of Arregui, Cabrera Jr. & Cobacho (2006) but with required realignments to match how utilities are practically structured in implementing the different activities. The **S**ystems, **A**udits, **A**nalysis and **M**etering (SAAM) framework is illustrated in Figure 35, showing the balance between individual activities and their interdependence within the four broad categories.

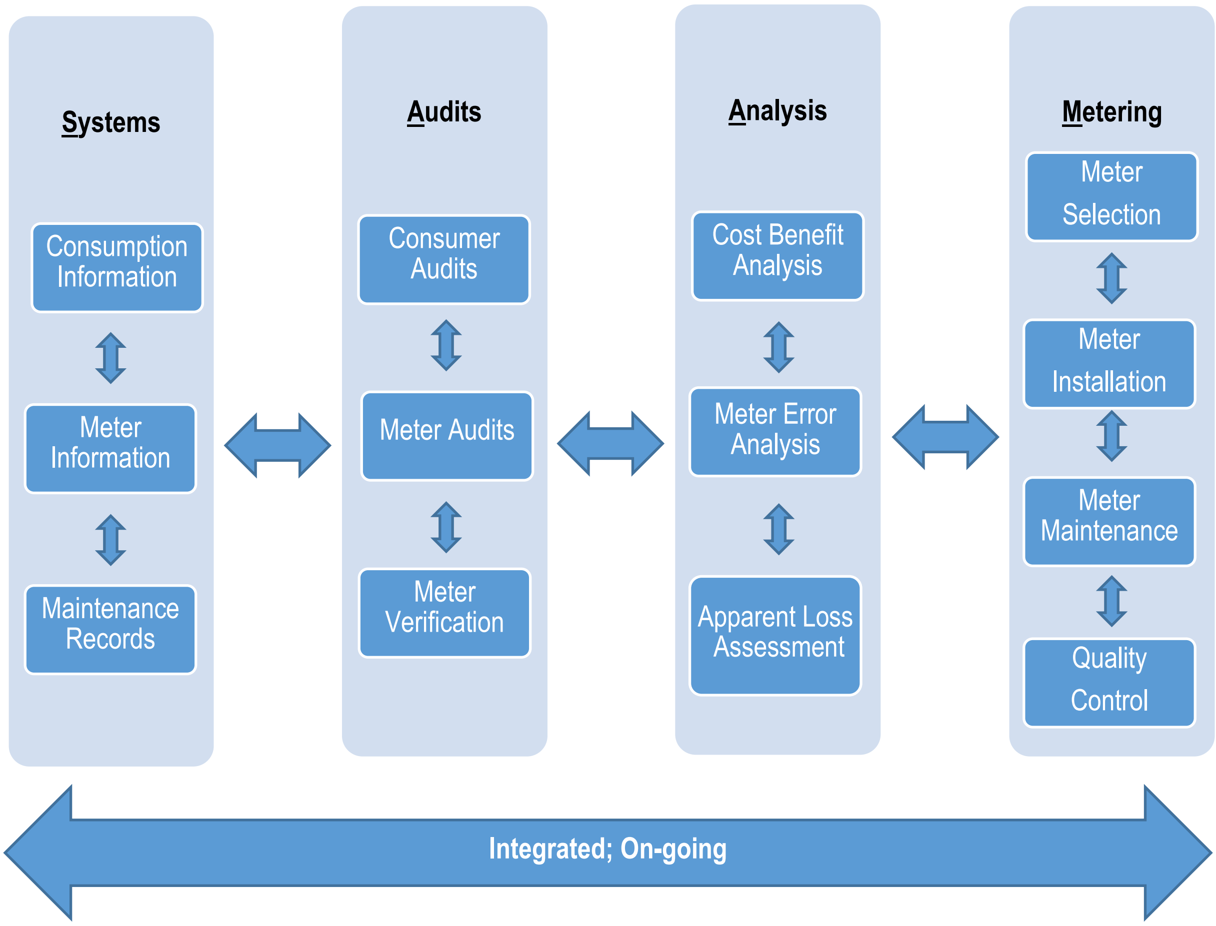

Figure 35: Improved Meter Management Framework
Source: Ncube & Taigbenu (2018)

From Figure 35 and knowledge of municipal water services, it becomes clear that municipalities do routinely carry out several the tasks and will benefit from being more proactive and strategic in further implementing the framework for the greatest benefit. The focus of this study is on the Audits and Analysis aspects and the activities of meter verification and meter error analysis. The results should further inform meter selection and guidelines for the implementation of further meter audits and verification exercises.

Essentially when meter management is done well in an integrated manner, it protects the consumer and results in minimization of the costs associated with the meter ownership over the duration of its useful life. Ultimately, apparent losses due to metering inaccuracies are also minimised.

2.6 SUMMARY

This review of the practices and methods of apparent losses estimation and management has shown that several AL estimation approaches have been developed and applied. As far as management of NRW, the utility of these respective AL estimation approaches varies owing to the extent to which the assumptions underlying these methods lead to over-simplification. Cost is revealed as a key factor that heavily informs the choice of one approach over another. The reality is that the methods that have the most utility for comprehensive water meter management come at a cost that may be prohibitive for most municipalities in the country.

The review also identifies several gaps with respect to sound water meter management practice and these include: -

- The absence of explicit guidelines for on-going verification to identify defective meters for South African municipalities. The testing of in-service meters is often done at the behest of the consumer.
- With respect to unavoidable apparent losses, also referred to as the Reference Annual Apparent Losses (RAAL), most of the existing literature assigns a default value which one has no way of telling if it considers local conditions. It is essential for the "default" values of RAAL to be determined in line with local metrological standards.
- There is no consensus on the optimal number of test flowrates as different studies reviewed relied on different test flow rates. It is therefore necessary that determination of the optimum number of test flowrates for the South African environment is done.

The database developed as part of this study facilitates for the mitigation of the costs implications mentioned above while also providing a resource that can be relied on to address the gaps listed. Its development has considered variations in meter performance that have been observed when meters of the same type are used on different systems where the supply source is different.

3 STAKEHOLDER ENGAGEMENT

This chapter summarises key findings from eliciting stakeholders' expectations and information in connection with the development of the Water Meter Performance Database and metering management in general. This part of the project was deemed an essential step in the project as capturing the diverse views and expectations would not only guide database development but would also ensure the delivery of a product that is relevant and immediately applicable to the target user groups.

3.1 METHODS AND TOOLS

The following entities, on account of their respective roles and experiences within the metering value chain, were considered relevant and key stakeholders whose views and expectations needed to be considered in the development of the project and its main deliverables:

- South African Bureau of Standards (SABS)
- National Regulator for Compulsory Specifications (NRCS)
- Water Meter Manufacturers' Association
- Water Services Authorities and/or Water Services Providers (Municipalities and Water Boards)
- Academic/Research Institutions

To ensure that the views and expectations of such stakeholders are adequately captured relatively early in the project's life, a Stakeholders Engagement Workshop was planned for as a key milestone of the project. This would help define the development of the various products (the database and the various guidelines) and subsequent deliverables of this project. To garner adequate support and understanding of the project, the following activities were undertaken leading up to the workshop: -

a) **Introduction of the Project to Stakeholders:** Telephone calls and email messages to identified stakeholders were sent to introduce the project, together with a letter of introduction from the Water Research Commission (WRC). This also served as a formal request for the participation of the identified institution in the project.

   In addition, the project team developed a webinar for the Water Institute of Southern Africa (WISA) which was advertised to all WISA members and delivered on 5 June 2020. The webinar was on the broader subject of water meter and apparent water loss management and included an introduction of the project together with requests for participation of attendees in the project.

b) **Virtual "One on One" Meetings:** A series of online meetings via MS Teams, Skype and Zoom were organised with a number of stakeholders on a "one-on-one" basis. While invitations were sent to several municipalities and organisations, successful engagements have only been with five municipalities, the South African Bureau of Standards (SABS), the National Regulator for Compulsory Specifications (NRCS) and the Water Meter Manufacturers Association. The individual sessions allowed for a more focused and in-depth discussion with each stakeholder to better understand their contribution within the metering value chain and what their expectations on the planned outputs from the project would be.

As part of the individual meetings, a standardised set of questionnaires was also administered to the municipal group of stakeholders centred around the existing water meter management practices.

c) **Stakeholder Engagement Workshop:** The final and ultimate stakeholder engagement activity was the workshop was conducted via MS Team on the 27th of August 2020. A total of a maximum of 53 participants (from 23 organisations) were registered on the MS Team during the workshop from an invitation list of over 70 stakeholders.

The workshop included presentations from the SABS, NRCS, Johannesburg Water, the Water Meter Association who all shared their respective roles and perspectives within the metering value-chain. After the project team presentations all attendees were also given a chance to ask questions and share their experiences and expectations. The minutes of the workshop are included as Appendix A.

3.2 KEY FINDINGS

With the progression of stakeholder engagements from the introductory meetings to the Stakeholder Engagement Workshop, it became clear that while there is a firm deliverable date for the stakeholder input, there will be need for ongoing sessions beyond those dates. In particular, the delivery of both the database product and its prototypes will required iterative feedback beyond those offered by the reference group and the initial stakeholder engagements. The following is a summation of the key output from the Stakeholder Engagement Sessions conducted for the project: -

i. **Inadequate regulations/standards/guidelines for in-service water meter testing:** while most respondents regarded the existing Legal metrology Act and the SANS 1529 suite of standard as sufficient, it became clear that these were focused on new meters and were deficient when it came to in-service water meters. The guidelines developed as part of this project provide a basis for the development of enforceable regulations on in-service water meter testing and the on-going verification requirements of SANS 1529.

ii. **Meter testing is largely reactive and inadequate:** all utilities surveyed indicated that that in-service meter testing is usually done at the behest of the customer, particularly when a utility bill is being contested. Proactive meter testing to inform metering policies is largely absent.

iii. **Pervasive use of spreadsheets for meter testing data:** as and when meters get tested, all municipalities and the labs interacted with make use of spreadsheets to record and store individual test results. There is limited analysis of the records observed to glean any trends in meter performance.

iv. **Meter testing according to SANS 1529 does not reflect field condition:** concerns were raised that the test flow rates prescribed are limited and over a very short period and will not always replicate field problems such as meter jumping and related endurance tests. Consideration of such endurance test is considered useful in uncovering some problems with in-service meters.

v. **Meter replacement periods are largely based on Rule-of-thumb estimates:** there is generally no scientific basis (most because of ii.) for determining the replacement period of municipal metering fleet. Although some meter manufacturers offer some guidance on how long after installation their meters should be considered for replacement, such guidance holds has not been tested nor verified across South Africa's water supply systems with their varying water quality and system configurations.

vi. **Inadequate funding allocations cited for limited meter replacements**: as with typical asset replacement programmes, inadequate financial resources have been identified as one key factor for not adhering to a meter replacing programme, where it exists.

vii. **Availability of illicit metering products on the market**: mention was made of widely available illicit products on the metering market that are undermining the industry and the accurate measurement of water. While the current focus of the proposed database is to only include historical meter test results from accredited testing facilities, it will also include a list of type-approved meter models as per the NRCS list and this should assist municipalities and meter users to identify illicit products. A request for the consideration of an immutable distributed ledger that can identify a specific meter throughout its lifecycle for both tracing its source and to also avoid the theft of meters from one municipality to the next was made.

viii. **Ownership, custodian, and control of the database product:** concern was raised on who will eventually be the primary custodian of the database and how users will be registered and use the database for only non-commercial and authorized uses.

ix. **Structural sector issues:** a few concerns were raised that are beyond the scope of this project but influence how meters are handled. These include the fact that while SABS Standard for water meters are prescribed by Legal Metrology, the SABS Mark is a voluntary service which manufacturers can opt out for. This means that such meters are exempt from the quality control requirements of the mark such as on-going testing even after type approval. The cost of the SABS mark is also seen as another deterrent which can be avoided unless users explicitly require that their meters must have the SABS mark. There was also a desire to better understand the relationship and roles of the SABS and NRCS in better detail.

All these different aspects and concerns were incorporated into the functional requirements of the respective deliverables.

4 HISTORICAL METER TESTING

Following the extensive stakeholder engagements described in Chapter 3, this chapter consolidates the meter testing reports and results that were provided by the participating municipalities. While many municipalities did promise to provide meter testing results, including initial verification results where available, only the entities in Table 5 were able to provide their results. It is anticipated that more results will be provided with time and this report will be updated accordingly.

Table 5: Participating Municipalities

Municipality/WSP	No. of Records	Period Covered	Accreditation Status and Comment
Municipality A	94	2016-2020	None – use of external accredited providers
Municipality B	612	2012-2020	None – use of external accredited providers
Municipality C	871	Various	None – only internal nonaccredited results
Municipality D	3,679	2001-2015	Internal accreditation, as a flow lab
Municipality E	*357**	2008-2018	None – use of external accredited providers
Total	***5,613***		

* Only summary data provided to date, awaiting actual test results from the accredited provider.

Table 5 confirms that there is limited routine meter testing in South African municipalities in both space and time. There is also high dependence on external accredited service providers, who in this study were fewer than three for all the municipalities. Both factors are a clear motivation for the consolidation of meter testing data. In addition, in almost all the cases the test records are essentially reactive tests that were done in response to user requests.

The test records were received as individual pdf files of the test certificates, the majority being from one external provider who had performed most of the tests for the municipalities. Municipality D data was fortunately received as a MS Excel verification record with all test records and did not need further processing. The pdfs from the rest of the municipalities were converted to MS Excel files and VBA macros were used to extract the data from them. Generally, all the tests were done in accordance with SANS 1529:1 and consisted of three tests at each at the permanent (q_p), transitional (q_t)) and minimum (q_{min}) flowrates. The average of the three tests was the basis of determining if the meter falls within the prescribed tolerances at each flow rate. Again, Municipality D was an exception, early data followed the same format, but they introduced two additional flow rates to better reproduce the meter error curve from the year 2004. The two flow rates are $0.5q_t$ and q_s, where the latter is the maximum flow rate for the meter.

Table 5 also shows the general locality of the meter tested which is an important factor to meter degradation as it incorporates water quality and meter management practices, which impact meter degradation. However, considering that most of the data in Table 5 is within the Gauteng City Region mostly supplied by Rand Water, some of the differences can be assumed to be negligeable. This is useful as there are inadequate datapoints for most of the municipalities when the meters are disaggregated further by age and meter reading.

It should be noted that while the focus of this study is the use of only accredited results, nonaccredited results were requested purely for comparative purposes and to understand what guidance municipalities required. Such guidance is included in the form of a guideline manual delivered as part of the final report and incorporates lessons learnt from all aspects of the project, including the testing of new meters. The results of Municipality D are therefore not incorporated into the database for the purposes of determining meter accuracy but are instructive in how meter testing can be improved.

Part of the data provided by Municipality D (about 2,100 records) have been previously analysed in Ncube & Taigbenu (2015) and Ncube (2019) and this project will extend that analysis. Additional data has been obtained from Ncube (2019) consisting of meter 123 test records from randomly selected meters within the Municipality D area of supply and from Fourie (2019) consisting of 200 test records of meters removed from the Municipality B in a similar reactive manner as all other municipality meter tests. The analysis of both datasets is contained in the respective publications and will therefore not be reproduced here other than incorporating the data into the database that was developed. The database has therefore well over 5,500 records, which is substantial considering the paucity of meter information in South Africa.

4.1 SUMMARY STATISTICS

A key factor in any meter performance evaluation is aggregating the meters according to their respective models as performance is a function of meter specifics. Table 6 summarises the meter models per municipality for the received test records.

Municipality D data, as would be expected due to a comparatively higher number of records, skews the data significantly. But in the absence of better information, the popularity of the meter models as depicted in Table 6 could be instructive on the general proportions of domestic meters used within the water sector in South Africa. Anecdotal evidence also tends to confirm the overwhelming use of Manufacturer A domestic meters followed by Manufacturer D domestic meters (Model 1 and Model 6). It is important to note that Model 2 and Model 5 meters are essentially the same, with the former being a plastic bodied version of the latter. These observations will also play a role in the selection of meter to be tested as part of this project.

Table 6: Usable Test Records

Meter Model	Municipality A	Municipality B	Municipality D	Totals
Model 1	52	54	116	***222***
Model 2	24	3	727	***754***
Model 3	0	98	2	***100***
Model 4	5	2	1262	***1,269***
Model 5	13	162	1401	***1,576***
Model 6		288	116	***404***
Other*		5	55	***60***
Totals	***94***	***612***	***3,679***	**4,385**

* These are models not found in other municipalities and are generally below five in number.

The distribution of all the water meters according to their meter age and the indicated registered volume at the time of testing are shown in Figure 36 and Figure 37, respectively.

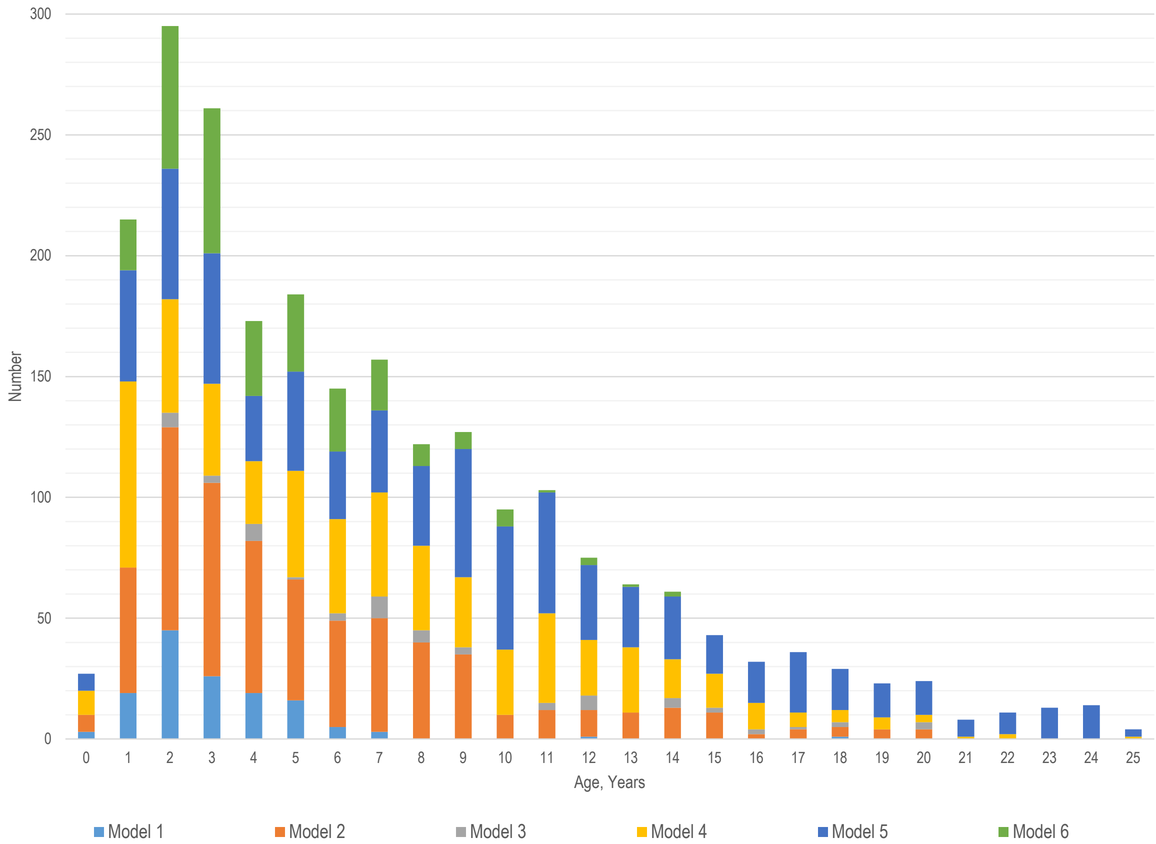

Figure 36: Number of Meters per Age

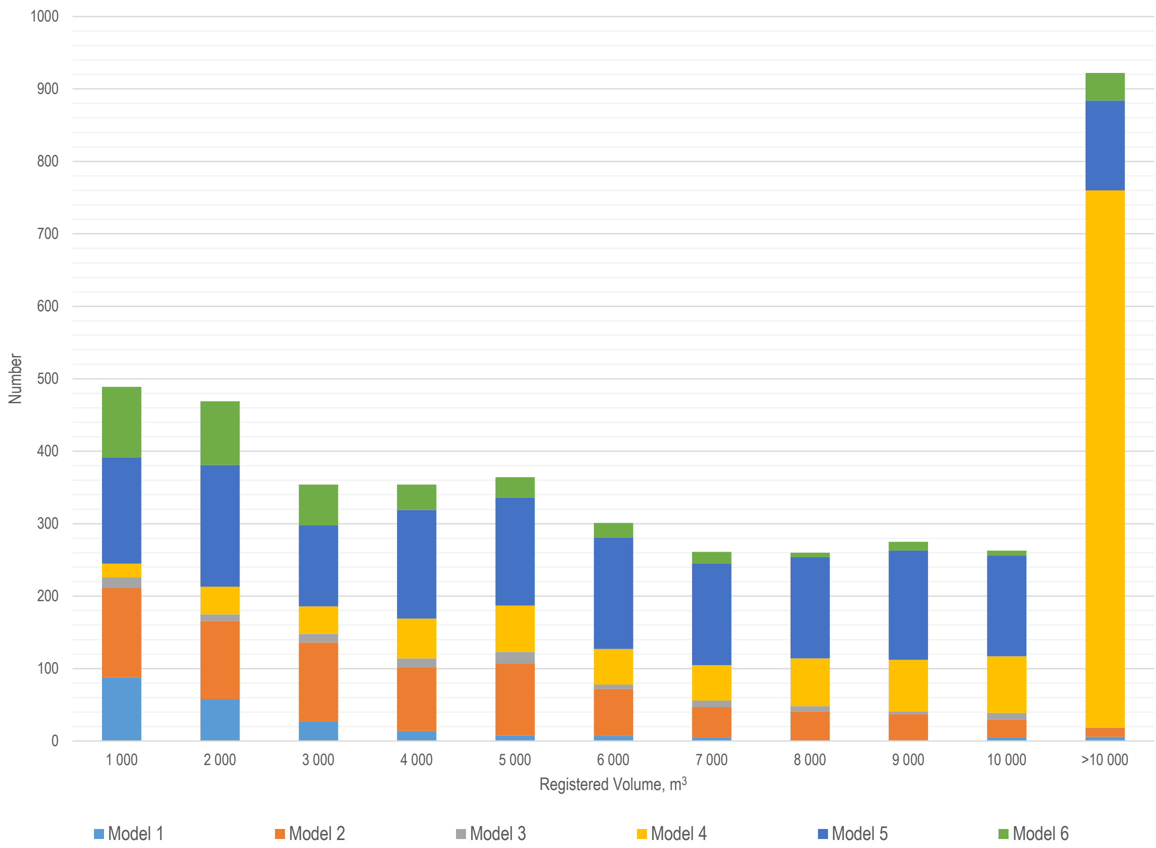

Figure 37: Number of Meters per Registered Volume

It is important to note that in most instances, the age of the meter was not indicated on the test results and no data was immediately available from the municipality. The serial number logic whereby the year of manufacture is codified into the serial number was utilised to derive the age. It was assumed that the year of manufacture was the year of installation for the purposes of determining the age of the meter. The age could therefore be determined for only 2,344 meters. A typical illustration of meters whose age was not determined is Model 3, denotated by zero figures in Figure 36. Despite the aggregation of data, trend analysis is the most meaningful for the three most common brands (Model 2, 4 and 5) as they generally have significant numbers across most of the age categories of interest. The limitations in numbers per age category are what make the aggregation of data essential for the sector.

The registered volume, shown in Figure 37, is the easiest to evaluate as it is what can be observed on the meter dial at testing stage and is a requirement for a successful test. It is therefore no surprise that there are many more meters with the accumulated volume than meter age data.

There are more meters with smaller registered volume, as would be expected in systems that are well managed, apart from those meters that have registered above 10,000 m^3. The limit of 10,000 m^3 was arrived at by using the average domestic monthly consumption of 30 m^3/month in some metros, implying that a typical consumer meter will take over 27 years to reach that volume, which is seen as more than adequate. The numbers for the registered volume are indeed significantly higher than those from the age distribution, but there are similar limitations for some of the meters, albeit at higher numbers. Interestingly, Model 4 meter has the largest distribution of meters that have registered beyond 10,000 m^3, which is very substantial and should typically be difficult to reach for domestic meters. This might be an indication that such meters when finally removed had long gone past their lifespan or that they serviced predominantly non-domestic consumers. Model 2, Model 5 and Model 4 retain the highest numbers across each registered volume category, with the addition of Model 6.

The composition by both age and volume per municipality area follows a similar trend with slight variations depending on which meter is the most dominant at municipal level as indicated in Table 7.

4.2 PROBABILITY OF FAILURE ANALYSIS

The probability of failure analysis was introduced by Ncube & Taigbenu (2015) to determine the likelihood of a meter failing against either the meter reading or the registered volume. The analysis was done at meter technology level, i.e. volumetric and velocity meters as there were inadequate numbers at model level. While this was indicative, the best approach remains at a meter model level as was done in this study, which again highlights the benefits of aggregation. The analysis simply takes the outcome of each individual test record (Pass/Fail) and uses the frequency of failure to determine the probability of failure at a particular volume range or age.

4.2.1 Probability of Failure with Accumulated Volume

Table 7 shows the frequency of the records that form the basis of the analysis for the probability of failure against volume. To ensure that only records with adequate data are used, an arbitrary minimum of 10 records per volume range was selected and those with less than that value were not used in the analysis (these values are indicated using red font colour in Table 7). In addition, for a plot to be considered, a minimum of five data points were deemed adequate, which if we consider the non-red figures in Table 7, would exclude Model 1 and Model 3 for the volume analysis.

Figure 38 to Figure 41 show the probability of failure for four meter models against accumulated volume. The degradation rate ranges from 0.01-0.02% per 1,000 m^3 of volume registered. The co-efficient of determination is acceptable for Model 2, Model 5 and Model 4 meters at 0.6, 0.6 and 0.8, respectively, which is relatively strong and is suggestive of the relevance of the suggested relationships. On the other hand, the Model 6 relationship is poor despite it being in general agreement with the trends from other meters.

Table 7: Frequency of Records per indicated Volume Range per Meter Model

Volume range	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
0-1,000	88	123	15	19	146	98
1,000-2,000	58	108	9	38	168	88
2,000-3,000	27	109	12	38	112	56
3,000-4,000	14	88	12	55	150	35
4,000-5,000	8	99	16	64	149	28
5,000-6,000	7	65	6	49	154	20
6,000-7,000	5	42	9	49	140	16
7,000-8,000	0	41	7	66	140	6
8,000-9,000	1	36	4	71	151	12
9,000-10,000	5	25	9	78	139	7

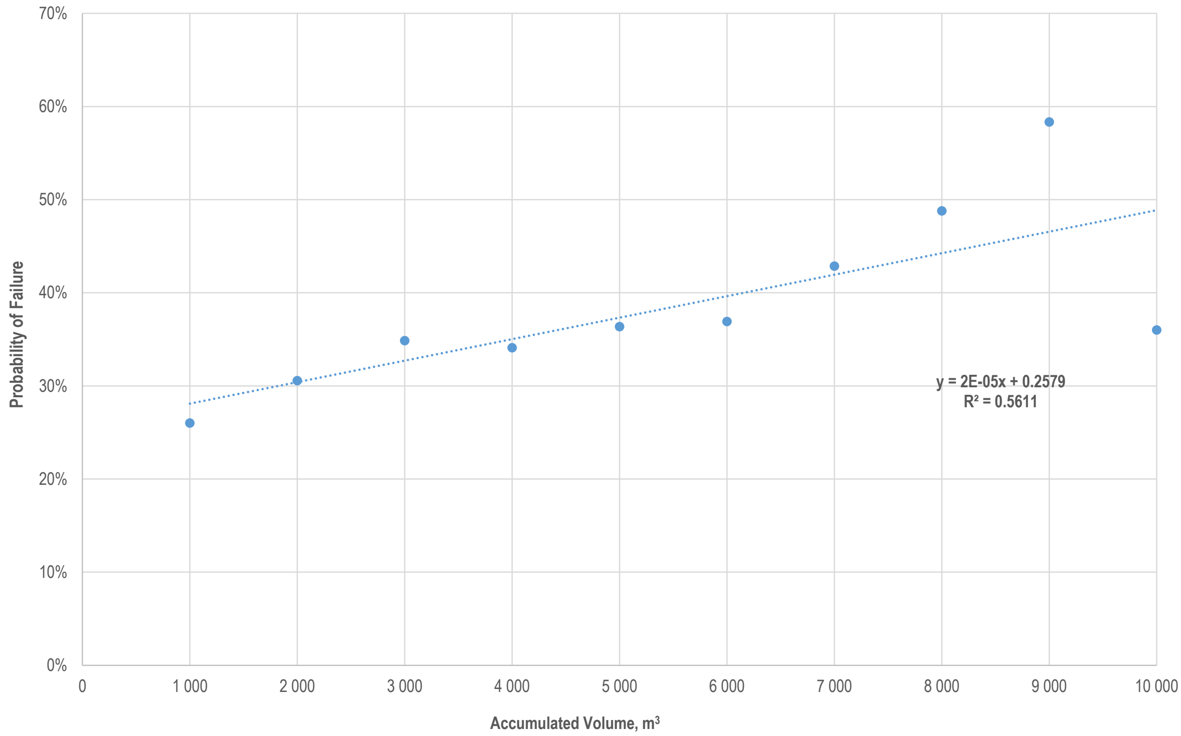

Figure 38: Model 2 Probability of Failure with Volume

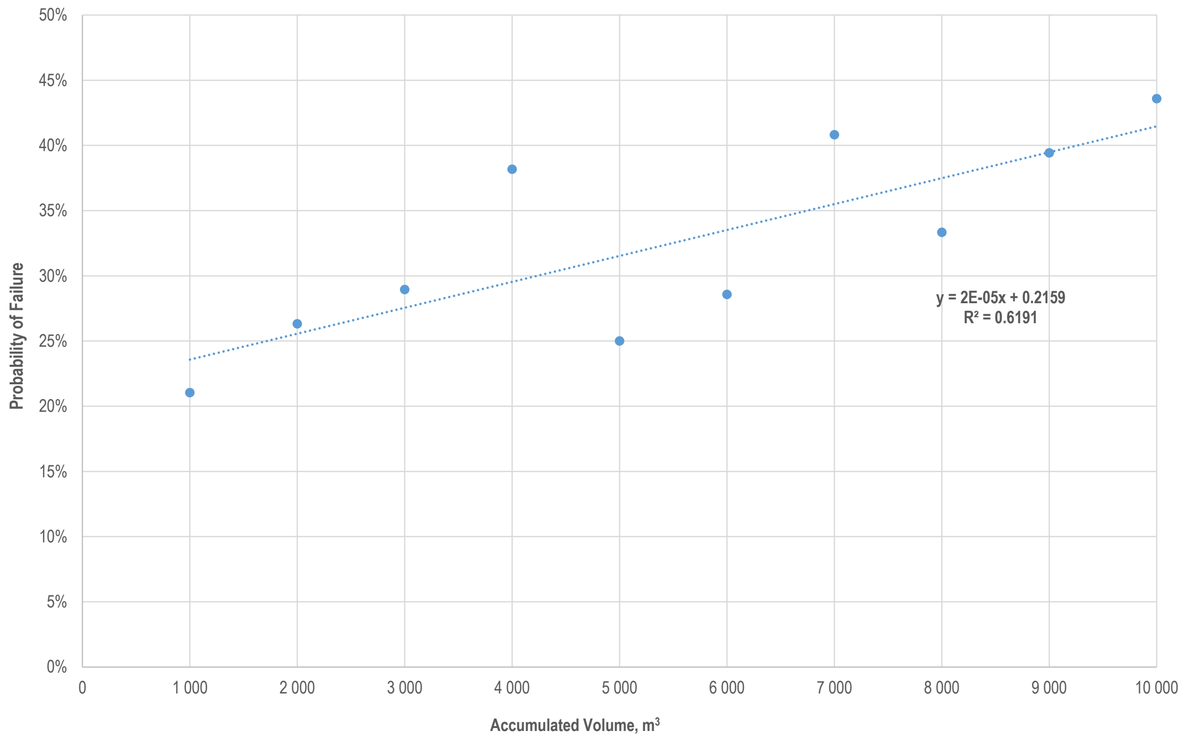

Figure 39: Model 4 Probability of Failure with Volume

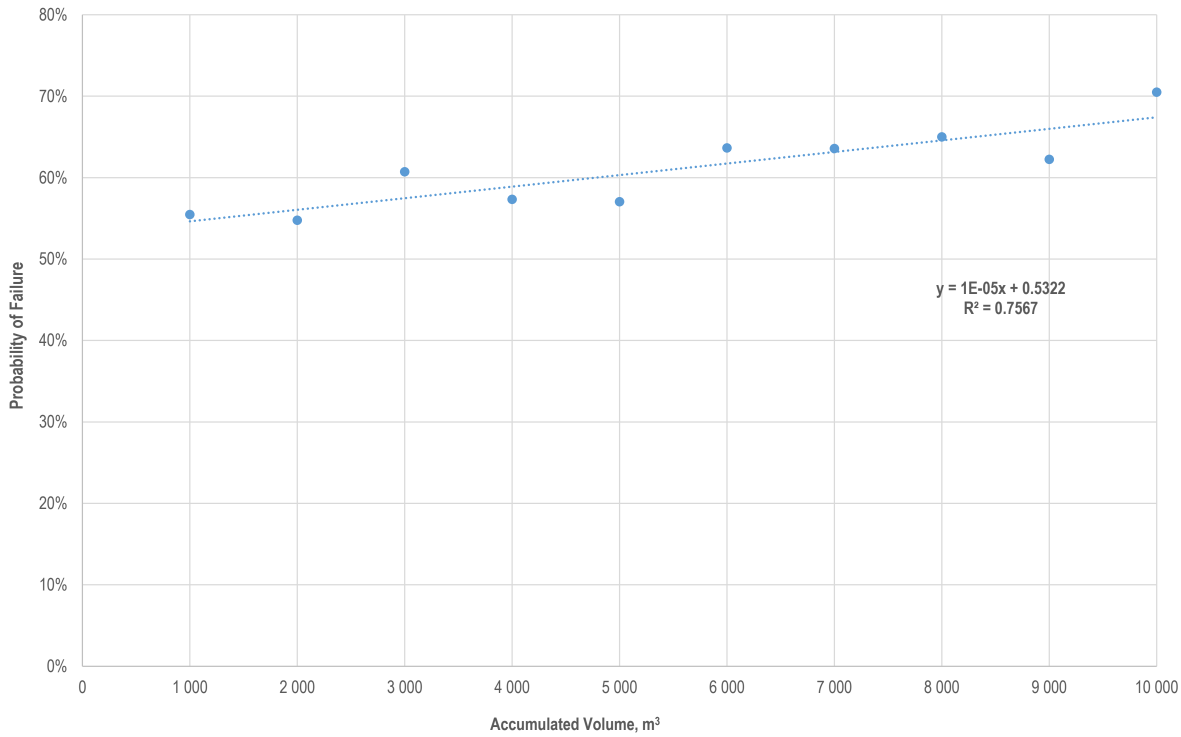

Figure 40: Model 5 Probability of Failure with Volume

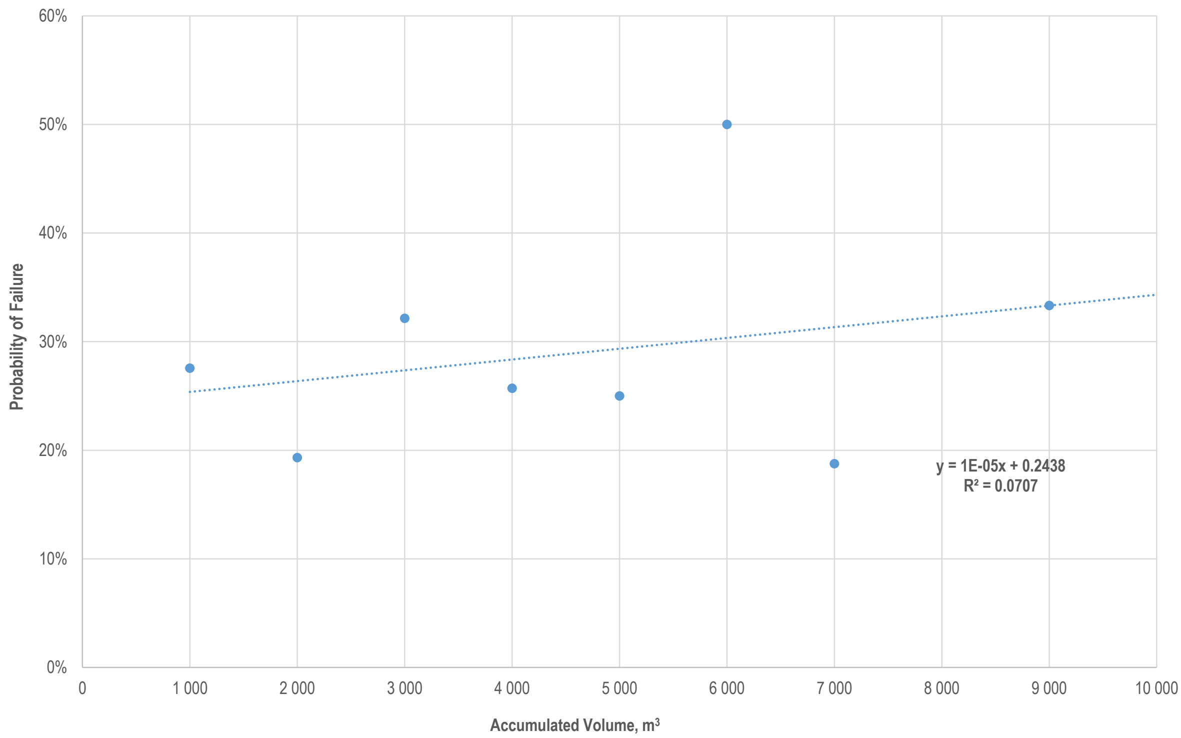

Figure 41: Model 6 Probability of Failure with Volume

The starting probability of failure for 3 of the 4 meter models is around 25% with the Model 5 being a very high +50%. In all cases, a +25% chance of failure for a new meter is undesirable and it will be validated with the testing of new meters. This, however, highlights the need of being prudent in interpreting the results of such analysis without having adequate globular data.

The probability of failure with volume registered results aligns with those found in Ncube & Taigbenu (2015), which is expected as the latter is a subset of the current results. With additional data, and necessary verifications over time, such results will move from being just indicative to being more nuanced.

4.2.2 Probability of Failure with Meter Age

A similar approach to that of the accumulated volume was followed using the meter age to analyse the probability of failure. Table 8 shows the frequency of records for each of the available meters. Despite having fewer records overall, only Model 3 meters did not meet the criteria of having at least 10 records per data point of the at least five data points. The probability of failure trends with age are shown from Figure 42 to Figure 46 for the qualifying meter models.

Table 8: Frequency of Records per indicated Age per Meter Model

Age Range	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
0	3	7	0	10	7	0
1	19	52	0	77	46	21
2	45	84	6	47	54	59
3	26	80	3	38	54	60
4	19	63	7	26	27	31
5	16	50	1	44	41	32
6	5	44	3	39	28	26
7	3	47	9	43	34	21
8	0	40	5	35	33	9
9	0	35	3	29	53	7
10	0	10	0	27	51	7
11	0	12	3	37	50	1
12	1	11	6	23	31	3
13	0	11	0	27	25	1
14	0	13	4	16	26	2
15	0	11	2	14	16	0
16	0	2	2	11	17	0
17	0	4	1	6	25	0
18	1	4	2	5	17	0
19	0	4	0	5	14	0
20	0	4	3	3	14	0

While Model 1 did meet the criteria and has a meaningful coefficient of determination above 0.6, it only had data for meters with an age of up to 5 years which might not be adequate for properly understanding the trend. On the other hand, although Model 4 has longer periods of data, it's R^2 value is close to zero indicating no meaningful relationship between the probability of failure with meter age.

The relationships for both Model 2 (Figure 44), Model 5 (Figure 45) and Model 6 (Figure 46) models have relatively strong relationships indicated by R^2 values of 0.5, 0.9 and 0.9, respectively. For Model 5, the probability of failure increases by 1% per year from a starting probability of 25% which is also high. In the case of Model 5 there is an indicated increase in the probability of failure of 3% per year, with a starting probability of failure of 9.5%. Model 6 has double the rate of increase at 6% with a much lower starting probability of failure of 4%. The starting and annual increase in the probability of failure for both the models (Model 5 and Model 6), coupled with higher R^2 values, are intuitively more acceptable than the values obtained from the accumulated volume analysis. This may suggest, in this case, that age might be a better predictor of the probability of failure than meter readings.

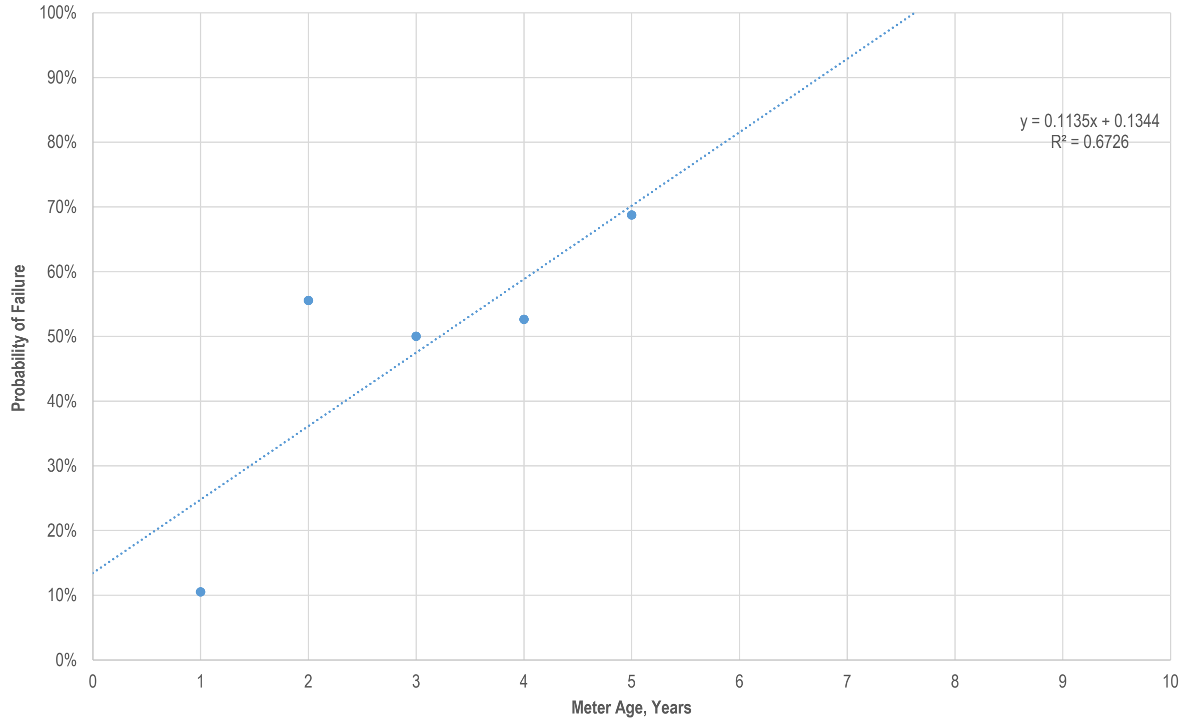

Figure 42: Model 1Probability of Failure with Age

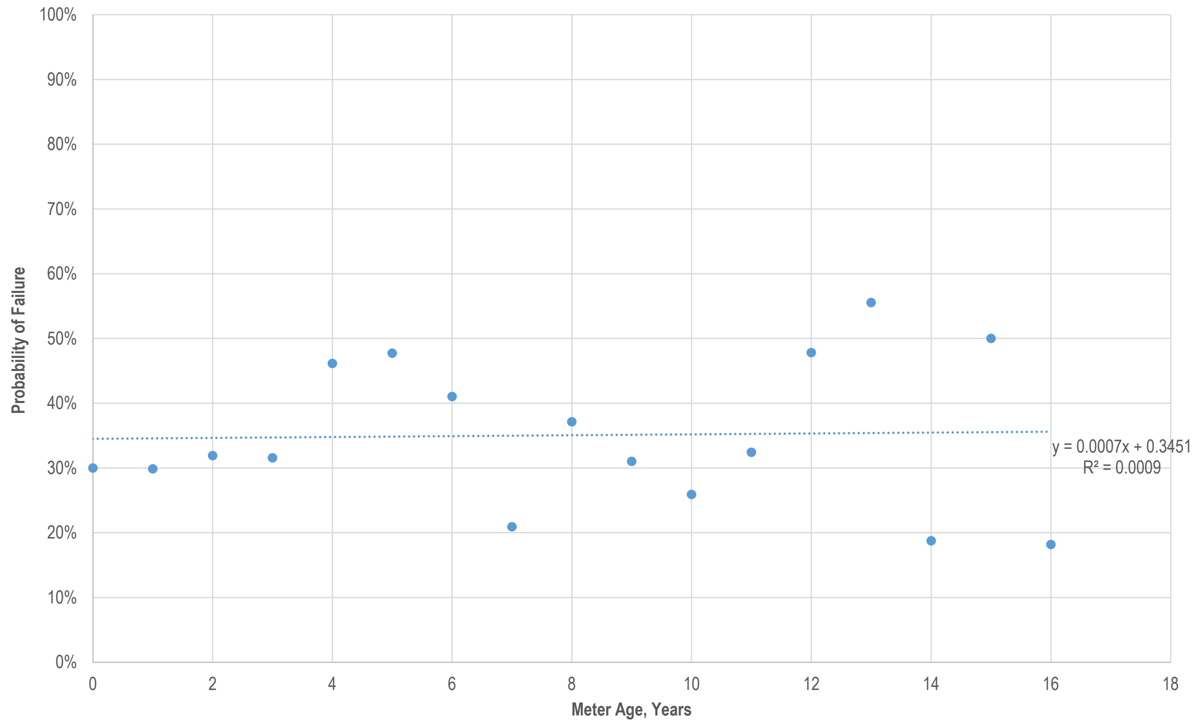

Figure 43: Model 4 Probability of Failure with Age

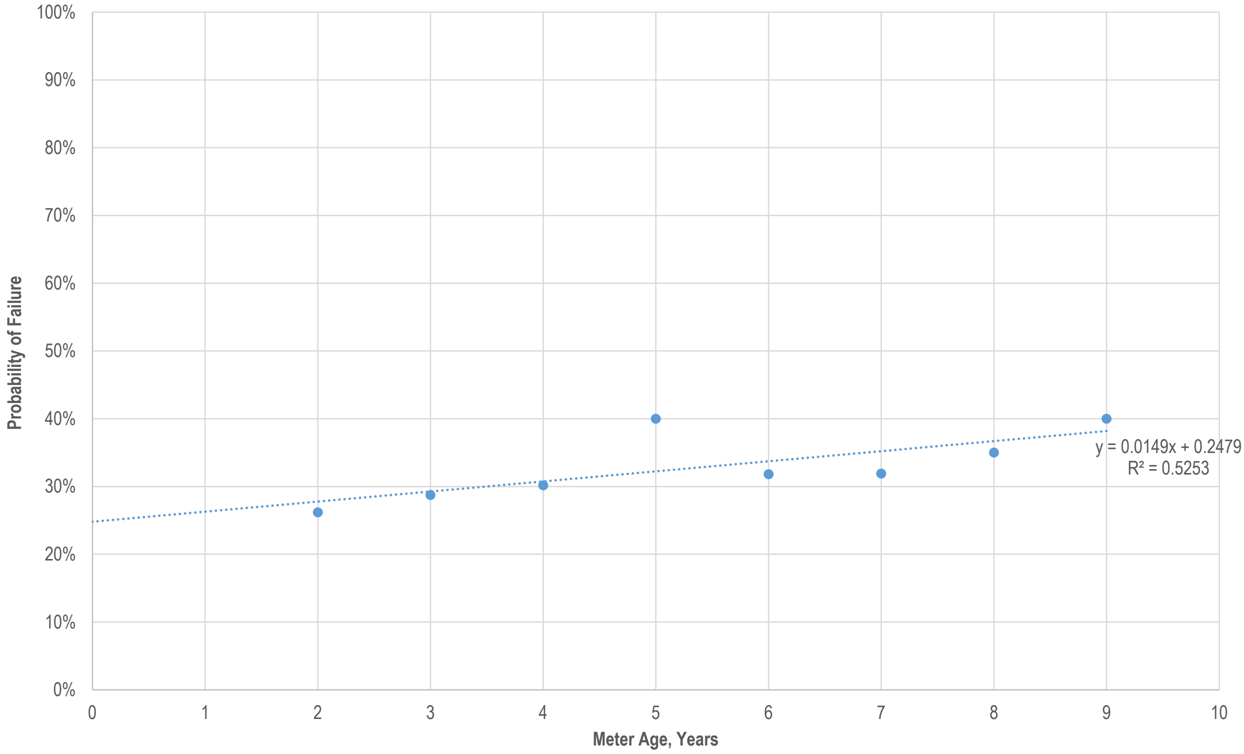

Figure 44: Model 2 Probability of Failure with Age

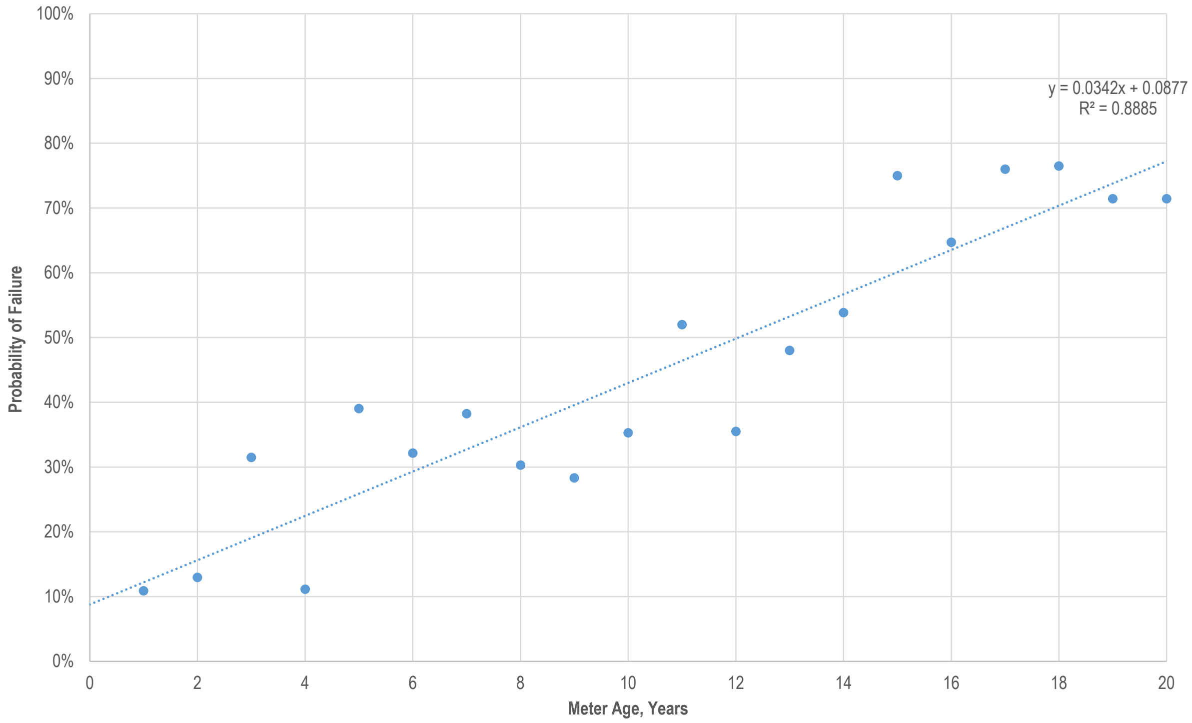

Figure 45: Model 5 Probability of Failure with Age

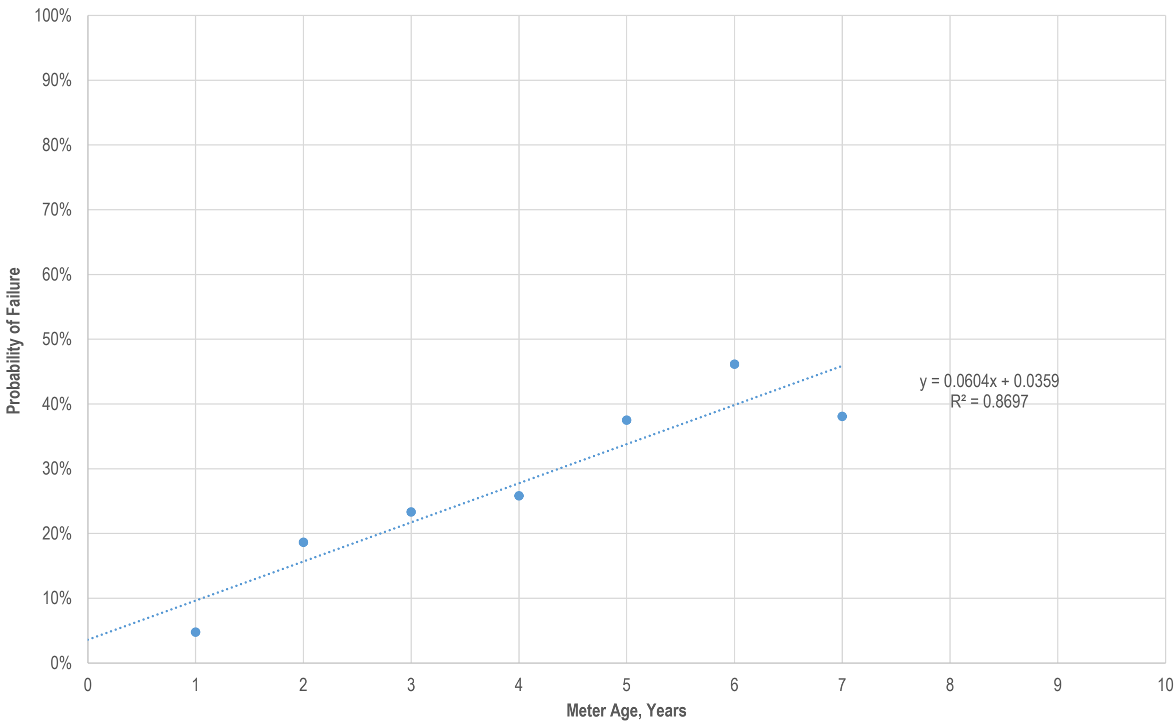

Figure 46: Model 6 Probability of Failure with Age

4.3 WEIGHTED ERROR ANALYSIS

The weighted error analysis is summarised in §2.3 and an important part of it is establishing and/or the use of a consumption pattern that is reflecting of the consumers in study area. In this case, the only known consumer profile that has been developed empirically for South Africa (City of Johannesburg) is described in Ncube & Taigbenu (2019a) and was thus utilised for this analysis. There is therefore an implicit assumption that the consumption profile of Johannesburg does not differ that much with what is experience in the other cities and towns. This, however, is an important gap that needs to be filled to ensure that water loss management is adequately informed in the country.

A similar approach to that utilised for the probability of failure of determining the qualifying meter models was also followed in this case. As such, as the same records have been utilised, the exclusions shown in Table 7 and Table 8 remain the same in this case.

4.3.1 Weighted Error with Accumulated Volume

None of meter models had relationships with an R^2 value greater than 0.5, indicating no attributable relationship between the weighted accuracy and the accumulated volume. Withstanding no attributable relationships, the trend of the Model 4 meter, shown in Figure 47, shows a counterintuitive picture for the multi-jet model. The weighted error decreases with age and would make the meter's accuracy improve with higher accumulated volume, which is not expected. The low R^2 however shows that the variation of the weighted error must be influenced by other factors other than the accumulated volume. Controlled meter testing for the varying registered accumulated volumes can be useful to verify if this trend is indeed the case with this meter model.

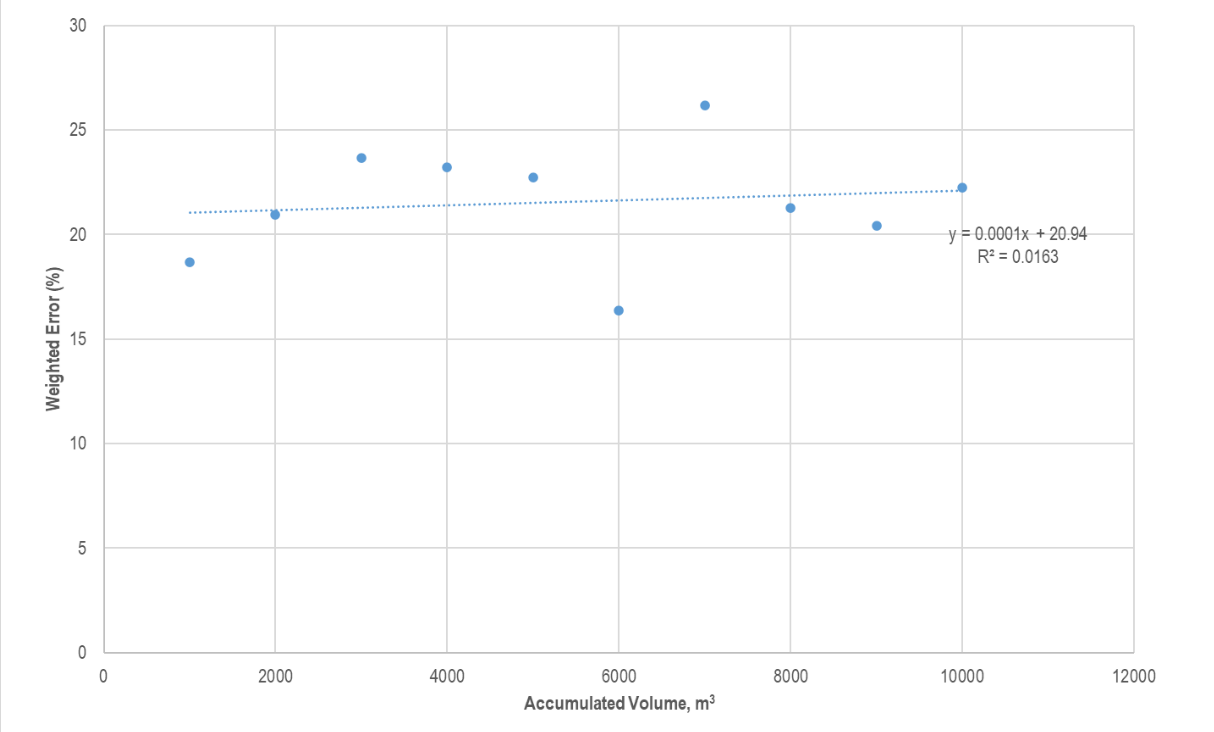

Figure 47: Model 4 Weighted Error with Volume

4.3.2 Weighted Error with Meter Age

Figure 48 shows the variation of the weighted accuracy of Model 1with meter age, with a reasonable R^2 of 0.7. The error increases annually by 1.2%, meaning in 10 years the meter would have lost about 12% of its initial accuracy, which is significant considering the age of the meter fleet within municipalities. The starting error is 7.8%, which will be verified with the initial weighted error of common meters.

Figure 49 shows the performance of Model 4, which like the variation of the weighted error with volume, shows what would be considered an inverted trend as the meter's accuracy improves with age. It is also a possibility that older meters had superior metrology than the newer meters that might explain the trend.

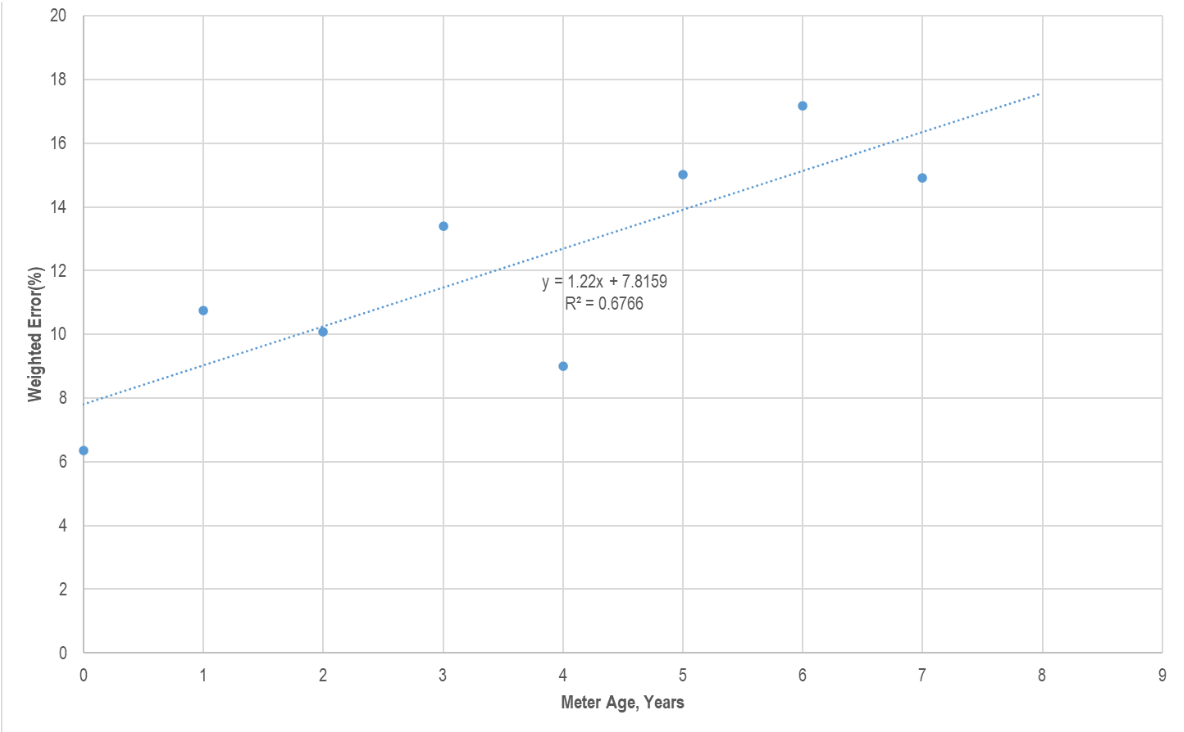

Figure 48: Model 1 Weighted Error with Age

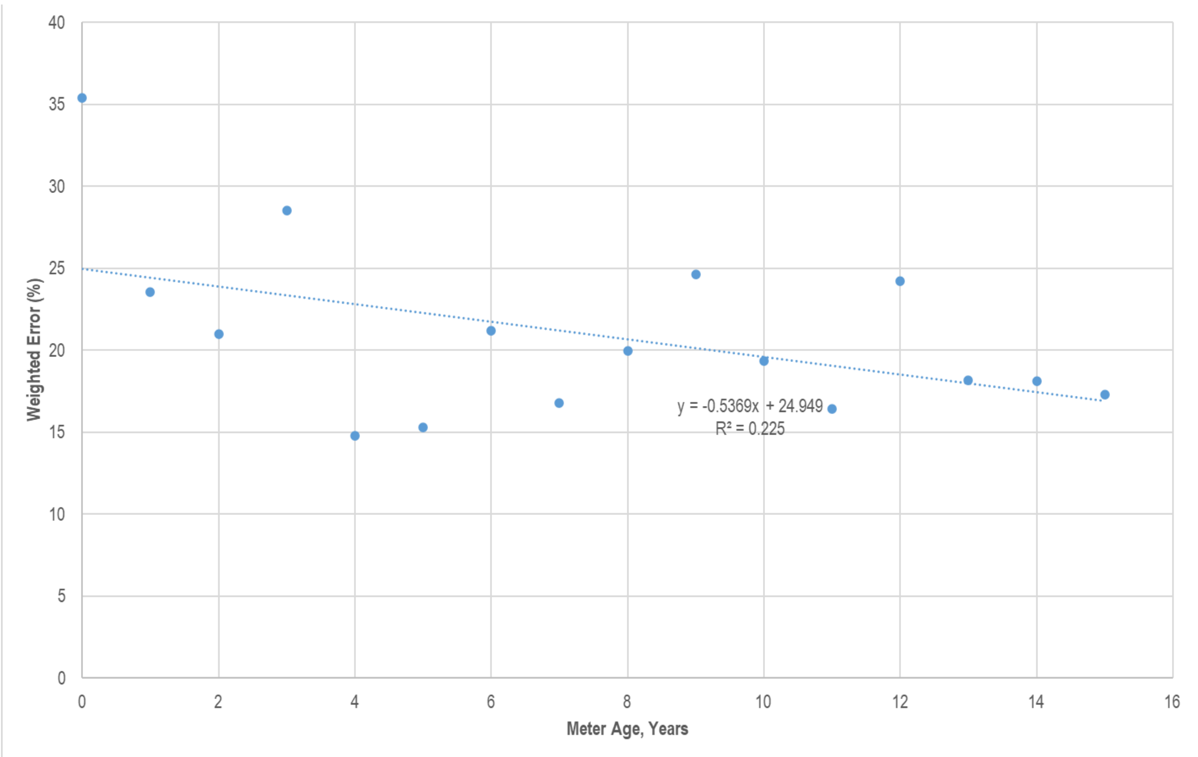

Figure 49: Model 4 Weighted Error with Age

In addition, due to the exact combination of the consumption profile and the meter error curve, the meter may overestimate at the point of highest proportion of consumption. Further investigations will be required to explain the behaviour portrayed by the meters. Despite this, the negative degradation of the weighted error (i.e. the improvement) is of similar quantum at 0.5% per annum as that observed for the Model 1 meter of 1.2% per annum.

4.4 KEY OBSERVATIONS

The context of collected data is particularly important to keep in mind in the interpretation of these results. The majority of all the tests were reactive tests of meter suspected, by either consumer or municipality, to be at the end of their lifespan. This therefore introduces some form of bias in the results. It will be important to supplement such data with planned meter tests that seek to determine the accuracy of the population of meters as existing in the field. This has been done for Municipality D in Ncube & Taigbenu (2019a) and should be replicated in other parts of South Africa to get a clearer picture on the accuracy of meters. The lack of proactive meter testing data is also indicative on the state of apparent water loss management in the country and needs to improve.

Part of the data was received from accredited laboratories came in PDF format, which is understandable to have an immutable record of testing. However, from an analysis point of view, these files need to be converted to a suitable file format, such as Microsoft Excel in this case, to both consolidate and analyse the data. As such, having processes that can minimise the amount of conversion work required, such as the proposed database, is an important aspect.

The non-accredited meter testing data reviewed is in a poor state and can be improved, even without obtaining accreditation. Some of the tests done are not conclusive, as they are done at non-prescribed flow rates and in certain instances at only one flowrate. As with all other municipalities interviewed, the data is also kept as individual files in a lone computer. As such, there is a clear need of putting together some guidance in terms of how meter testing should be done to build up some information on meter performance.

Test reports format and content is largely dependent on the testing lab and it is apparent there are no set requirements by municipalities, who tend to be generally interested only in a pass/fail outcome. The different meter test laboratories therefore use different formats in capturing the test results and this makes consolidation difficult. Some form of standardisation with minimum requirements could benefit the industry, particularly in assisting municipality in setting up some form of specification for test results.

Some meter attribute data was missing in the test results, the most significant being the meter date of manufacture. This is linked to the lack of standardisation on the test report format and the lack of adequate record keeping at municipal level. Some meter labs have also reported that the lack of related meter information makes it difficult to advise their clients appropriately. For the purposes of the database and any such related analysis, the absence of attribute data makes the determination of meter age at the testing date impossible to determine accurately.

There were several errors that were picked in the meter error percentage for some test records, with very high values that do not make sense. While such results were excluded from the analysis, a database that allows the verification of values that have been supplied by a verification officer will ensure that such errors are minimised.

Owing to the lack of standardisation, some reports have meter tests performed at 3 flowrates while others do them for 5 flowrates. The logic behind either is the interpretation of the SANS 1529-1 Standard, which is silent on meters that are in-service. Some industry best practice of the ideal number of test points should therefore be developed to balance the cost and value of the output of the data, over and above determining whether a meter complies with the accuracy requirements of the standard.

In terms of the results obtained from the analysis, it is clear that some of them require further elucidation and that the use of reactive data only may be a source of error in the results. That said, there are some very clear trends that are indicative on the need to proactively manage meters better by knowing their accuracy and state with both age and recorded volume.

To counteract some of the challenges currently being experienced in the sector, a meter management database and application developed as part of this research. The application can handle activities ranging from capturing meter accreditation data, individual test reports, importing historical testing data, analysis and reporting all within a centralised platform that consolidates data from different municipalities, flow laboratories and the NRCS. The database is securely hosted centrally in the cloud to facilitate the consolidation of data from different sources. Access to this database is only possible via the Meter Performance Monitor application which is available for download via a set URL that is emailed to registered users. Each organization with individuals that need access to the Meter Performance Monitor system will need to identify an administrator who will manage the creation of user accounts within that organization. This individual will then need to send an email to info@aquants.co.za so that their administrative account may be created. Once the system account for this administrative user is created, the user may download the application and login. From this point onwards, user accounts within this organization are created and managed by this administrator.

Only requests that come from recognised and approved organisations (municipalities, flow laboratories, the NRCS, the WRC and other such users) will be approved and provided with credentials for the Meter Performance Monitor application and the database. Users are only able to view and add data for their specific municipality but can report on the nationwide data without being able to drill down to a meter level.

The functionality of the database application is described in detail in Appendix A.

5 INITIAL WEIGHTED METER ERROR OF COMMON METERS

It has been shown in the preceding sections that one critical aspect that is currently missing within the South African, and indeed the broader African context, is data on starting accuracy of water meters and in turn the respective weighted accuracy that takes the consumption profile into account. The uniqueness of the consumption profile per area, region and consumers, in addition to the variation in water meters in each of the area mean that initial weighted error results from other countries and regions cannot just be applied locally.

Two important considerations in the determination of initial weighted accuracy of meter are the common meter models and the number of test flow rates that required per meter. The latter is discussed in greater detail in the following section.

5.1 SELECTION OF WATER METERS

With respect to common meter models, Table 6 was used as the basis of the common meters with an inherent assumption that the test records are representative of common meters in the South African networks. This was checked against Ncube (2019), which included field installation data and part of the meter testing data included in this study, and the meters in Table 6 were found to be largely representative of meters in the field. In addition, there was another meter model which had significant field installations but was relatively new to Municipality D. The final meter selection and the numbers of meters bought and tested are shown in Table 9.

Table 9: Purchased New Meters

Meter Manufacturer	Meter Model	No.	Material	Technology	Class	Remarks
Manufacturer A	Model 2	15	Brass	Volumetric	C	
	Model 4	10	Brass	Multi-jet	C	Discontinued, most expensive
	Model 5	15	Plastic	Volumetric	C	
Manufacturer B	Model 3	15	Plastic	Multi-jet	C	
Manufacturer C	Model 7	15	Plastic	Volumetric	C	
Manufacturer D	Model 1	15	Plastic	Volumetric	C	
	Model 6	16	Plastic	Multi-jet	B	Additional meter for trial run
Totals		***101***				

All the meters were purchased from the sales department of the manufacturer, or authorised sale representatives, as would be purchased by any customer. The purpose of the purchases was not disclosed upfront to ensure that meters that would have been purchased by any member of the public were also offered to the project. While verification certificates were requested with all purchases, except the additional Model 6 which was bought at a hardware shop, it was clear that while the supply of such meters with certificates is regulated, several manufacturers had to be followed-up with numerous times to provide the certificate. In fact, one supplier had to supply an alternate batch of meters as no certificates were available for the first batch. It is therefore important that this aspect be addressed by the NRCS to ensure that even meters that end up at hardware stores are sold with the verification results to demonstrate meter conformance to the required standards.

5.2 DETERMINATION OF THE OPTIMUM NUMBER OF TEST FLOWRATES

Arregui et al. (2013) evaluated several meter models at 20 different flow rates to determine the optimum number of required test flow rates. The optimum number of test points was one that minimised the meter error and was found to be eight test points. However, Arregui et al. (2014) used ten flowrates in the analysis of domestic water meters field performance as the determination of the error curve at low flow rates, where large variations occur, requires exceptional care to obtain a precise representation of the actual performance of the meters in the field. Considering these important studies, Ncube & Taigbenu (2019a) slightly modified the recommendation of Arregui et al. (2013) to suit meters common in South Africa, together with the incorporation of existing test flowrates adopted locally. Fourie, Marnewick & Joseph (2020) also adopted ten flow rates for meter degradation analysis in Gauteng with slightly variations of the flowrates. However, the optimality of these ten flowrates has not been evaluated for local conditions. This is particularly important in the South African context with limited water meter testing where unnecessarily increasing the number of tests flowrates will put additional strain on already limited financial resources.

The two local studies (Ncube & Taigbenu, 2019a; Fourie, Marnewick & Joseph, 2020) used a combined 223 tested at 10 different flowrates and therefore provide an excellent basis for the evaluation of the optimum number of test point for local conditions.

5.2.1 Ncube & Taigbenu (2019a) Dataset

The study tested 123 water meters that were removed from the field using stratified sampling to be representative of the Municipality D meter network. The meters therefore adequately represented both the meter models and the meter readings within Municipality D. This means that the weighted accuracy calculated is intrinsically that of the water meters in Municipality D. These meters were tested using ten flowrates which are reproduced in Table 10, together with the equation which clearly indicates the rationale in how the different flowrates were computed. It is important to note the use of standard flowrates to derive each of the ten flowrates which makes their computation relatively easy. One important improvement to these flowrates would be the use of the starting flow rate (the flowrate at which the meter starts recording flow) of the meter as the initial test flowrate, in cases where this is possible.

Table 10: Test Flowrates (Municipality D)

Size	*q_p, ℓ/h*	*Q1*	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*	*Q8*	*Q9*	*Q10*
15 mm	1,500	7	15	22.5	30	60	120	750	1,500	2,250	3,000
20 mm	2,500	12	25	37.5	50	100	200	1,250	2,500	3,750	5,000
25 mm	3,500	17	35	52.5	70	140	280	1,750	3,500	5,250	7,000
Any other	q_p	$0.5q_{minC} - 1$	q_{minC}	q_{tC}	q_{minB}	$0.5q_{tB}$	q_{tB}	$0.5q_p$	q_p	$1.5q_p$	$2q_p$

Using the raw data of the study, this project recalculated the weighted accuracy and error for each of the test records by varying the number of test flowrates used to estimate the weighted error. Figure 50 summarises the output of the analysis.

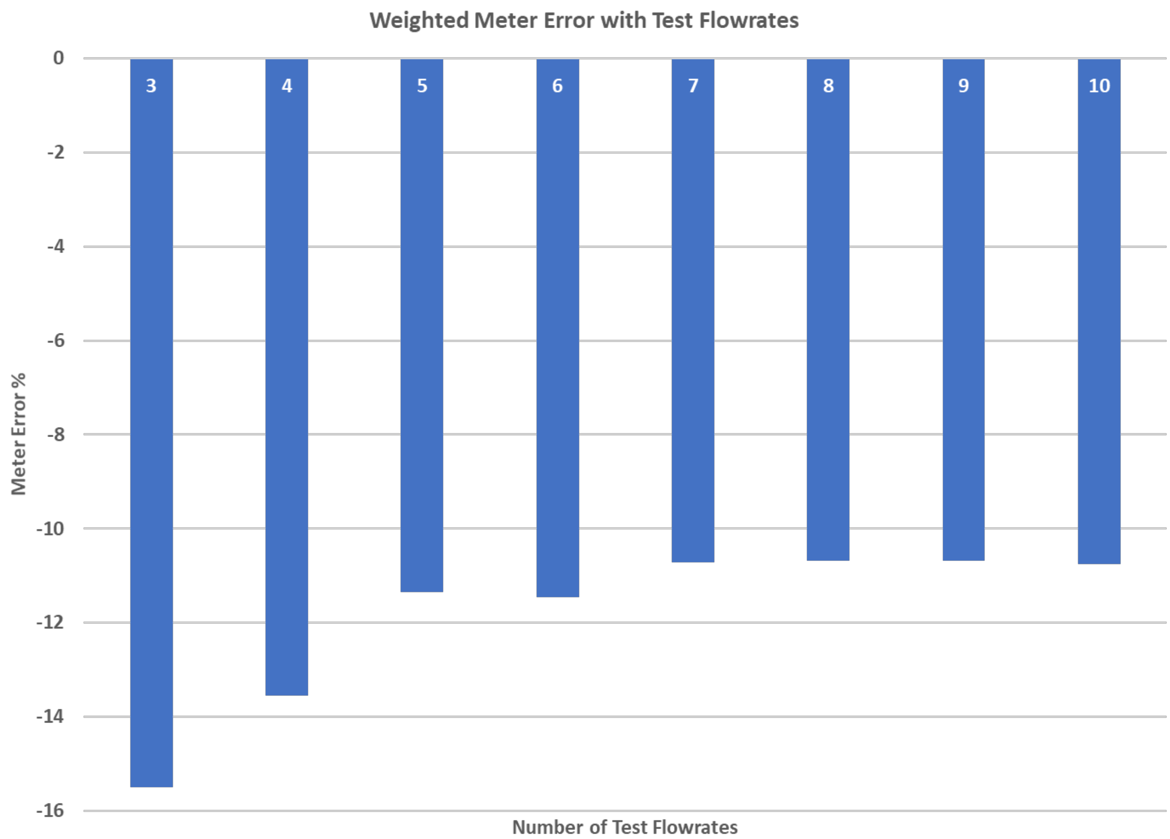

Figure 50: Impact of Number of Test Flowrates (Municipal D)

The weighted meter accuracy increases with increasing number of flowrates, or conversely the error decreases with the increasing number of test flowrates. In all cases, better accuracy is achieved at 10 flowrates, with 4.74% difference in weighted accuracy when calculated using three flowrates (q_{min}, q_t, and q_p) and the ten flowrates. The inadequacy of the common use of three test flowrates for the estimation of meter error and the weighted meter accuracy is clearly demonstrated in this case.

It is important to note an important distinction in this study from the trend recorded elsewhere in literature where the weighted error trends increase with more test flowrates as shown graphically in Figure 32 (Johnson, 2019). This peculiarity is due to the compounding effect of the South Africa (Johannesburg) consumption profile which has high incidence of relatively low flows compared to the profiles of other countries. The net effect is that locally, the use of three test flow rate tends to exaggerate the weighted meter error and this overestimation is reduced by increasing the number of flowrates. Another notable difference is that the omission of certain test flowrates (for 7, 8 and 9 test flowrates) overestimates the meter accuracy by 0.04-0.08%. While these are minor differences, it is instructive on the fact that the choice of specific meter test points is not trivial and should be given due consideration.

5.2.2 Fourie, Marnewick & Joseph (2020) Dataset

The study tested 200 water meters of two models (same manufacturer) from the Municipality B. Unlike Ncube & Taigbenu (2019a), the meters tested for this dataset were those requested by consumers when suspecting a faulty meter or those that had been flagged for verification through various city processes. This is an important distinction as the meters are not representative of an installed meter fleet but are those meters that are potentially at the end of their useful life. The use of the dataset must ideally be limited to such potentially end-of-life meters and not making conclusive trends about a water meter fleet in general. In this study, we have opted to review any meaningful trends and compare them against the data of Ncube & Taigbenu (2019a).

The test flowrates applied in this dataset are adapted and summarised in Table 11. While there are some different flow rates to the prior study, the differences are not considered to statistically alter the results of such an analysis.

Table 11: Test Flowrates (Municipality B)

	Q1	***Q2***	***Q3***	***Q4***	***Q5***	***Q6***	***Q7***	***Q8***	***Q9***	***Q10***
15 mm meter, q_p = *1,500 ℓ/h*	7	15	30	45	60	120	240	750	1,500	3,000
Relationship to key flows	$0.5q_{minC} - 1$	q_{minC}	$2q_{minC}$	$2q_{tC}$	$2q_{minB}$	q_{tB}	$2q_{tB}$	$0.5q_p$	q_p	$2q_p$

Similarly, using the raw data of the study, the weighted accuracy and error was recalculated for each of the test records by varying the number of test flowrates used to estimate the weighted error. The consumption profile in Table 13 and Table 14 are however utilised instead of the average consumption profile that was adopted by the study. Figure 51 summarises the output of the analysis.

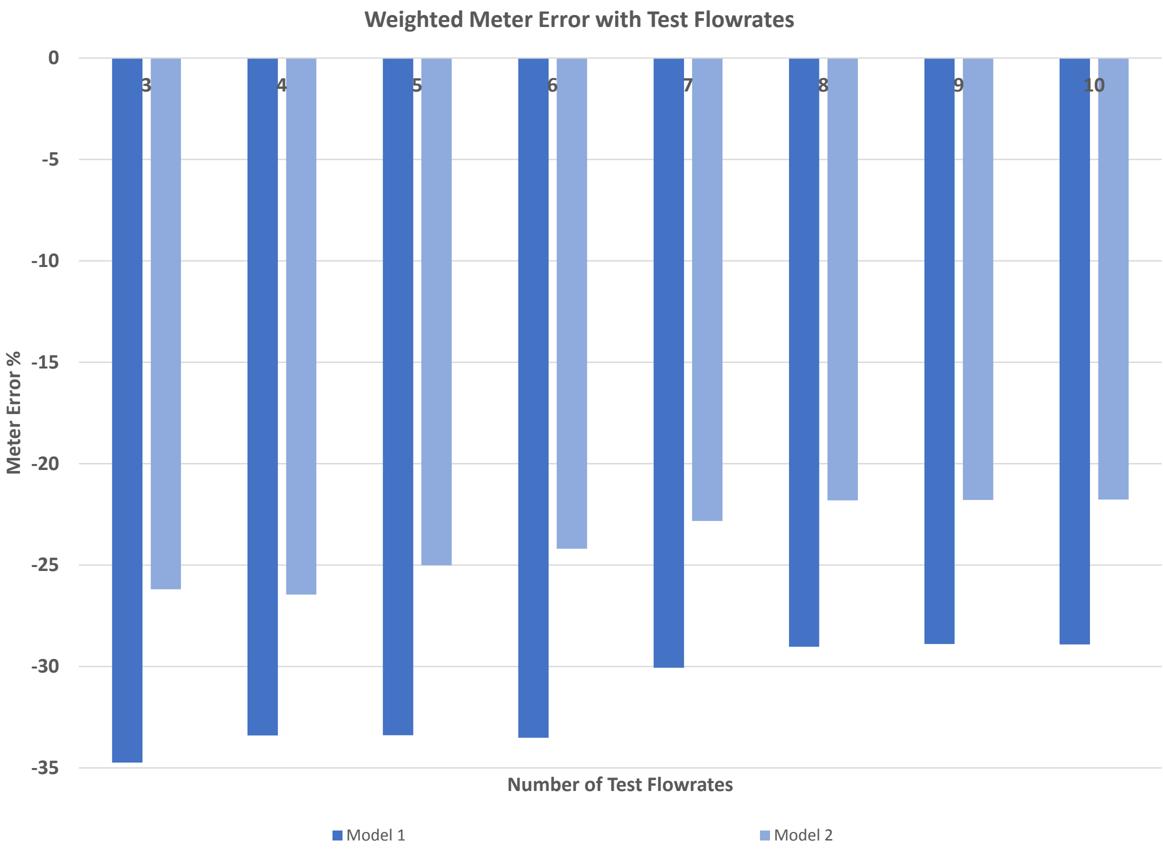

Figure 51: Impact of Number of Test Flowrates (Municipality B)

As one moves from three to ten test flowrates, there is an overestimation of the weighted meter error by 4.7% and 5.8% for Models 1 and 2, respectively, for this dataset. There is therefore a clear demonstration once more that the number of flowrates does matter and the trend, in overall, is that fewer flows tend to overestimate the weighted meter error. This is consistent with the observations from the previous section (§5.2.1). It is also clear from the highlighted portions of Table 13 that there is scope for omitting certain flowrates without having a substantial impact on the estimation of the meter error.

As indicated earlier, the use of these datasets for making broader conclusions without factoring in the meter reading and/or age of the meters used is strongly discouraged and as is the averaging of the weighted accuracy of the two models to paint a general picture. By definition, the weighted meter accuracy considers a representative meter population and a representative consumption profile – without these, the use of the term should be adequately qualified.

5.2.3 Adopted Flowrates

Using the discussions of §5.2.1, the study adopted the following rationale:

- The four flowrates specified in the SANS 1529 standard (q_{min}, q_t, q_p and q_{max}) should ideally be the minimum requirement as they define the flow range that a meter can be subjected to with prescribed performance standards at these flowrates.
- All flowrates which when omitted lead to a high variance in weighted error must be included while conversely, those that do not should be excluded.

From the highlighted region of Table 11, the omission of Q6 and Q7 seem to have a limited impact in the weighted error. Further interrogation of the data also shows that if Q10 is included, the influence of Q9 in the weighted accuracy is minimal and therefore can also be excluded. Table 12 shows three additional variations of the test flowrates that were assessed, against the best option of 10 flowrates.

Table 12: Alternate Variations of Test Flowrates

No. of flowrates	***10 (baseline)***	***3***	***6***	***7***
Included flowrate, Q*	1-10	2, 4, 8	1-2, 4-5, 8, 10	1-5, 8, 10
Weighted Accuracy	89.24	86.62	89.89	89.19
Weighted Error	-10.76	-13.38	-10.11	-10.81

One observation was that due to the inflection of the error curve at the transition flowrate, this flowrate could be omitted with limited impact. While the other two variations were worse off, the seven test flowrate option underestimates the meter accuracy by 0.05%. This is a superior estimate that also fulfils the requirement of evaluating the meter accuracy over the meter measuring range (q_{min} – q_{max}) compared to the seven flowrates of Table 11 which is closer in magnitude by 0.01% but overestimates the error and does not include the permanent and maximum flowrate.

Considering the results of Ncube & Taigbenu (2019b) that found that meter degradation locally was about 0.7% per annum, underestimating the meter accuracy by 0.05% is very negligeable and will have no meaningful impact. In view of the time and the cost of meter testing, the margin of the error is minimal and the use of the seven test flowrates is therefore considered optimum. The seven test points were accordingly adopted for the testing of new water meters.

One obstacle in the determination of weighted accuracy estimates, particularly for studies that did not undertake consumption characterisation studies, is the determination of the consumption profile at the same level of detail as the test flowrates. Various studies tend to interpolate the previous results, and this is not without its drawbacks. Using the original consumption characterisation data of Ncube & Taigbenu (2016), a complete consumption profile including flowrates that can be easily adapted for use by most studies has been produced in Table 13 and Table 14.

Table 13: Consumption Profile (Part 1 ≤ 120 ℓ/h)

Consumption Category	*Flowrate, ℓ/h*								
	7	**15**	**22.5**	**30**	**35**	**45**	**60**	**96**	**120**
Business	2.68%	5.48%	6.93%	10.04%	0.56%	0.33%	21.12%	1.97%	12.02%
Public Benefit Orga	2.02%	3.11%	3.33%	8.45%	0.77%	0.21%	25.22%	0.89%	19.89%
Residential	5.50%	9.02%	5.89%	8.73%	0.97%	0.60%	20.04%	1.50%	12.14%
Multi-Purpose	1.93%	4.22%	2.82%	6.00%	0.87%	0.33%	18.64%	1.70%	18.60%
All	3.05%	5.54%	4.59%	8.17%	0.81%	0.37%	21.24%	1.48%	15.92%

Table 14: Consumption Profile (Part 2 > 120 ℓ/h)

Consumption Category	*Flowrate, ℓ/h*								
	240	**300**	**750**	**1,173**	**1,500**	**2,500**	**3 000**	**3,500**	**5,000**
Business	13.81%	5.31%	11.87%	6.06%	1.33%	0.44%	0.06%	0.05%	0.00%
Public Benefit Orga	16.45%	4.13%	10.21%	3.36%	1.06%	0.86%	0.05%	0.01%	0.00%
Residential	13.73%	2.70%	10.71%	6.01%	1.57%	0.83%	0.06%	0.05%	0.00%
Multi-Purpose	13.69%	4.30%	15.19%	8.21%	1.96%	1.39%	0.15%	0.08%	0.00%
All	14.45%	4.01%	11.99%	5.90%	1.49%	0.92%	0.08%	0.05%	0.00%

It should be noted that these are essentially the same consumption profiles in Ncube & Taigbenu (2016) and Ncube & Taigbenu (2019a) with instances of corrected for formatting errors where decimal places were truncated. Using Table 13 and Table 14, the consumption profile for the adopted meter test flowrates in shown in Table 15.

Table 15: Adopted Test Flowrates and Consumption Profile

Seven Test Flowrate, Q	*Q1*	*Q2*	*Q4*	*Q5*	*Q7*	*Q8*	*Q10*
Test Flowrates, *ℓ/h*	7	15	30	60	120	1,500	3,000
Consumption Proportion at Flowrate	5.50%	9.01%	14.61%	21.57%	13.64%	34.66%	0.89%

However, due to a mix-up in the nomenclature of the test flowrates tables, the values of Table 15 were eventually used at the lab with Q1-Q5, Q9 and Q10, with the introduction of 40 ℓ/h as opposed to the 120 ℓ/h in Table 14. The advantage of this is that the meter error curve tends to be more variable at 40 ℓ/h and flatter at 120 ℓ/h and therefore more detail was added to the meter curve. This does not change the recommendation of Table 15.

5.3 INITIAL METER ACCURACY AND WEIGHTED METER ERROR

5.3.1 Initial Meter Accuracy

The water meter testing was done in partnership with the manufacturer independent and SANAS-accredited Johannesburg Water Flow Laboratory over the period of March 2021 to January 2022. A total of 101 meters (see in Table 16) were tested at the adopted seven test flowrates in line with Johannesburg Water Flow Lab standard operation procedures. The individual test reports were accordingly consolidated and analysed further to determine both the average initial meter error for each meter model and the weighted meter error per model. A few points were ignored in the analysis when it was clear that there could have been some error in its capturing. Where these were encountered, they were not considered in the subsequent analysis. The summary of the test results is summarised in Table 16.

Table 16: New Meter Pass Rate

Meter Manufacturer	Meter Model	No. Tested	No. Passing*	% Pass Rate*
Manufacturer A	Model 2	15	4	26.7
	Model 4	10	0	0
	Model 5	15	0	0
Manufacturer B	Model 3	15	9	60
Manufacturer C	Model 7	15	0	0
Manufacturer D	Model 1	15	1	6.7
	Model 6	16	15	93.8
Totals		***101***	***40***	***39.6***

* Against requirements of SANS 1529 over the **entire** error envelope

The results of Table 16 are disappointing and surprising at the same time as they clearly show a very low compliance of new meters to the SANS 1529 requirements from the onset, despite having verification certificates that prove otherwise. This is in part because this study tested the meters at more flowrates within the error envelope including at points where the manufacturers may not have adequately calibrated their meters at those specific flowrates. This highlights an important aspect that error curves as contained in specification documents are not necessarily representative of reality. These results also validate the high failure rates and in turn the results of the probability of failure analysis in §4.2 further underscoring the importance of verification of new meter accuracy by the regulator and municipalities is a great need to improve on this poor initial performance.

The actual detailed meter error curves per meter class are shown in Figure 52 (Class C) superimposed against the respective normative meter error envelope for each meter class. Previously, Class C meters were found to be the most appropriate for Municipality D in Ncube

(2019) and would likely be as appropriate to most municipalities within South Africa. As such, their performance is of specific relevance.

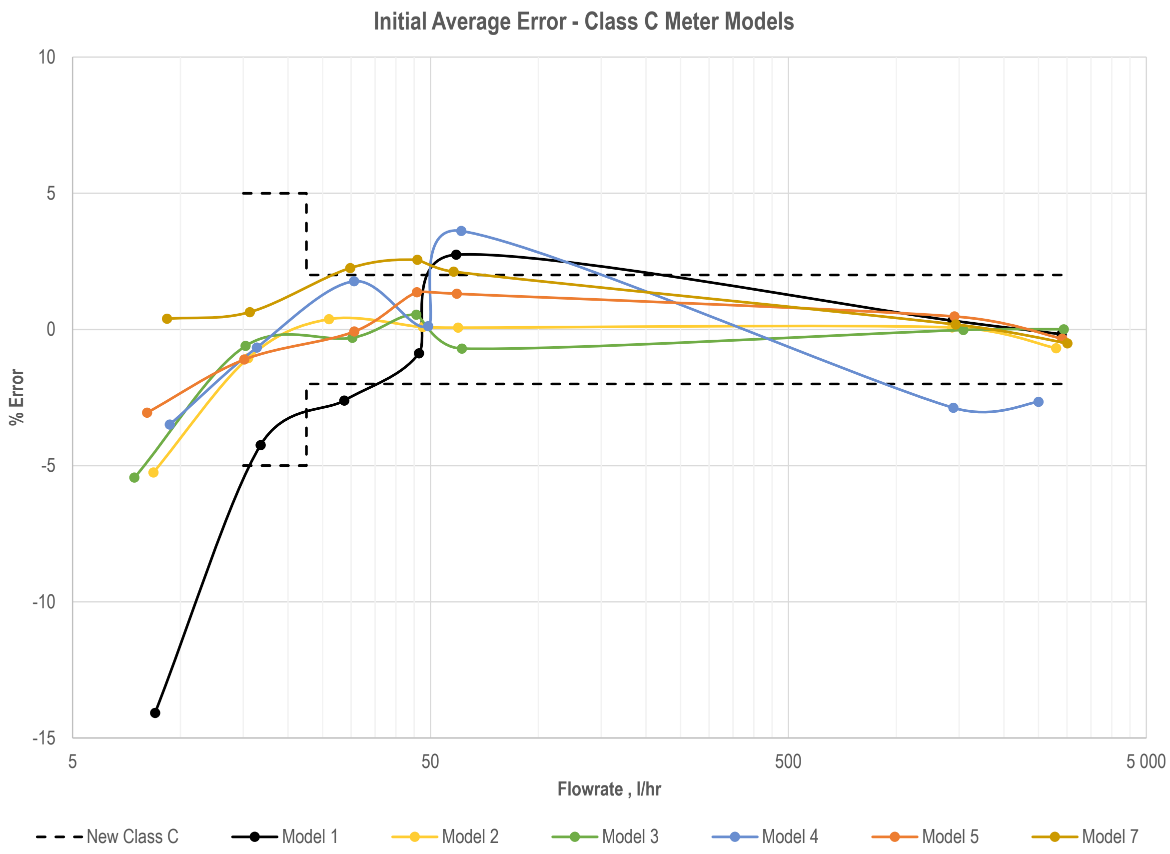

Figure 52: Initial Error for Class C Models

Figure 52 shows only three meter models being fully within the prescribed meter error envelope. The other three meters are failing to be within the ±2% range for the flows of 22.5-60 ℓ/h and the upward trend of the error curves imply that there will be an over-estimation of the flow through a meter which would mostly disadvantage consumers. While all the meter models seem to generally comply with requirements at the three standard test flowrates, it is clear that reliance on these 3 test flowrates alone may be inadequate for obtaining an accurate picture of meter performance.

Despite some of these shortcomings, the performance of most of the Class C meters is very good at low flows, as their error in these low flowrates are within or around the ±5% error margin. This makes them ideal for South African contexts where high levels of onsite leakages, which tend to be low flows, have been reported in literature. There is a 63% occurrence of leakage within Johannesburg with the estimated monthly leakage ranging from 11-41 m^3/month (Ncube & Taigbenu, 2016. This is very similar to the 64% value recorded by

Lugoma, Van Zyl & Ilemobade (2012), also within Johannesburg. This study therefore confirms why utilities and municipalities with similar challenges should be considering the use of such meters. It must be noted that the Class C meters, as evaluated here, comprise both volumetric and velocity meters and therefore there is adequate choice for utilities who have requirements for a specific technology.

The error curve of the only Class B meter model evaluated in this study, a velocity meter, is shown in Figure 53.

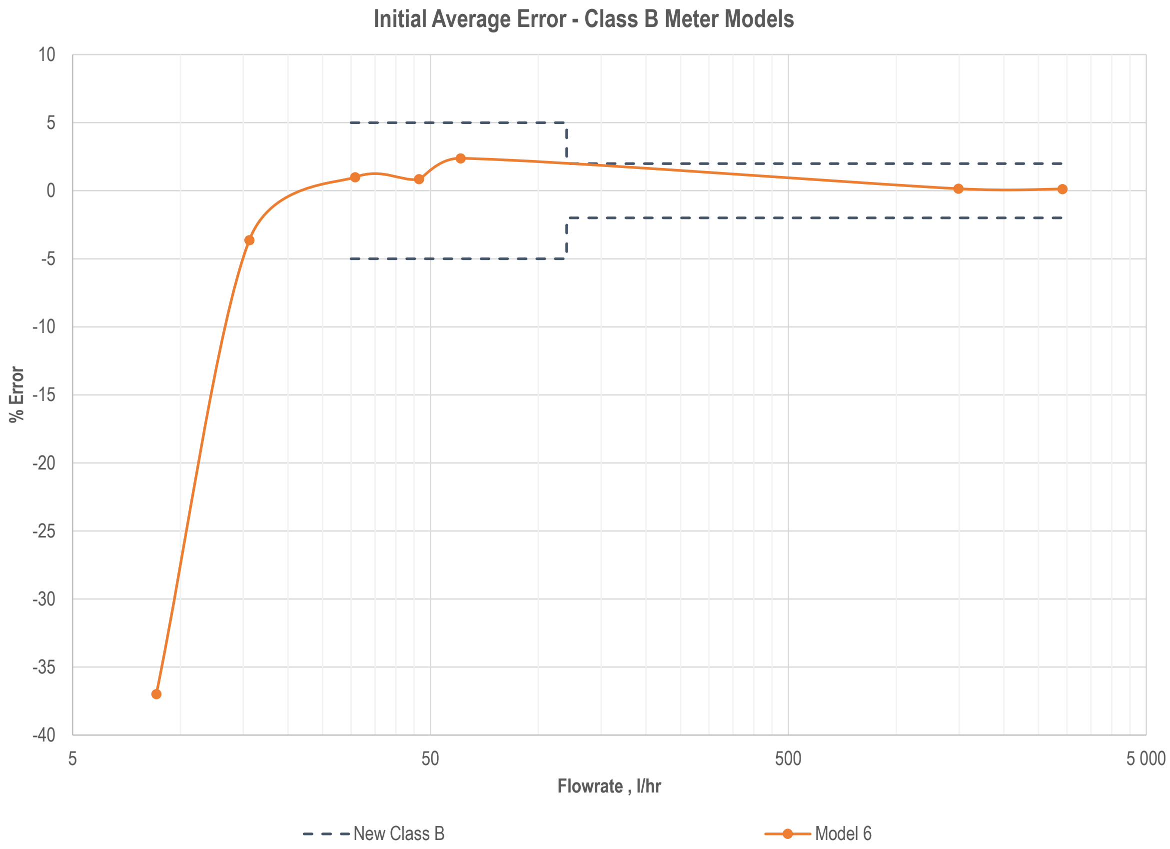

Figure 53: Initial Error for Class B Model

The model shows very good performance and compliance levels as it also meets Class C requirements at all the standard test flowrates. However, the error at low flows is, as would be expected, much worse than that of the Class C meters and would therefore be unsuitable for areas with high incidences of low flows. Otherwise, based on the outcome of this study, the Class B meter model will be as good as any Class C model that is available in the country.

This underscores the value of avoiding judging meters and meter models just by their class label but rather using their verified specifications and taking into consideration the consumer profile. For that matter, it is known that certain manufacturers do get their meters classified to inferior classes due to onerous requirements for higher classes and the inability of local certification bodies to do the work timeously.

5.3.2 Initial Weighted Meter Accuracy

The adequacy of the water meter models used in this study for measuring the average South African consumer can be determined through the imposition of the meter accuracy at respective flowrates against the presumed consumption profile of such a consumer over similar flowrates. In this case, the consumption profile of Table 17 is adopted and used together with the meter accuracies derived in §5.3.1.

The initial weighted meter accuracies are shown in Table 17 and graphically in Figure 54, together with average weighted accuracy for all the meters. In general, all meter models evaluated tend to underestimate the quantity of water flowing through the meter by up to 7% when new. This underestimation is similar to that observed in other studies such as Arregui, Balaguer & Soriano (2017) where the initial weighted error of ISO velocity meters ranges from -0.71% to -3.87%, 4.56% for AWWA single-jet meters, -4.46% for the AWWA multi-jet meters, 0% to -1% for ISO oscillating piston meters and up to -11.37% for AWWA oscillating piston meters. Such results clearly show that meter technology and the consumer being measured are very crucial in meter selection and management.

Table 17: Initial Weighted Meter Accuracy

Meter Model	Technology	Class	Weighted Accuracy (95% CI)
Model 6	Multi-jet	B	94.4% ± 0.7%
Model 1	Volumetric	C	93.2% ± 1.9%
Model 2	Volumetric	C	96.7% ± 0.4%
Model 3	Multi-jet	C	95.1% ± 1.1%
Model 4	Multi-jet	C	97.5% ± 0.5%
Model 5	Volumetric	C	97.4% ± 0.2%
Model 7	Volumetric	C	98.3% ± 0.5%
Average			***96.1 ± 0.4%***

It is also evident from Table 17 that within each meter technology group there is meaningful variation in performance with both groups overlapping. Multi-jet meter (velocity meters) errors range from -2.5% to -5.6% while volumetric meters (piston meters) range from -1.7% to -6.8% for a consumer like an average Johannesburg residential customer. Most of the meters have consistent metrological performance as shown by the narrow uncertainty levels, apart from Model 1 and Model 3 that had wider variations. Some Class C meters have an initial weighted accuracy that is inferior to the Class B meter which, again, underscores the need to look beyond the class and technology of a meter in purchasing and usage decisions.

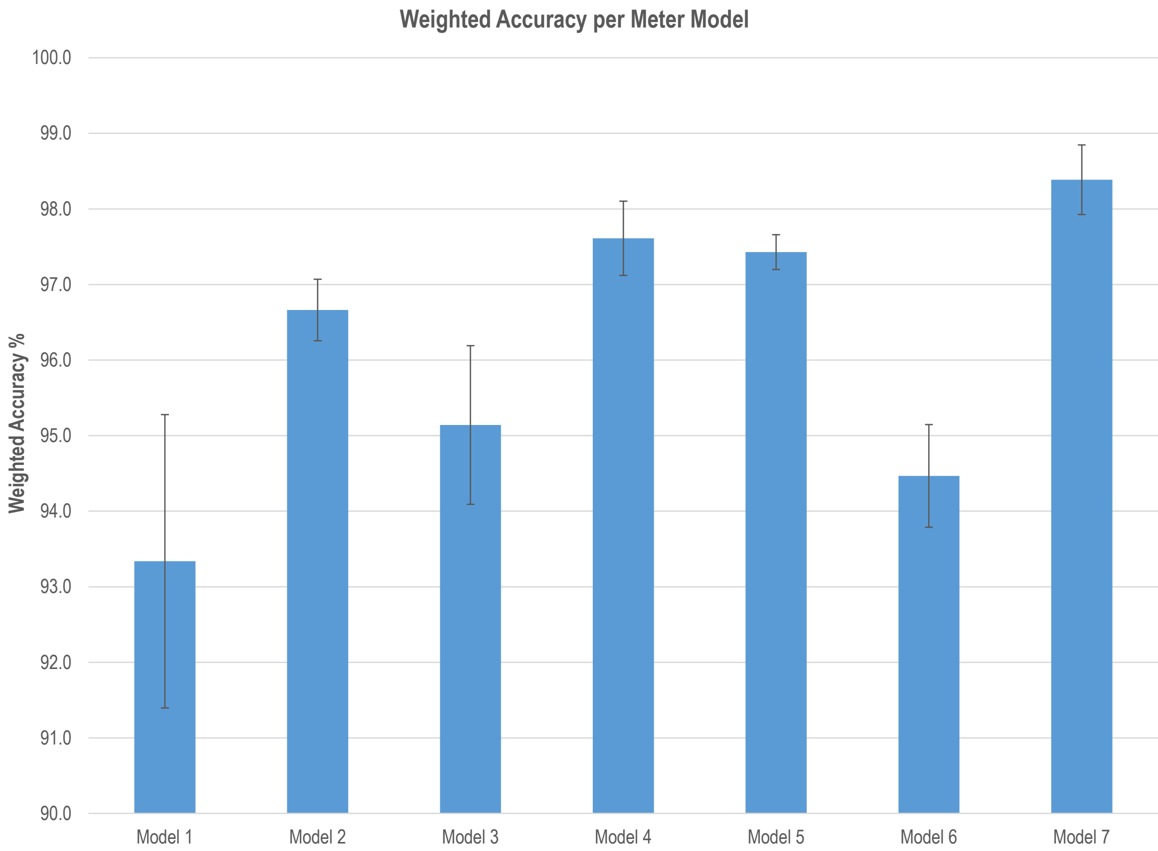

Figure 54: Initial Weighted Meter Accuracy

The starting error of Model 1 was estimated to be 7.8% in §4.3.2 compared to 6.8% ± 1.9% (i.e. 4.9% to 8.7%), which is similar. This validates the usefulness of aggregated data for the meter model in estimating the meter error an any point in time with a degradation rate of 1.22% per year in use.

It is important to reiterate that these initial errors are but a part of a bigger puzzle and do not always tell the entire story. For a start, the main assumption of this study is that the City of Johannesburg residential consumption profile is applicable for the rest of South Africa, but it is possible that there might be subtle differences in certain areas that may change the starting errors for the very same meters. It is also important to get to quantify the degradation rate of each of the respective meters as that has a bearing on how they will perform over time. The cost of the respective meter models is also a key aspect of the selection criteria.

Using the tool developed by Ncube (2019), it is now possible to fill some of the gaps in meter selection criteria for the country. Figure 55 shows the input screen for the various parameters required to estimate the optimal meter model for the specified consumption profile and meter accuracy details. The price of the meters was as purchased for this study and the initial errors are those determined in Table 17. The degradation rate used is that found for common meters in Ncube & Taigbenu (2019b) and a similar value is used for all meters, which is not usually the case in real life. The current City of Johannesburg tariffs for a consumer who uses 30 kl/month, together with fictitious meter installation costs are used for this exercise.

Variable Parameters for Each Meter

No	Make and Type	Price	Initial Error	Degrade Rate	Add. Costs
1	Model 1	334.65	7%	0.70%	
2	Model 2	373.75	4%	0.70%	
3	Model 3	379.5	8%	0.70%	
4	Model 4	828	3%	0.70%	
5	Model 5	658.95	3%	0.70%	
6	Model 6	320.85	6%	0.70%	
7	Model 7	641	2%	0.70%	
8					
9					
10					

Fixed Parameters for all Meters

Consumption Parameters		Rising Block Tariff Details		
		Level	Limit, kl	Rate, R/kl
Average annual consumption, kl	360			
Indicative tariff, R/kl	R24.89	1	6	10.87
		2	10	11.54
Meter Installation Costs (Common)		3	15	19.69
Meter Removal and Installation Costs, R	R2 500.00	4	20	28.66
Administration Costs, R	R150.00	5	30	39.37
Salvage Costs, R	R0.00	6	40	43.61
		7	50	55.69
Financial Rates		8		59.33
Interest Rate, %	7.25%	9		
Inflation Rate, %	4.30%	10		
Real Discount Rate, %	2.83%			

Figure 55: Meter Selection Input

The selection involves performing a cost benefit analysis (CBA) over the useful life of the meters, which is also determined at the same time. The results of the analysis are shown in Figure 56. The optimal replacement period of all the meter models for the given parameters are essentially the same at 10-11 years. This is likely what replacement rates should be in the South African context for consumers who use 30 kl/month, but this is generally not the case. Meters beyond this period are therefore costing municipality money.

Meter Selection Recommendation

Run Analysis

Costs and Benefits at optimum replacement period for each meter

Make and Type	Years	Least NPV	PV Revenue	PV Costs	Benefit:Cost	% Revenue Lost
Model 1	10	R44 158	R71 539	R10 748	9.22	10.9%
Model 2	10	R33 566	R74 156	R8 170	14.41	6.9%
Model 3	10	R48 252	R70 588	R11 744	8.10	12.3%
Model 4	11	R32 078	R81 086	R8 475	16.23	6.2%
Model 5	11	R32 090	R80 914	R8 478	15.65	6.4%
Model 6	10	R40 191	R72 491	R9 782	10.64	9.4%
Model 7	11	R28 764	R81 775	R7 600	18.98	5.3%

Recommendation

Meter Make and Type: Model 7
Benefit to Cost Ratio: 18.98
% Revenue Lost: 5.3%

Figure 56: Meter Selection Recommendation

In the current scenario, due to the use of the same degradation rate, the meter with the best starting accuracy is clearly a better performer, despite its unit price being higher than most of the meters. Because of the unknown degradation rate, it is always wise to perform a sensitivity analysis for any chosen meter as is shown in Figure 57 for the same Model 7 meter with a 70% variation of the degradation rate.

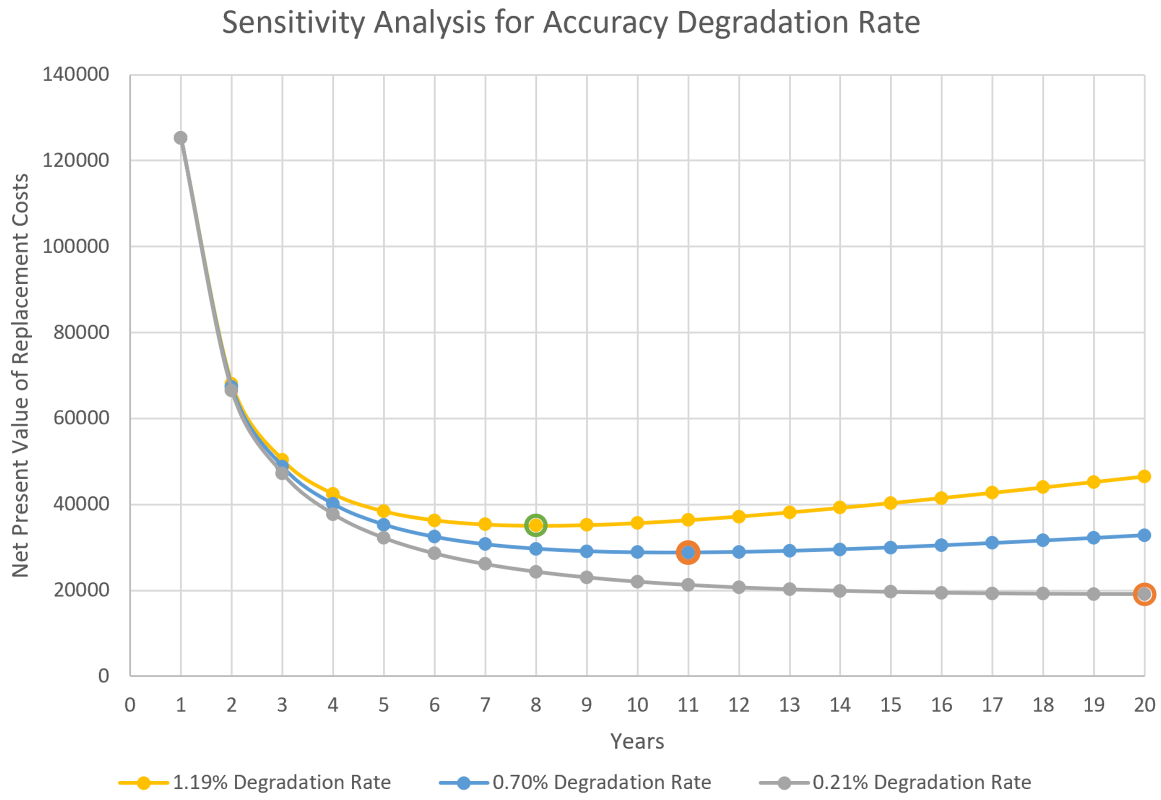

Figure 57: Sensitivity Analysis for the Recommended Meter

A 70% variation in the degradation rate leads to a considerable variation in the optimum meter replacement period from as low as 8 years, which would be undesirable. It should be noted that such a high degradation rate is not implausible as has been observed in §4.3.2 for Model 1.

On the other hand, in the case that the degradation rate is much better, the useful life increases to a desirable 20 years. Unfortunately, municipalities are known to keep meters well over 30 years and this exercise shows that even for a meter with the best starting weighted error, assuming the least degradation rate than that provided for in literature only gives a useful life of 20 years. The practice therefore needs to be improved and evaluating meter degradation rates of meter models proactively is a good step towards informed and better meter selection and management. This study has delivered a database of available historical meter tests that can be built upon to provide just that information.

One key takeaway from this meter selection demonstration in how the results of the study can be used is that the prevalent use of least cost in water meter purchasing decision is not smartest thing to do. There is more at stake than just the meter price and institutions making purchasing decisions need to take this into account.

5.4 KEY OBSERVATIONS

In this chapter, the common meters that are used in the municipalities that participated in this study, and by proxy the whole country, have been identified, selected and bought from the respective meter manufacturers. The process did show that the availability of meter verification data and test certificates tends to be optional and is not a standard issue with meter purchases for most of the manufacturers. This is a practice that must be changed to ensure that meter data is democratised as much as possible, particularly as not all meter users are empowered to know that such data is theirs in the first place. Sensitisation of stakeholders, particularly municipalities who are the main users of meters is considered essential.

While previous studies have recommended the use of eight to ten test flowrates for the evaluation of metering accuracy, this study has shown that for a marginal decrease in estimation accuracy, it is possible to use six test flowrates instead. The cost of meter testing in both time and resources involved, can therefore be considerably less as about 40% of the testing requirements can be sacrificed without much loss in meaningful outcomes. In addition, an expanded and reconfigured consumption profile has been produced to allow for the flexibility of applying different testing requirements. It should be noted however, that the use of other flowrates without a scientific basis or the need to verify one can be fraught with challenges, least of which is the added cost with marginal benefits.

Using the adopted test flowrates, the project evaluated 101 new water meters of seven different models that are common in South Africa to determine their initial weighted accuracy and applicability for local conditions. Only 40% of the meters were in full compliance with SANS 1529 requirements, which is very low and unacceptable. The low pass rate is masked by the fact that meters tend to be calibrated to meet the requirements of the 3 standard flowrates but fall outside the error envelope at other points as these are not evaluated. The use of standardised test to ensure that all meters are fully compliant over the range of flows a meter is meant to work over should be something that must be done for the sector to improve this low pass rate. It was also shown that neither the meter class nor its technology are necessarily good predictors of the ability of a meter to pass or to have superior accuracy. Therefore, it is important to collect and collate meter performance data regularly to be able to evaluate and uncover such anomalies and be better informed in making meter management decisions.

Finally, the initial weighted accuracy of new meters in South Africa has been assessed, which is a first for South Africa and the African continent. This provides a better basis of determining the useful life of water meters and how they can be better managed to improve the management of apparent water losses. The average initial weighted accuracy of water meters in South Africa was determined to be 95.5% and is indicative of minimum apparent loss levels for a brand new meter. Current guidelines on possible apparent water losses need to be revised to reflect that a 4.5% initial apparent loss error is likely to be the best possible figure assuming an equal spread of the meters tested. A demonstration of the implication of the results has also been done that seems to indicate that based on the starting error of the common meters, and an average degradation rate of 0.7% per year, the average meter replacement period of local meters should be 10-11 years for a typical consumer who uses 360 kl per year.

It should be noted that while these results are for domestic meters sized 15 mm, the results are equally applicable to any advanced meters and other such metering systems whose metrology components comprise similar mechanical meters. This will include the existing prepaid meters (tag-based or STS based) that use any of the meters evaluated in this study. In addition, it should be noted that from the consumption profiles adopted in this study, 15 mm meters are the most appropriate for use as the apparent losses associated with 20 mm and 25 mm meters would be much higher for the same category of users.

6 WATER METERING GUIDELINES FOR SOUTH AFRICA

The preceding chapters have painted a picture of the metering landscape in South Africa, together with the common practices by utilities, municipalities and water meter manufacturers and resellers. §3.2 summarises the key findings from stakeholder consultations, which have been confirmed through the quantitative analysis and other work of the report. It is important to recall that.

i. **Inadequate regulations**: meter buyers need to take proactive steps to influence the quality of the meters in the market, including to better managing meters making up their metering fleet.
ii. **Inadequate meter testing and labs**: there are limited accredited flow laboratories within South Africa, largely dominated by meter manufacturers. The limited testing requires optimisation and aggregation to deliver better value to the water sector and to better inform meter management. Democratising such data will go a long way in improving the metering sector.
iii. **Old meters are prevalent in SA networks**: there is a high proportion of domestic water meters that have registered over 10,000 kl (equivalent to 28 years for an average consumer).
iv. **The average useful life of new meter is about 10-11 years**: assuming a degradation rate of 0.7% per annum. Vis-à-vis (iii) above, the sector needs to do more to manage meters better and have meter replacement decisions informed by actual data, including actual degradation rates.
v. **Aggregation of meter data works:** However, the absence of proactive testing data is a challenge as the results from suspected failed meters obviously would inevitably skew the results and the interpretation, therefore. Planned meter testing of functional meters will better inform the sector. Meter data aggregation also requires some form of standardisation on reporting which could be solved using the developed database.
vi. **Seven test flowrates approximate the meter curve well:** specially selected test points were shown to adequately represent the required meter accuracy of various meters. This will be a mean less resource requirements for the limited meter labs.
vii. **Only 40% of new meters met the SANS 1529 requirements:** when tested at other flowrates within the error envelope, a lot of meters failed. There is need to ensure that the calibration of meters does not narrowly focus on the standard flowrates in the standard but the entire error envelope.

viii. **The average initial weighted accuracy of water meters in South Africa is 95.5%:** as such the average minimum apparent water levels in South Africa would be 4.5% of the volume consumed. The composition of meters is critical in determining this level.

A database that can capture all approved meters in South Africa, upload historical meter testing, record all meter tests as they happen, print test certificates, and perform various reporting functions has been developed as part of the project. Its functionality is described in the User Manual included as Annexure A to this report. However, for the database to be of better use to the rest of the country, there is a need to have some form of guidance as to how meter tests should be done and reported. Over and above that, there is a greater need to better inform the water meter user on the best way to select and manage water meters, and in the longer run to influence the quality of the meters that are available within the water sector.

Following is a summary of key metering aspects that are summarised from; standards such as the Australian Standard AS 3565.4:2007 (Reaffirmed in 2019) Meters for water supply Part 4: In-service compliance testing; the Water Services Association of Australia WSA 11 Code of Practice and the American Water Works Association (AWWA) Manual M6, literature (Arregui et al., 2003, 2009, 2012; Arregui, Cabrera Jr. & Cobacho, 2006; van Zyl, 2011; Johannesburg Water, 2016; Ncube, 2019), and the findings of this research. The reader is encouraged to consult such material for further discussions on some of the material.

6.1 CONSUMER PROFILING

A water meter's primary purpose is to accurately measure the consumption of a specific consumer at any point in time. The prerequisite for this is that the meter be appropriate for the specific consumer or groupings of homogeneous grouping of consumers. It is therefore inadequate to speak of meters without an in-depth understanding of the consumption profile being measured by such meters.

As such, while the Johannesburg consumer profiles have been reconfigured to be suitable for various testing points, they still reflect Johannesburg consumers. It is therefore important that consumption profiles of more consumers in other municipalities be determined. It is also important to note that consumption profiles are also not necessarily static particularly in developing economies, as such occasional updates of the profiles will also be useful over time.

The best approach of determining consumption profile is through the installation of new high accuracy meters of high resolution (measuring millilitres at (sub)second intervals) to profile the real-time consumption of grouping of consumers selected via stratified random sampling per municipality or region. The objective of such sampling should be to eventually obtain representative samples of the targeted consumer groups. The ensuring consumer profiles are useful in determining specific metering requirements for the respective consumers and the estimation of the weighted meter accuracy for the same consumers.

Another important benefit of consumer profiling is the wealth of information useful for the sizing of water meters. Historically, meter sizing (together with other plumbing fixtures) has been based on the Hunter Curves developed in 1940 but are largely outdated and for very different consumers. The output of consumer profiling can therefore be used to directly determined the meter sizing requirements and for updating the Hunter Curve for a particular local. Examples of how this can be done is included in Ncube (2019: 168).

6.2 METER AUDITS

Having done the work to adequately understand the consumer requirements, the next step is to evaluate how well the existing meters and any future meters meet these requirements. This invariably requires an audit of the meters within a municipality, particularly as all the municipalities have existing metering bases whose information is usually of a poor quality. The objective of meter audits is to complete all meter information, including verifying meter quality, and to learn of any misalignments between the consumer profile and the installed meters.

Instituting such meter audit programmes should ideally start with high value clients such as Top 100 consumers, Top 5% or any such metric, and eventually cascade to every meter on the network. It should be noted that meter reading is in fact a de-facto meter audit, and the process can be adequately improved to be able to deliver that. This would also include upskilling the meter reader to be able to perform such tasks. Figure 58 is an example of Job Card extract from Ncube (2019) that summarises the kind of information that both a quality assurance review and a meter audit can collect. It should be noted that while a lot of this information is of a technical nature, adequate training is sufficient to get a literate person to identify the required information.

It should also be noted that every meter flow logging activity that a municipality get to do is another important meter audit component that must be preserved. This is irrespective of the purpose of the flow logging exercise as it will invariably provide information on both the meter and the consumer and should therefore be collated for use in the long run. Key uses of such logging data is the confirmation of user profiles, meter sizing applications, determination/confirmation of on-site leakage and its quantum and distribution in time, and other such uses.

CAPTURED/OLD METER DETAILS				OBSERVED/NEW METER DETAILS (MAIN METER)			
Make	[Prepopulated]	Type	[Prepopulated]	Make	e.g. Kent	Type	e.g. Single Jet
Number	[Prepopulated]	Class	[Prepopulated]	Number		Class	B C D
Size	[Prepopulated]mm	Factor	[Prepopulated]	Size	mm	Factor	
Reading	[Prepopulated]	Digits	[Prepopulated]	Reading		Digits	
Position	[Prepopulated]			Position			

Combination Meter (Smaller Meter Details)	Type	e.g. Single Jet	Number						
Size	mm	Class		Factor		Digits		Reading	

WORK CARRIED OUT						
Correct fittings used?	Yes		No		Type of fittings	[Specify]
Correct installation, alignment and depth?	Yes		No		Comments	[Specify]
Corrosion prevention?	Yes		No		Type of protection	[Specify]
Service reinstated?	Yes		No		Comments	[Specify]

Reinstatement	Paving		Garden		Road		Rubble removal		Other	[Specify]

Figure 58: Meter Audit and Quality Assurance

6.3 NEW WATER METER TESTING

Meter testing is at the heart of meter management as only available the empirical standard by which the accuracy of a meter can be determined.

6.3.1 Accuracy Limits

The accuracy limits that all new meter must meet before delivery are specified in SANS 1529:1 (normative Annex B.2) as

- 5% for flowrates of less than q_t; and
- 2% for flowrates of not less than q_t.

Discretional tolerances that have been known to have been agreed upon and used by manufacturers have no basis in the standard and should not be allowed. It is also important that municipalities confirm from actual test results of meters delivered to them that this is the case.

It is very important to note as well that while the SANS 1529 was updated recently in 2019, it remains outdated and is like the ISO 4064:2006 whose latest version is 2014 (adopted from OIML R49-3:2013). These updated international standards have refined several parameters including the use of tighter meter error envelopes refined meter classes. It is therefore not beneficial to the industry at large that any tolerance be made on the existing forgiving accuracy limits.

6.3.2 Testing Requirements

Again, the requirements of the testing of new water meter particular by manufacturers are clearly spelt out in the SANS 1529 suite of standards with no ambiguity. These must be always adhered to. Another important aspect is ensuring that the output of such testing is available as standard, without having to be requested. Currently, some suppliers are reluctant to make verification certificates available and those who do avail them when requested do no not always include the actual meter error at the respective flowrates, which is information that will better inform meter management efforts. This must be a standard requirement, and at the least, a requirement for all public procurements where failure to supply such certificates constitute a breach of contract with has consequences for future participating in public procurement.

As has been shown in the new meter testing of this research, new meters are marginally compliant to the requirements and will continue to be unless measures are taken to ensure that this is not the case. It is recommended that regulatory and statutory bodies such as the NRCS and SABS, start instituting standardised random testing of new meters to validate the claims of manufacturers. The Metering Association, currently under the auspices of the DTI can also play an integral part in encouraging its members to self-regulate and be able to evaluate each other's meters on an ongoing basis.

As demonstrated again in this project, it will be important that test flowrates other than the three prescribed ones are also incorporated into new meter conformance tests to ensure that calibration does not concentrate only on fine-tuning a few points but the entire meter error envelope.

6.3.3 Meter Acceptance Sampling

Municipalities and water meter users should start exercising greater control and influence in the quality of the meters they get by adopting stringent quality control processes that include meter acceptance sampling and testing.

ISO 3951 is a useful standard that may be applied in detailing the sampling procedures for inspection by variables. This includes selecting the acceptable level of quality, the level of inspection required and the specification limits of the meters, which are predefined for water meters. The acceptability of a batch of meters is therefore determined by how it fares against these predetermined variables. Incorporating such requirements as part of purchasing decision does come at a cost but is cost beneficial in the long run as only acceptable quality meters will end up within the municipal networks and consumer properties.

The National Instrument Test Procedures for Utility Meters (NITP 14) of the National Measurement Institute of Australia provides some guidance on sampling of meter batches for the purposes of initial verification. While this is different, the principle is the same. The NITP 14 adopts Inspection Level II and Acceptance level of 1% whose details are shown in Table 18.

Table 18: Sample Sizes and Acceptance Levels for Inspection Level II

Size of batch	Sample size	Acceptance levels					
		Special		0.1%		1%	
		Accept	Reject	Accept	Reject	Accept	Reject
Inspection level II							
2 to 8	2	0	1	0	1	0	1
9 to 15	3	0	1	0	1	0	1
16 to 25	5	0	1	0	1	0	1
26 to 50	8	0	1	0	1	0	1
51 to 90	13	0	1	0	1	0	1
91 to 150	20	0	1	0	1	0	1
151 to 280	32	0	1	0	1	1	2
281 to 500	50	0	1	0	1	1	2
501 to 1200	80	0	1	0	1	2	3
1201 to 3200	125	0	1	0	1	3	4
3201 to 10 000	200	0	1	0	1	5	6
10 001 to 35 000	315	0	1	1	2	7	8
35 001 to 150 000	500	0	1	1	2	10	11
150 001 to 500 000	800	0	1	2	3	14	15
500 001 and over	1250	0	1	3	4	21	22

From Table 18, if a batch of, say, 100 meters is under evaluation, the sample size will be 20 meters that will be tested and they will only accept the batch the number of meters that pass are equal to or less than zero (0) or reject the batch if the number of meters that fail are equal to or higher than one (1).

6.4 IN-SERVICE WATER METER TESTING

While the use of an accredited flow laboratory is essential for legal aspects and credibility of results and is generally recommended for all aspects of this guideline, such laboratories are very limited within the country. For that reason, the use of unaccredited municipal laboratories for the day to day meter management and the appropriate testing of water meter at the right test flowrates can be beneficial to any water utility. Municipalities are therefore encouraged to also apply these guidelines in their unaccredited test benches. However, it is recommended that the use of accredited laboratories be used for annual programmes that would influence the changing of meters on an annual basis.

6.4.1 Accuracy Limits

Like new water meters, the acceptable limits of in-service are also specified within SANS 1529:1 as

- 8% for flowrates of less than q_t; and
- 3.5% for flowrates of not less than q_t.

However, unlike new meters which must be tested before being installed, the requirement for in-service meters is that their accuracy remains within the specified limits without any indication of how this should be done. This is despite an explicit requirement that water users must ensure that their meters remain in a verifiable condition. The following sub-sections answers the how.

6.4.2 Meter Sampling

The recommended approach of meeting the ongoing verification requirement is instituting a statistical testing program that regularly samples meters for testing from the field. The objective of such sampling and testing would be to determine the variables affecting meter performance and ultimately determining the meters that no longer met the accuracy requirements and should be therefore removed from service. The key variables for networks with homogeneous water quality will largely be meter make and model, meter age (or meter installation date) and/or meter reading aggregated by network water pressure in certain instances. Water quality may be a key variable if water quality differs substantially within the municipal network. A progressive approach will invariable be the best approach.

The meters are chosen using random stratified sampling that ensures that pulled meters are representative of the in-service meters being assessed. Such representation must factor in the variables of interest as described above. An appropriate confidence interval (CI) for the sampling program should be chosen (recommended CI of 95%), that will determine the number of meters to be tested (sample size) per period. It is also recommended that the sample size determined through the confidence interval be increased by at least 10% to cater for variations and difficulties in the field and in meter testing, including any other outliers.

Because the meters selected are representative of in-service meters, the test results will be instructive on both the current level of apparent losses and the meters that should be considered for replacement as they no longer meet the accuracy limits. However, in the initial stages, it may be difficult to have proper representation at a meter make/model level for many municipalities and users are encouraged to take the statistical significance of any sampling and meter testing before making capital decisions.

The Australian Standard AS 3565.4:2007 provides best practice in how the sampling of in-service meters is done:

1. All installed meters (at publication of the standard) were deemed to have an initial compliance period of 1,920 kl or 8 years and will only need to be evaluated towards the end of that period.
2. New meters (pattern and type, or variant of existing meters) must be tested within 1 to 3 years of being put in service to determine the compliance period against set criteria. Invariably, the maximum period is limited to 1,920 kl or 8 years which translates to an average monthly consumption of 20 kl for the 8 year period.
3. Samples shall be selected at random from uniform populations with sample size determined based on the population. For instance, a population of >35,000 meters will require a sample of 315 meters to be tested while a population of 1,201-3,200 will have a sample of 50 meters. At a limiting quality of 8%, the maximum number of meters allowed to fail would be 18 and 3 respectively.
4. If the samples fail, the population may be redefined and the sampling redone, or the population is tested (100%) and failing meters removed, or the population is deemed to have failed and all meters removed.

It should be noted that an essential prerequisite for meter sampling and testing is the availability of up-to-date meter database that has adequate and correct information on in-service meters. Such information includes (Ncube, 2019);

- Manufacturer and product specification details such as the permanent flowrate, the serial number, meter manufacturer, meter model, meter type (multi-jet, single jet, etc.), meter class, meter length, number of dials, meter factor (if any), direction of flow and the meter approval number.
- Meter verification details.
- Meter installation/connection details such as date, reading, geolocation, connection type, service type, and type of supply.
- Meter maintenance and related requirements.

6.4.3 Consumer Initiated Meter Testing and Removal

The analysis of historical meter testing data has shown that not all meters that are removed from service are defective. The probability of failure for such meters has also shown that such probability increases with time or volume registered by a meter. Municipalities unfortunately spend a lot of effort and resources in testing meters that should not be tested as the probability of failure is too high. What is also disturbing is that the meters that do not fail are tested using tariffs that make the municipality subsidise requests that are at times are unjustified.

It is recommended that municipalities build up datasets of how meters that have been tested perform and be able to come up with cut-off points that allow them to;

- Proactively change meters with a high probability of failure before they are prompted by consumers
- Simply change certain meters on request without testing when the probability of failure is too high.
- Charge full costs for consumer initiated meter tests to cover the cost of meter removal, new meter installation and meter testing. Current meter change tariffs are rarely sufficient to cover all these costs. The rational for this is that in cases where the meter is faulty, the consumer is reimbursed (credited) while when the meter is not faulty, the municipality does not incur any costs for changing and testing a compliant meter.

6.4.4 Meter Removal and Transportation for Testing

Meters should be carefully removed from the field without damaging them or subjecting them to rough treatment to ensure they reach the lab in the same condition as their in-service state. The meters must also not be drained of water and should be plugged or sealed on both ends upon removal, ideally using the plugs of the new meter that will be replacing the removed meter. Other than preventing the meter from drying out, this ensures that foreign ingress does not get into the meter.

The meters must thereafter be individually tagged with relevant details such as the work order details, removal date and other such relevant information that will help identify the meter and/or provide contextual field information. During transportation and storage prior to testing, effort must be taken to maintain the meters' operational condition meters by (Water Services Association of Australia, 2012):

- not exposing them to vibration or mechanical shock (such as may occur in a vehicle) for a prolonged period as undue shaking or bumping.
- packaging them to suit the expected transportation conditions; and

- avoiding storing them in an external environment.

6.4.5 Testing Requirements

There are currently no set requirements for the testing of in-service meters at a flow laboratory in local standards. Because of this, some meter laboratories tend to follow Annex B of SANS 1529 which can be problematic. An example of this is the performing of hydraulic pressure test at 2,400kPa for plastic meters that have been in-service for many years subjected to 20-88kPa (2-9 m head). Such meters will invariably fail the test as they will leak but this is not to say the meters were defective. Annex C of SANS 1529 refers to in-situ meter testing and should be the template of testing in-service meters at a lab as it excludes requirements associated with the testing of new meters such as the hydraulic test.

The testing flow rates in SANS 1529, are limited to q_{min}, q_t, $0.5q_p$, q_p, and q_s. Most municipalities and laboratories tend to mostly focus on the flowrates q_{min}, q_t, and q_p, which are common for new meters. While the three test points are useful as minimum for any testing program, the overestimation of 4.74% on the weighted meter error compared to when using ten flowrates is important to recall. Together with the experience that meters do pas at these flowrates but failure at others give credence to additional testing points particularly if the purpose of the tests is not simply to check for meter compliance but to build better meter information.

The flowrates of Table 19 are the recommended test flowrates for any meter testing programme that seeks to build information on meter performance within a municipality.

Table 19: Recommended Test Flowrates

Seven Test Flowrate, Q	*Q1*	*Q2*	*Q4*	*Q5*	*Q7*	*Q8*	*Q10*
Test Flowrates, *ℓ/h*	7	15	30	60	120	1,500	3,000

In case where the lab can, it is further recommended the Q1 of Table 19 be substituted by the starting flowrate of a meter to determine the accuracy at that value as it will likely be a better representation than the 7 *ℓ/h.*

For each of the test results, the pass/fail status of the meter is recorded by considering only the results within the error envelop. The weighted meter accuracy of the meter is found by multiplying the accuracy of the meter at the specific flowrate with the proportion of the consumption that happens at that flowrate, as determined in §6.1.

Best practice codified in the Australian Standard AS 3565.4:2007 is that when meters are tested and the weighted error calculated, the meters can only remain in service for an additional period if the meet the requirements of Table 20. Meeting Criteria 1 would mean that the number of meters with a weighted error of less than 2% are lower than the acceptance number (18 and 3 for a population >35,000 and a population of 1,201-3,200 respectively). Criteria 2 is checked if Criteria 1 is not met, as would be Criteria 3 if Criteria 2 is not met. In essence, the highest acceptable weighted error for the meters in that jurisdiction is 4% at which point the meters will need to be retested before 960 kl or 4 years, whichever comes first.

Table 20: In-service Compliance Period for Water Meters

Criterion					
1		2		3	
Upper and lower error of sample	Compliance testing period	Upper and lower error of sample	Compliance testing period	Upper and lower error of sample	Compliance testing period
≤ ±2.0%	1920 kL or 8 yrs	≤ ±3.0%	1440 kL or 6 yrs	< ±4.0%	960 kL or 4 yrs

In essence, every meter in the network would have a sample that represents it in the ongoing in-service meter testing to determine how long such a meter would remain in service. This should be the target for South African municipalities and utilities taking into the account the possible weighted accuracy within the country. As an example, applying the criteria of Table 20 and assuming the meters tested are representative, only one meter model meets Criteria 1, two meter models meet Criteria 2 and only one meets Criteria 3. The other three meters would outrightly fail and would need to be replaced as soon as the results are confirmed. This is instructive on why establishing such testing requirements is critical.

6.5 METER DATA ANALYSIS

Literature has demonstrated the value of going through meter data routinely to gleam emerging trends that can help meter owners better manage their fleet. Local examples include Brinkley, Ilemobade & Ncube (2020), Ncube (2019), Ncube & Taigbenu (2019b), Moahloli, Marnewick & Pretorius (2019), Ncube & Taigbenu (2015), Couvelis & van Zyl (2015) and the analysis that has been done in this study. Typical analyses include:

- Probability of meter failure analysis
- Meter error degradation analysis
- Apparent loss estimation
- Weighted meter error degradation rates

- Meter replacement cost-benefit analysis
- Cost benefit analysis for different meters

There is therefore a wealth of information that can be obtained from both meter testing data and meter consumption data that municipalities should be routinely looking at. It therefore means that a lot of thought must also be put into how this data is stored for ease of access and interrogation. While billing databases are a very useful source of data, the gold standard in meter accuracy is the bench test and this should be the priority for all analysis.

The use of the meter performance database developed as part of this project is one way of easily storing meter testing data and reporting on it using the predefined reports, which can be further developed and improved.

6.6 METER MANAGEMENT

The foregoing discussions are all meant to prepare the required groundwork and provide a basis for informed and prudent water meter management. Measurement and data are prerequisites for enhanced meter management.

van Zyl (2011) provides a good overview on the integrated water meter management from a South African perspective while Arregui, Cabrera Jr. & Cobacho (2006) is a more comprehensive reference with an international perspective. Both references are invaluable and should be in the library of anyone dealing with water meter management. This part of the guideline distils some of the key aspects.

6.6.1 Meter Selection and Procurement

Meter selection should be informed by lifecycle costing consideration and the operational realities of the water utility. For example, if the area experiences a lot of intermittent water supply with high turbidity levels consideration should be given to the fact that rotary pistol meters will get stuck and damaged more frequently while multi-jet meters may register air especially when the network is not charged correctly. The municipality must therefore consider this in their meter choices.

It is advisable not to have an overconcentration of one meter make and/or model as a means of diversifying against the risk of failure of a particular meter. The substantive composition of each type of meter within a meter fleet must be influenced by an economic evaluation through determining the net present value (NPV) of the costs of infinite replacements, known as the net present value of the replacement chain (NPVC) (Arregui et al., 2010). Solving for the NPVC will also provide for the optimum replacement period as illustrated in §5.3.2, with the necessary recommendation of what would be the best performing meters. Such analysis requires prior data which includes the initial weighted error and the estimated degradation rate of the meters being evaluated, which will invariably take time to compile.

Having done the NPVC assessments, the logical step will be to use the same information in procurement decisions. It was shown in §5.3.2 that the meter that is optimal is one of the most expensive as it has the lowest starting error – least cost procurement would be unable to do capture that and water services managers need to be able to better scope their requirements to better bring out the quality element. This might also entail capacitating relevant procurement decision makers on why the consideration of meter accuracy and quality is in keeping with the tenets of cost-effective procurement over the lifetime of the meter.

Procurement documents must also clearly articulate the acceptance testing requirements together with all other requirements as the actual meter testing results at verification of each delivered meter.

6.6.2 Meter Installation

Meter installation and maintenance can be viewed as where the rubber hits the road as the best efforts in meter selection and sizing can be easily undone through incorrect installations. As precision instruments, meters require adherence to strict installation criteria, typically defined by meter manufacturers and standards such as the length of straight pipeline before and after the meter and the correct alignment (Ncube, 2019). van Zyl (2011) provides main installation requirements as;

- Correct orientation of both the pipe work and the meter, as specified by the manufacturer
- Minimum straight lengths of pipe (with no fittings) directly upstream and downstream of the meter
- Installation in the correct direction of flow as typically indicated by an arrow on the meter body.
- Installation of a separate meter strainer upstream of the meter, where required and when not coming pre-installed within the meter body. Such strainers should be accessible to facilitate cleaning and replacement.
- Installation of isolating valves, ideally both upstream and downstream of the meter, to be able to carry out any maintenance on the meter and within the consumer’s property.
- Meters connected to electricity power supply may require lightning and electrical surge protection in lighting prone areas.

- Plastic bodied meters are required to be protected from sunlight and should therefore be installed in appropriate housings.
- Appropriate corrosion protection should be considered for all steel pipes used within the installation, particularly if above ground, with suitable UV protection.
- Special consideration should also be placed on the associated fittings connecting the meter to the rest of the network as these may compromise the connection and the meter.

Meter information is usually generated during the meter installation process and paying attention to detail at this stage, presents the least-cost method of gathering accurate meter and consumer information for the utility (Ncube, 2019). Aiming for seamless integration from purchasing, material management and works order management would allow the selection of a specific meter with all its details during the work/job management and installation which minimises errors and duplication of effort.

6.6.3 Meter Maintenance

Water meter maintenance requires simple but important actions, such as cleaning of strainers, cleaning and repair of meter boxes, fixing leaks and replacing damaged registers and register covers, with larger meters requiring visual inspection of the meter body and chamber for visible damage (van Zyl, 2011). Correct maintenance practices such as (Ncube, 2019);

- the proper scouring of pipelines after a repair ensures that minimal suspended solids get trapped in meters strainers.
- the proper (slow) opening of valves and use of air valves after service interruptions minimises the flow of high velocity air through the meters which can damage them and lead to incorrect readings.
- the maintenance of adequate flow rates within the water networks minimises the settling of suspended matter within both the networks and the meters leading to clogged strainers.

Timely meter replacement is a key component of meter maintenance that should not be ignored, and utilities should have planned replacement on an ongoing basis.

6.6.4 Quality Assurance

Having done all the planning and activities described above, it is very important at each step to ensure that the plan is being implemented as envisaged. This includes ensuring the right meter (make, class, size, material, accuracy, etc.) is install correctly (right position, alignment, spacing, etc.) at the right consumer and that the data captured is complete and reflective of site conditions. Further activities should review if the meters are being replaced at the right time and with similar or better meters, including a review of the impact of meter replacement.

A feedback loop from all quality assurance activities must also be in place to ensure that meter management continually improves with an impact on the apparent water losses.

6.6.5 Meter Data Archiving

It is important to recall that meters are custody transfer devices. Information on meter management process and the final meter test results can be a final arbiter in cases of consumption disputes, some of which can be significant. It is therefore important that the municipality, and indeed flow labs, collect and collate meter data with this in mind and ensure all processes can withstand scrutiny, particularly legal scrutiny.

7 CONCLUSIONS AND RECOMMENDATIONS

This research project has;

1. Performed a literature review on meter performance evaluation and key indicators of water meter performance, with emphasis on domestic meters. Key findings have been that there is a shortage of explicit guidelines and standards for the testing on in-service meters, including the flow rates and processes to follow for the same.
2. Key stakeholders that included municipalities, water boards, meter manufacturers and associations, NRCS, SABS and consulting firms on their experiences and challenges within the water meter industry. The lack of standards and guidelines for in-service meters was highlighted, together with the lack of proactive meter testing to inform metering decisions.
3. Historic meter testing data was obtained from a few municipalities and utilities that have used accredited laboratories. It was shown that the collation of such data is useful and does bring value but most importantly that a platform that make the capture and collation of such data uniform and easier is useful. The poor quality of non-accredited meter data has underscored the need of guidance in how such tests must be done.
4. Developed a database for water meter performance results for South African utilities, with tools to evaluate meter performance of the populated data. All analysis that are contained in this report are possible within the developed tool.
5. Evaluated and determined the optimal number of test flowrates that are representative of the meter error curve with minimum deviation on meter accuracy as seven test points.
6. Evaluated the metrological performance of 101 new water meters consisting of seven meter models common in South Africa. The compliance of the new meters was found to be marginal at 40% over the entire meter error envelope. The weighted meter accuracy of new meters was found to range from 93.2-98.3%, with an average of 96.1%.
7. Developed water meter guidelines to offer guidance on the management of meters, and how meter testing can be best done locally.

The outputs of this research are useful for the water industry, particularly in the context of South Africa being a water stressed country that requires the best measurement and management of the finite water resources. Considering the findings of this research that include limited proactive meter testing and performance evaluation, many illicit meter on the market and relatively poor new meter compliance, the industry could benefit from more normative requirements that will move the needle of water meter management in the country. The following are the key recommendations to achieve this;

I. **Establish National Norms and Standards for Water Metering:** The Regulations relating to Compulsory National Standards and Measures to Conserve Water (Water Services Act) mandates universal metering but does provide give any guidance on their management. The National Norms and Standards for Domestic Water and Sanitation Services (Government Gazette, No. 41100, 8 September 2017) does not even refer nor acknowledge the legislative requirements for metering devices and is largely inadequate. It is therefore recommended that the Department of Water and Sanitation reviews the existing norms and standards with a view of establishing meter management as outlined in this project as a basic requirement for all water users.

II. **Update Legal Metrology Regulations aspects relating to Water Meters**: The Legal Metrology Act Regulations (Government Gazette, No. 41854, 24 August 2018) defines the requirements for all measuring instruments including water meters. However, water meters are one of the few devices excluded from any prescribed periodic verification when other 12 instruments, including gas meters and liquid measuring devices are included. In addition, meters larger than 100 mm are not included in the definition of a water meter in Regulation 114. This does not reflect the importance of the accurate measurement of water resources in a water scarce country. It is therefore recommended that these regulations be updated to include science-based on-going verification requirements for all water meters. Water-centric regulations maybe more appropriate in conjunction with the norms and standards of DWS recommended in (I).

III. **Update the SANS 1529 Suite of Standards**: these standards are substantially behind the rest of the world in terms of requirements imposed on the metering device. It is recommended that these standards be accordingly updated to be at the same level as the latest OIML R49 suite of standards. A number of meter manufacturers in the country already comply with these requirements.

IV. **Establish mandatory meter and consumer audits:** as demonstrated in this study, there is need to establish meter and consumer audits at local and national levels. Such requirements will not only help in building up more accredited laboratories within the country but will ensure that datasets that will inform meter management are built. Such requirements can form part of the Blue Drop incentive based regulations incorporating the No-Drop requirements at the local level, while the DWS, NCRS, SABS and other such national bodies perform national audits that will ensure the quality of meters within the industry are up to standard and also supplement the audit work of local municipalities and users.

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Appendix A:

Meter Performance Monitor

A meter performance database developed as part of the Water Meter Performance in South Africa Research Project funded by the Water Research Commission (WRC)

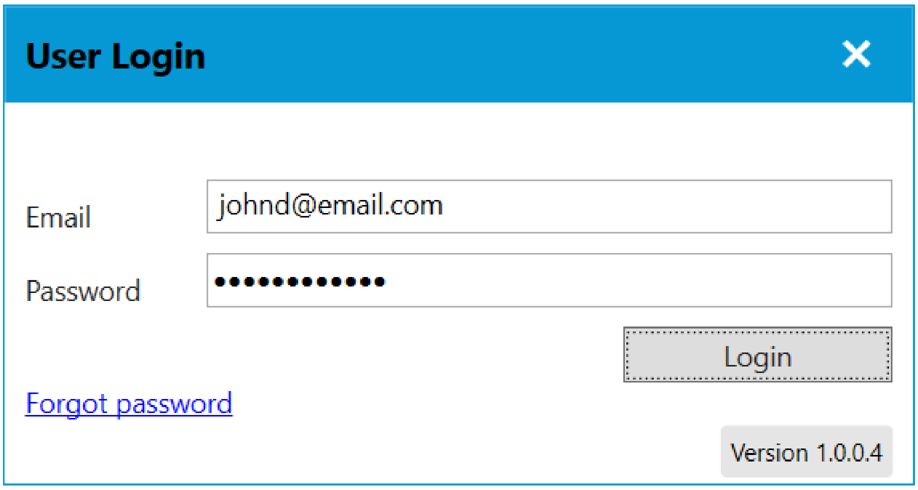
Meter Performance Monitor – User Manual

Contents

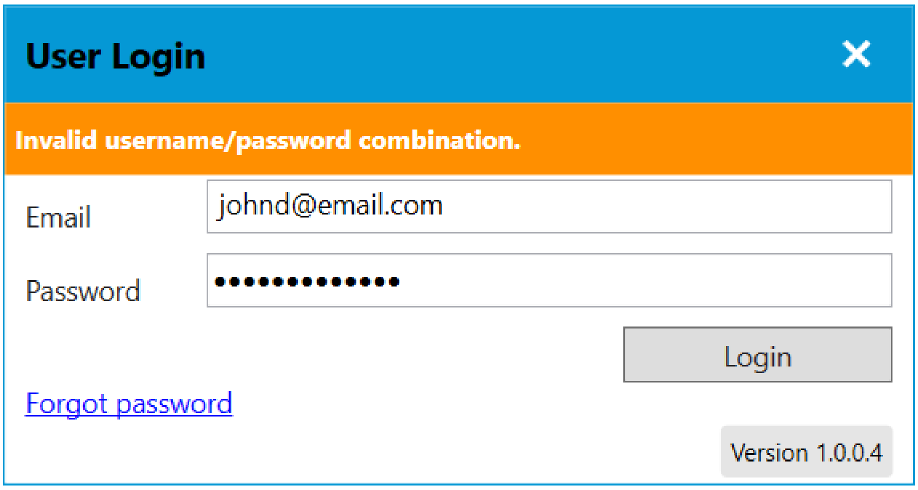
9.1 USER AUTHENTICATION AND AUTHORIZATION

9.1.1 Authentication

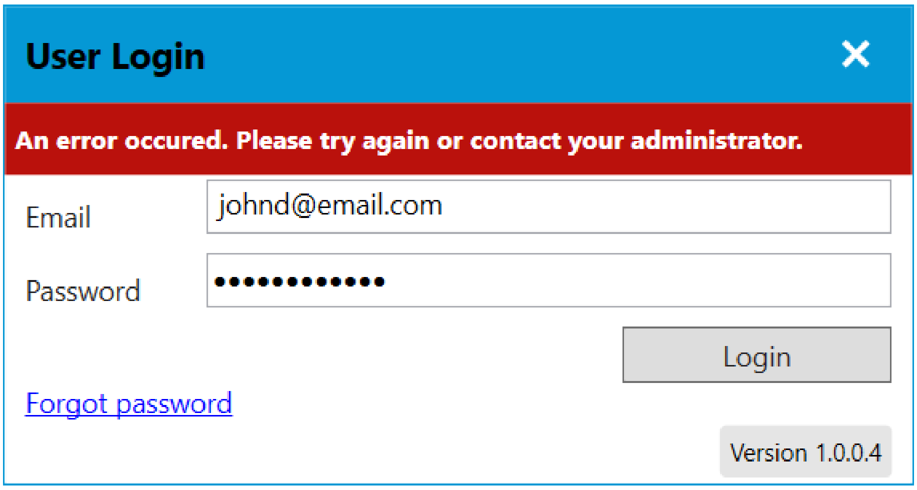
Allows the system to verify that a user is who they claim to be via password authentication.



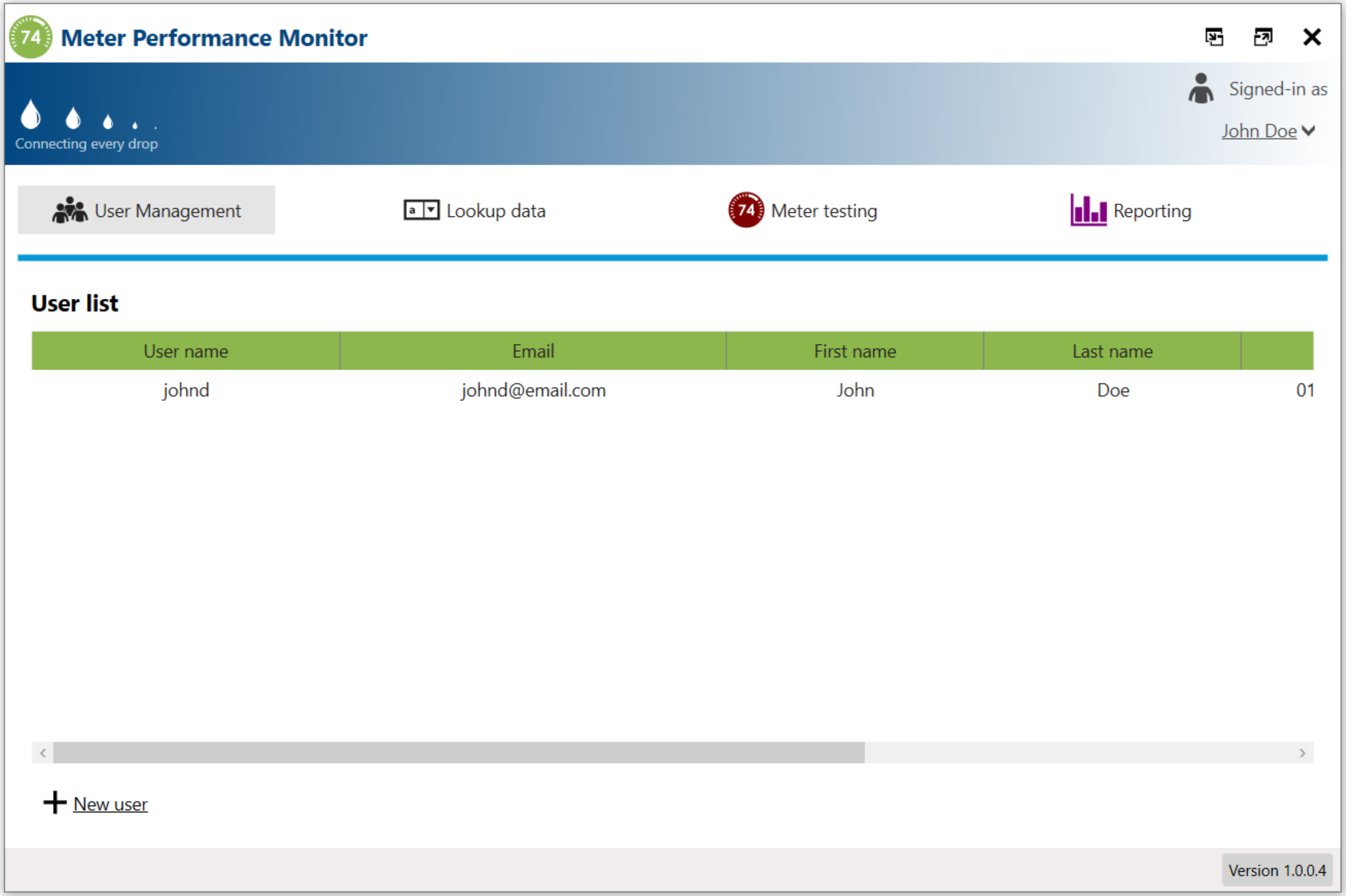
Should an invalid email and/or password be entered, the following message will be displayed:



Should the database or the RESTful endpoints, i.e. the services that connect to the database, be inaccessible, the following message will be displayed:

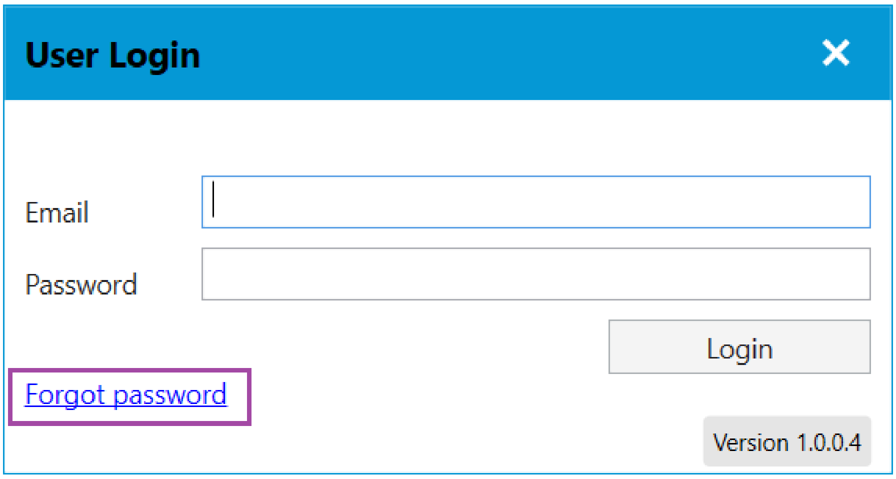

User Login
An error occured. Please try again or contact your administrator.
Email
johnd@email.com
Password
Login
Forgot password
Version 1.0.0.4

On successful login, the main application UI is shown:

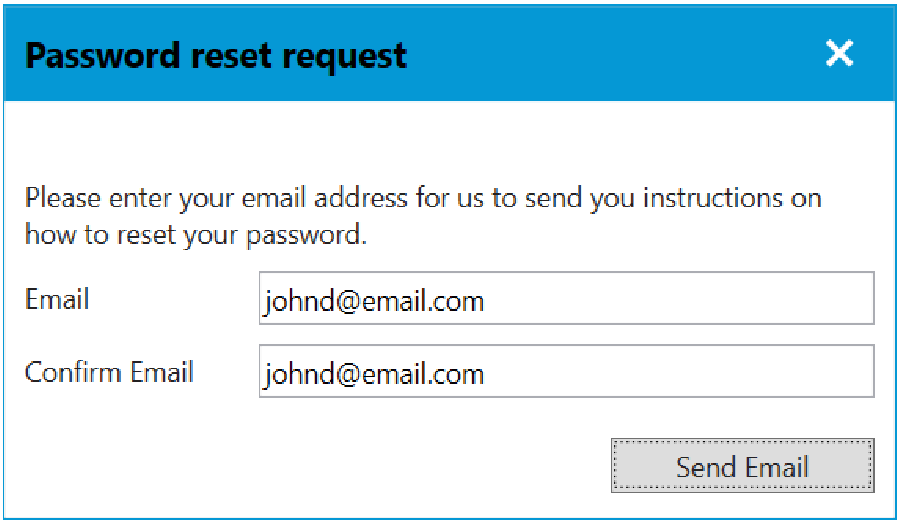


9.1.1.1 Password Reset

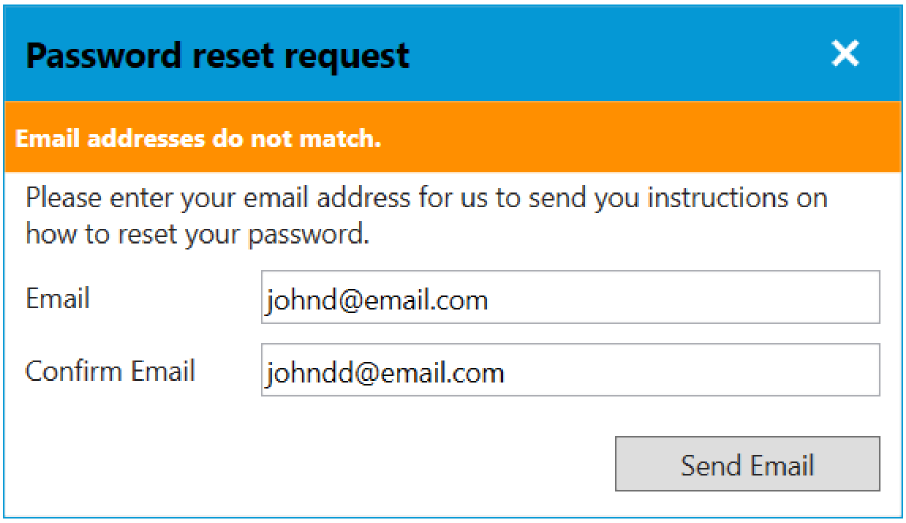
Should a registered user forget their password, the Login window provides a link for the user to initiate the password reset process.



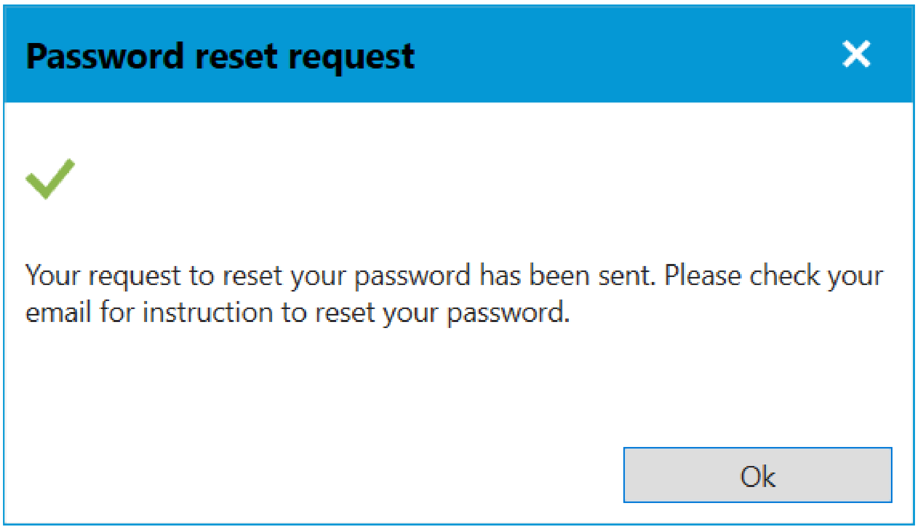
Clicking the *Forgot Password* link highlighted above initiates the password reset workflow.



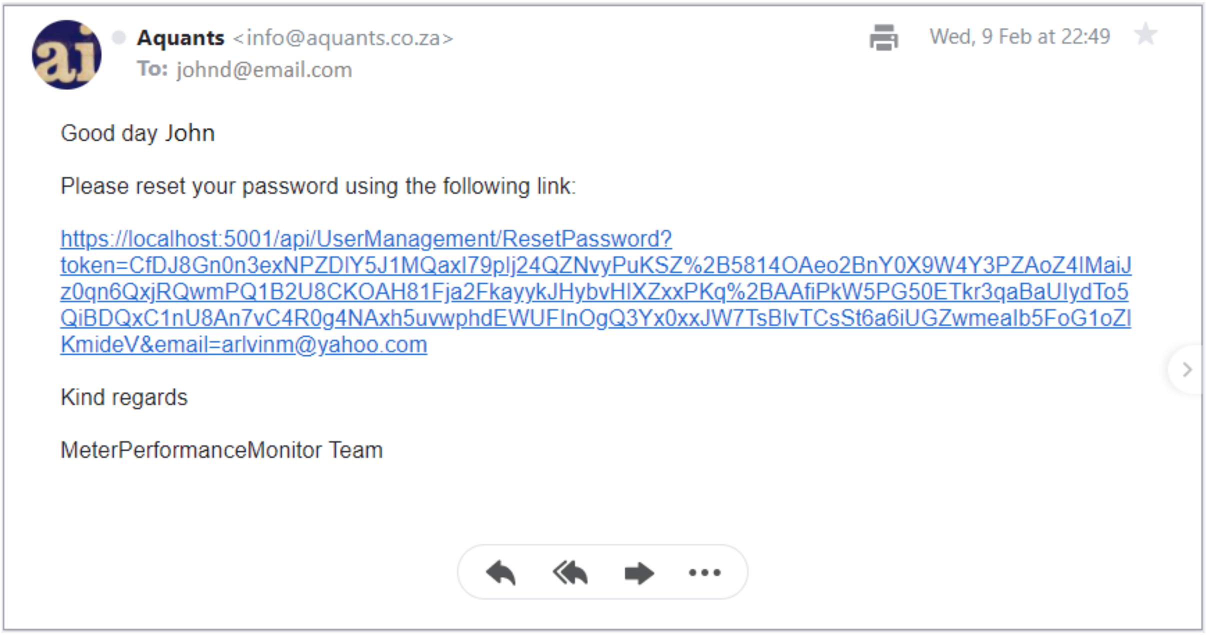
In this window the user should enter (and confirm) the email address that they registered onto the system with. Should different email addresses be entered, the following message is displayed:



If a valid email address is entered, with a matching confirmation, then a password reset email is sent to the user and the following window is displayed immediately, notifying the user that the password reset email has been sent successfully.



The layout of the email that is sent to the users is shown below. The link is highlighted in blue and when clicked it will navigate the user to the page where they can reset their password.



Aquants <info@aquants.co.za>
To: johnd@email.com

Wed, 9 Feb at 22:49

Good day John

Please reset your password using the following link:

https://localhost:5001/api/UserManagement/ResetPassword?
token=CfDJ8Gn0n3exNPZDlY5J1MQaxl79plj24QZNvyPuKSZ%2B5814OAeo2BnY0X9W4Y3PZAoZ4IMaiJ
z0qn6QxjRQwmPQ1B2U8CKOAH81Fja2FkayykJHybvHlXZxxPKq%2BAAfiPkW5PG50ETkr3qaBaUlydTo5
QiBDQxC1nU8An7vC4R0g4NAxh5uvwphdEWUFInOgQ3Yx0xxJW7TsBlvTCsSt6a6iUGZwmealb5FoG1oZl
KmideV&email=arlvinm@yahoo.com

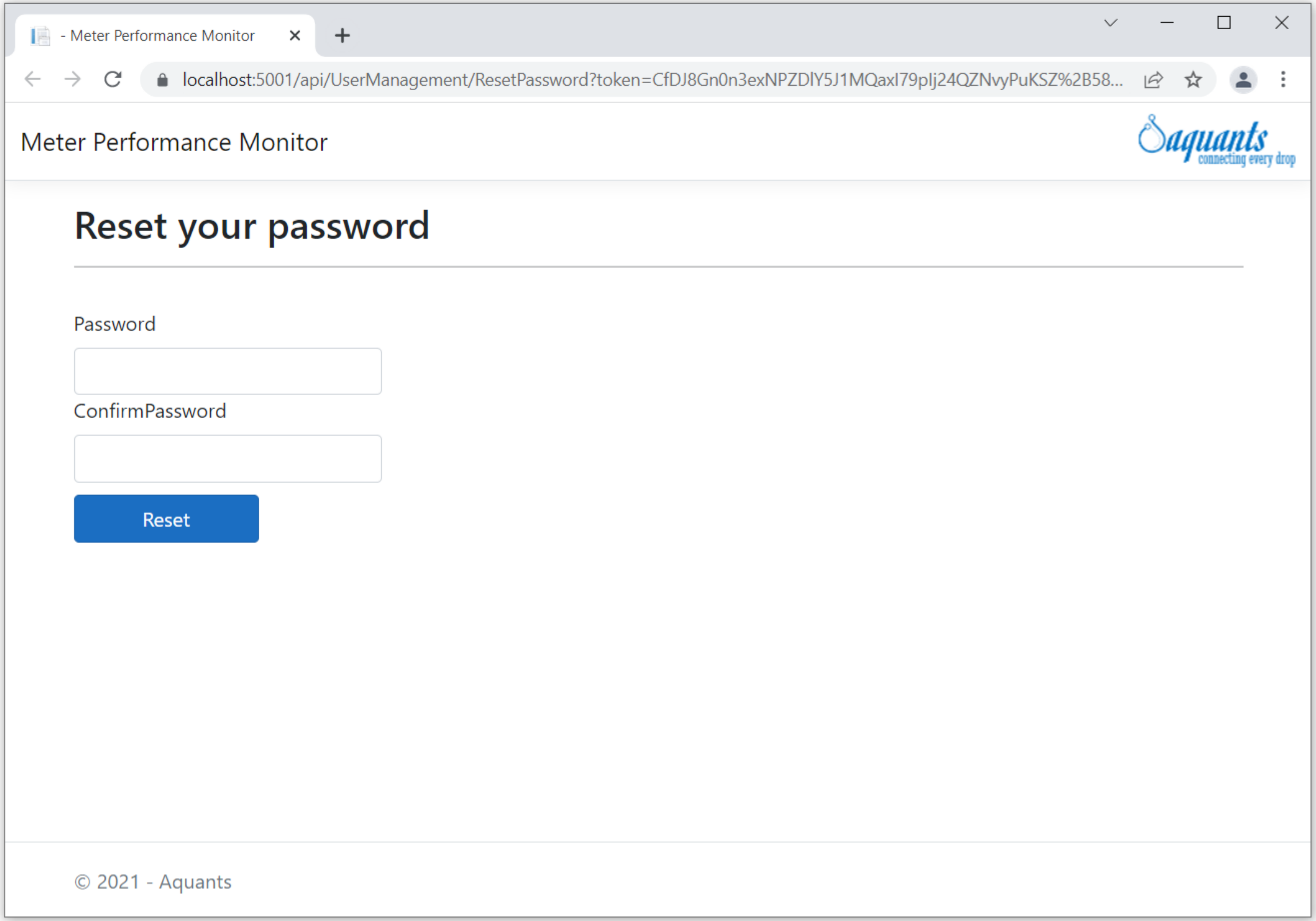
Kind regards

MeterPerformanceMonitor Team

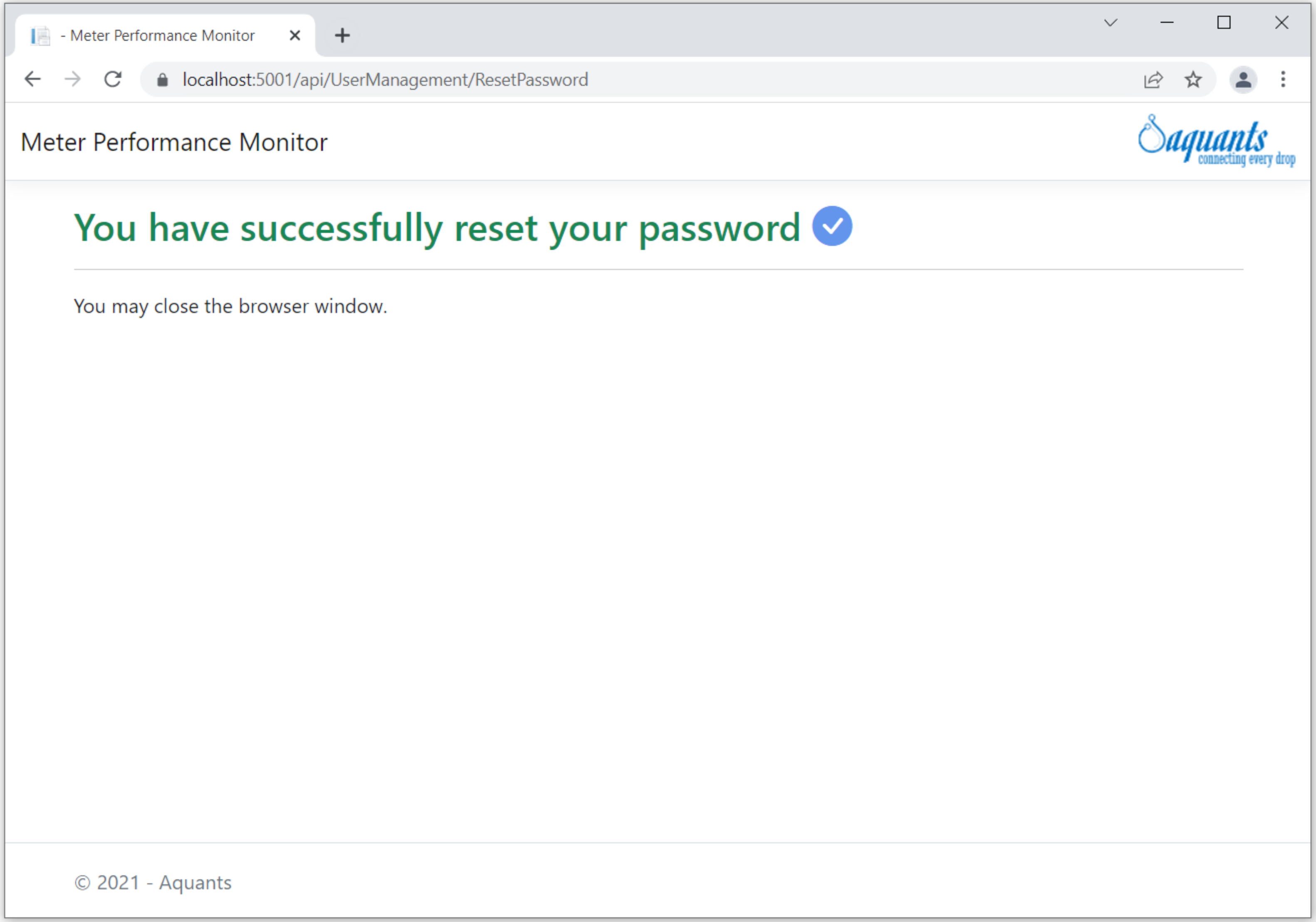
NOTE

This link in the email is only valid for three hours. Should the user not use the link within three hours, they will have to restart the password reset workflow by clicking the “Forgot Password” link in the Login window, as described earlier.

Clicking the email link above brings the user to this password reset page where the user enters their new desired password and confirms:

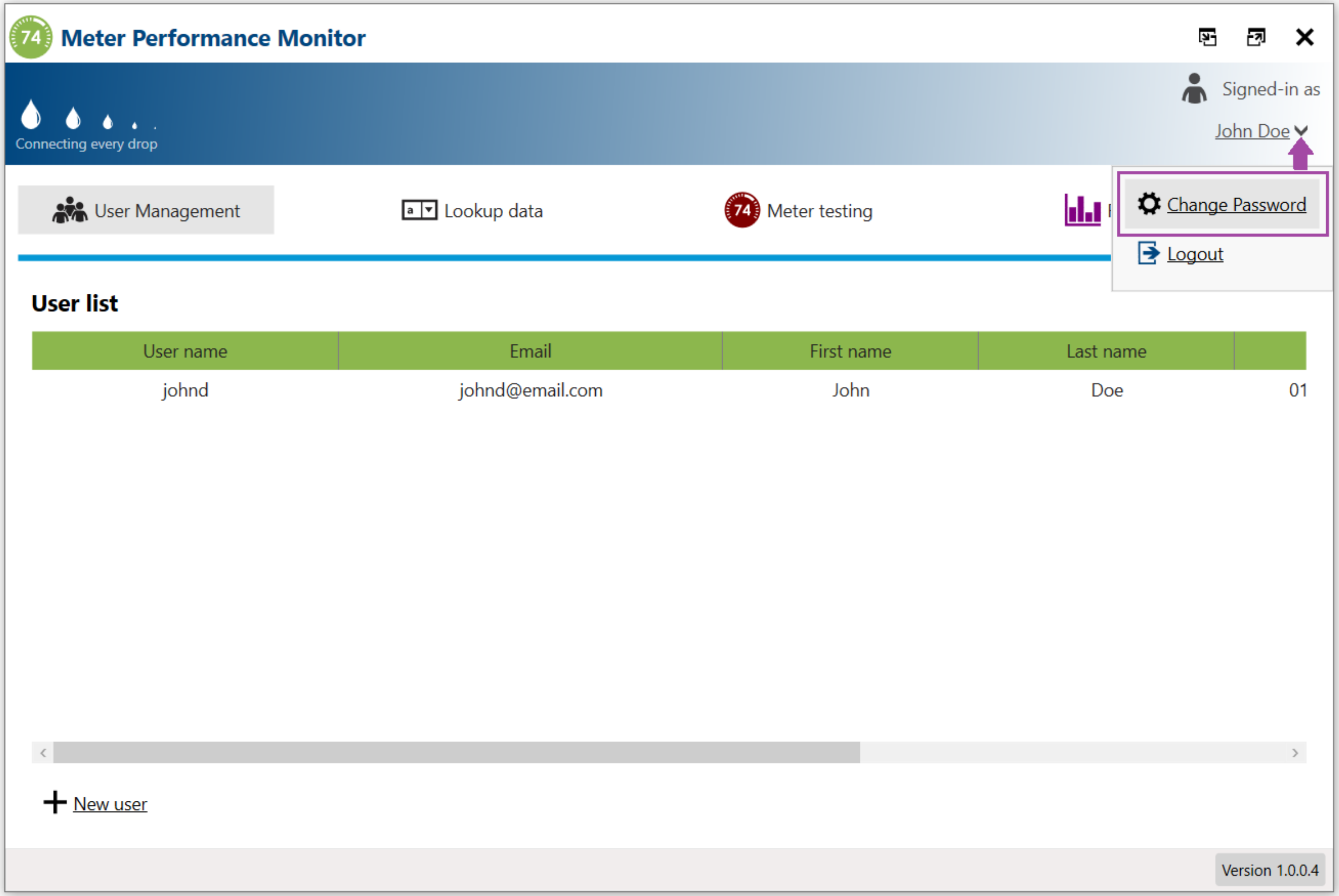


Once successfully reset, the following message is displayed:

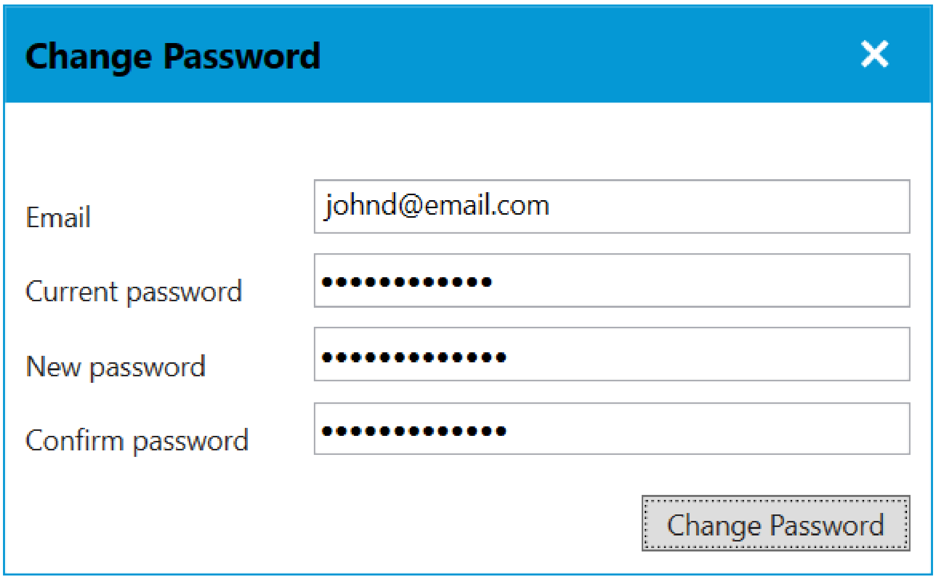


9.1.1.2 Change Password

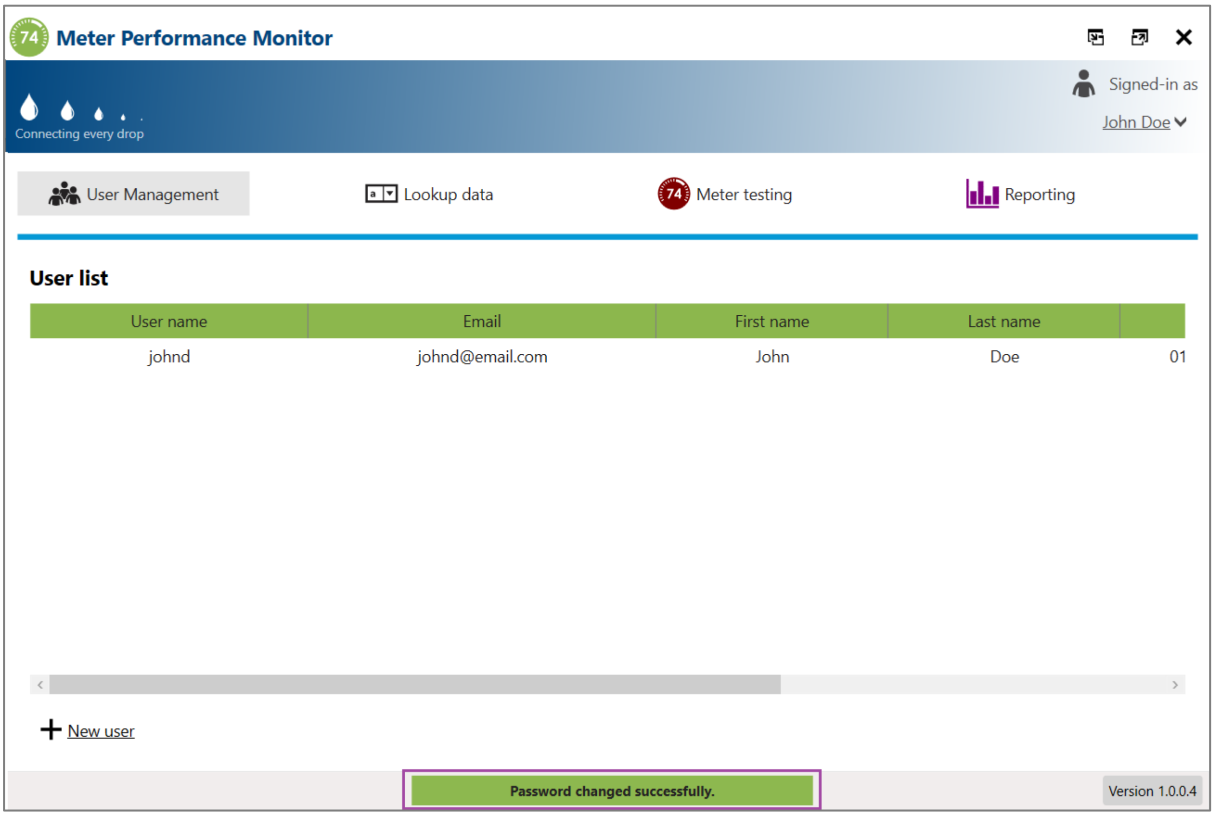
Once logged-in, the user is able to change his/her password by clicking the chevron on the right of the logged-in user's name:



Clicking the Change Password link pops-up the following window:



By filling-in all the fields above, the user is able to change their password for successive logins.



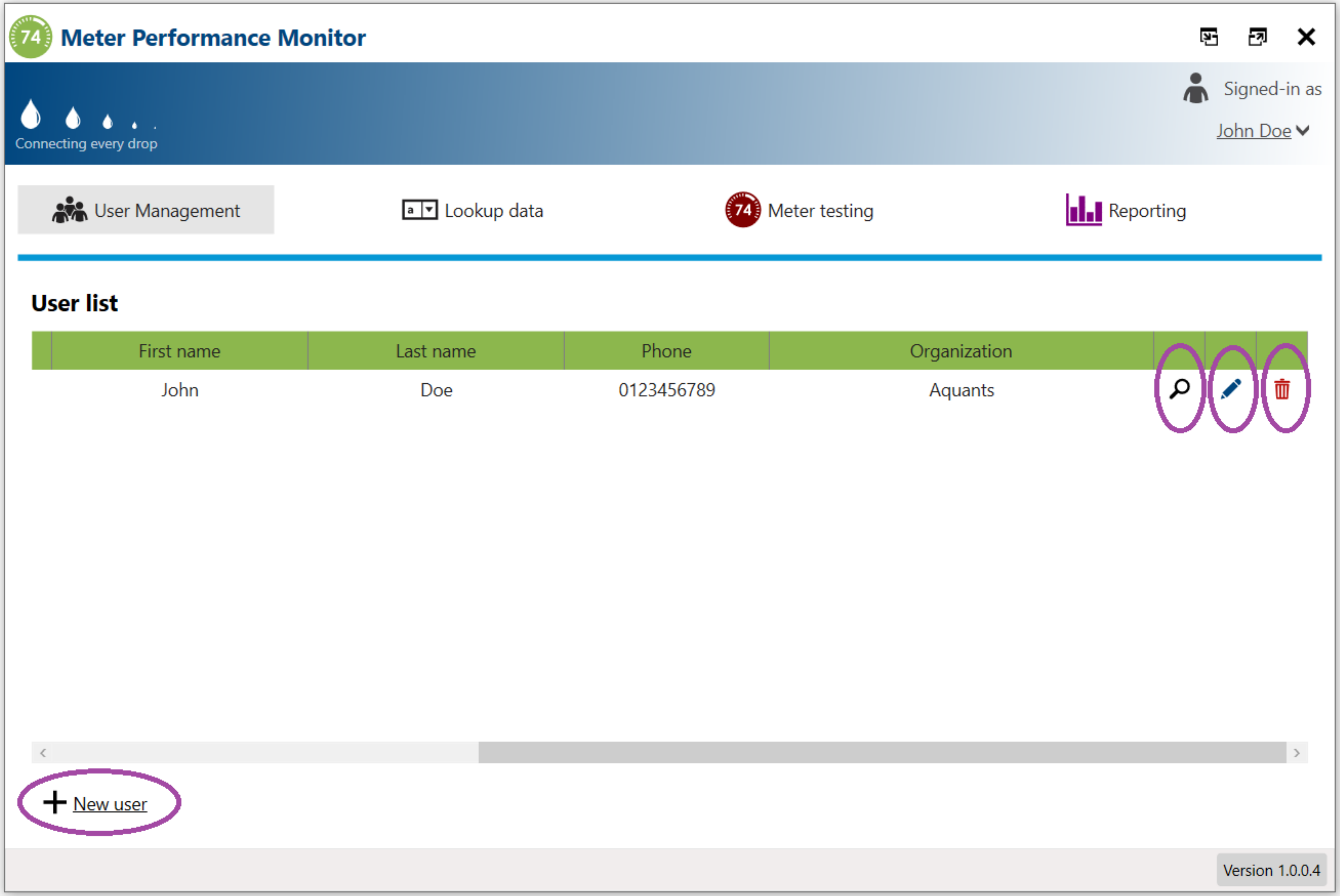
The *toast* highlighted above indicates that the password change was successful. This *toast* disappears after a few seconds.

9.1.2 Authorization

Allows the system to determine what modules a user may access in the system and what operations that user may perform in those modules to which they have access.

This will be discussed under the User Management module.

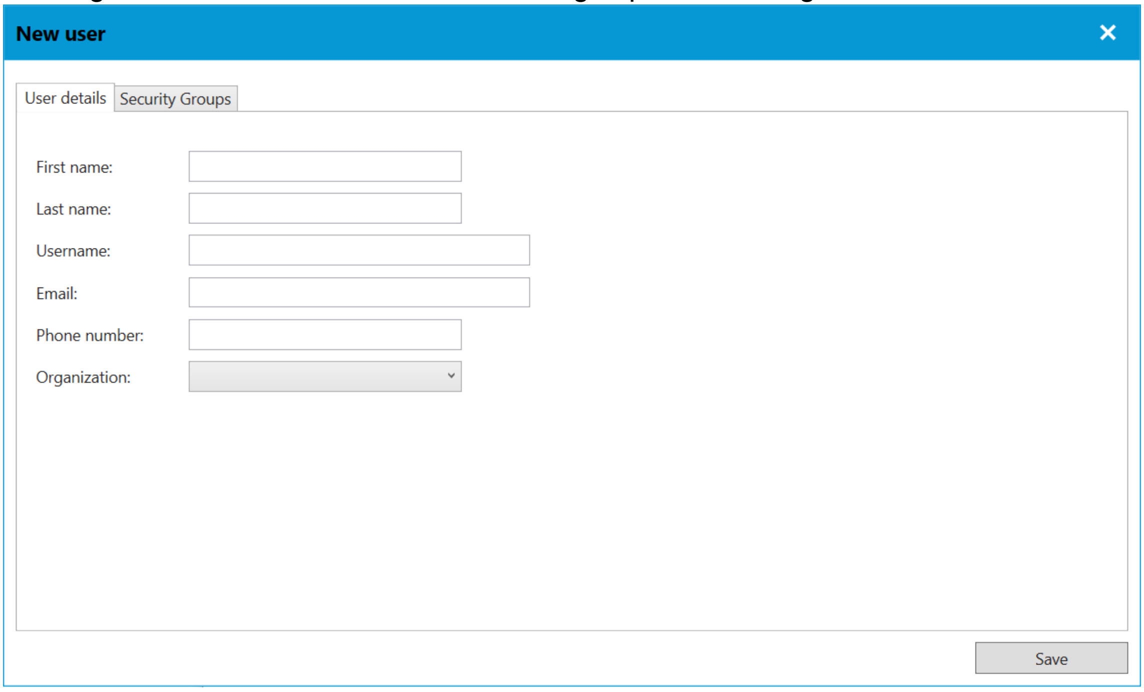
9.2 USER MANAGEMENT MODULE


Meter Performance Monitor
Signed-in as
John Doe
Connecting every drop
User Management
Lookup data
Meter testing
Reporting
User list
First name
Last name
Phone
Organization
John
Doe
0123456789
Aquants
New user
Version 1.0.0.4

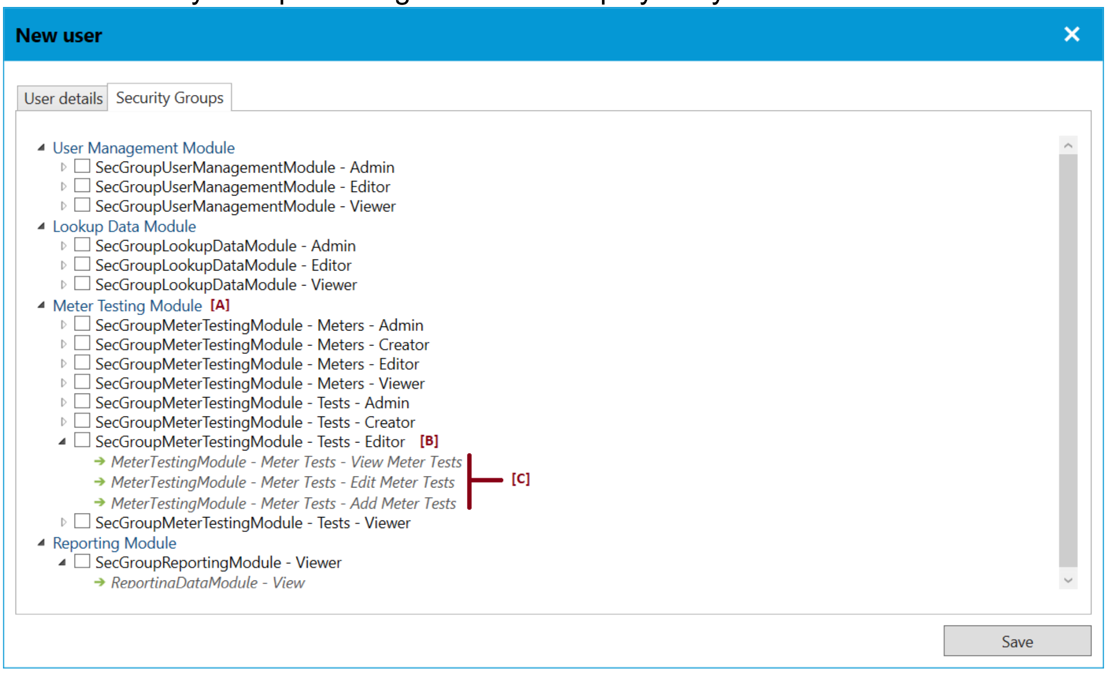
- Contains a read-only grid with a listing of all the currently-registered system users.
- The highlighted actions (buttons) are only accessible to users with the respective permissions. For example, only a user with the permission to "Add Users" will have the "***+ New user***" button in their window. Users who do not have this permission will not have the button on their screens. The same applies to the other highlighted buttons, i.e. "View details", "Edit" and "Delete" buttons.

9.2.1 Registering a new user

- Clicking the "***+ New user***" button above brings up the following window:



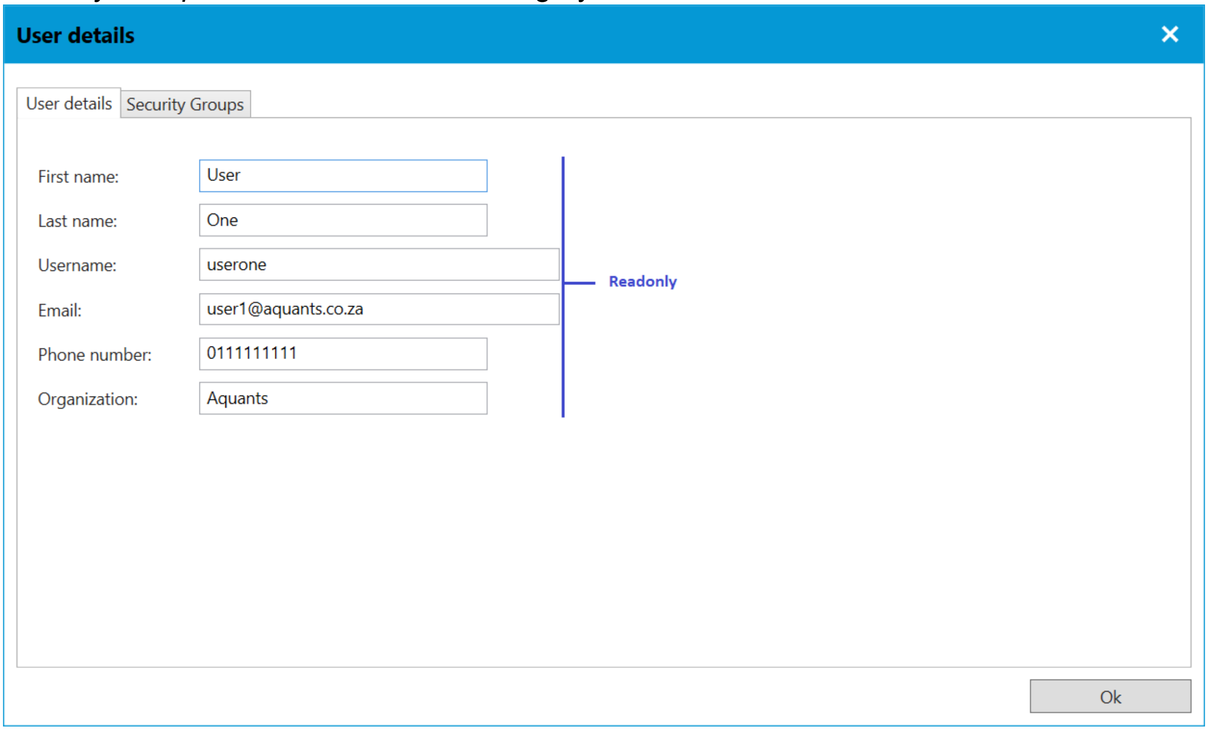
- Upon selecting the Organization, the Security Groups available for users in the selected organization are loaded and displayed in the *Security Groups* tab. The Security Groups are organized and displayed by module.

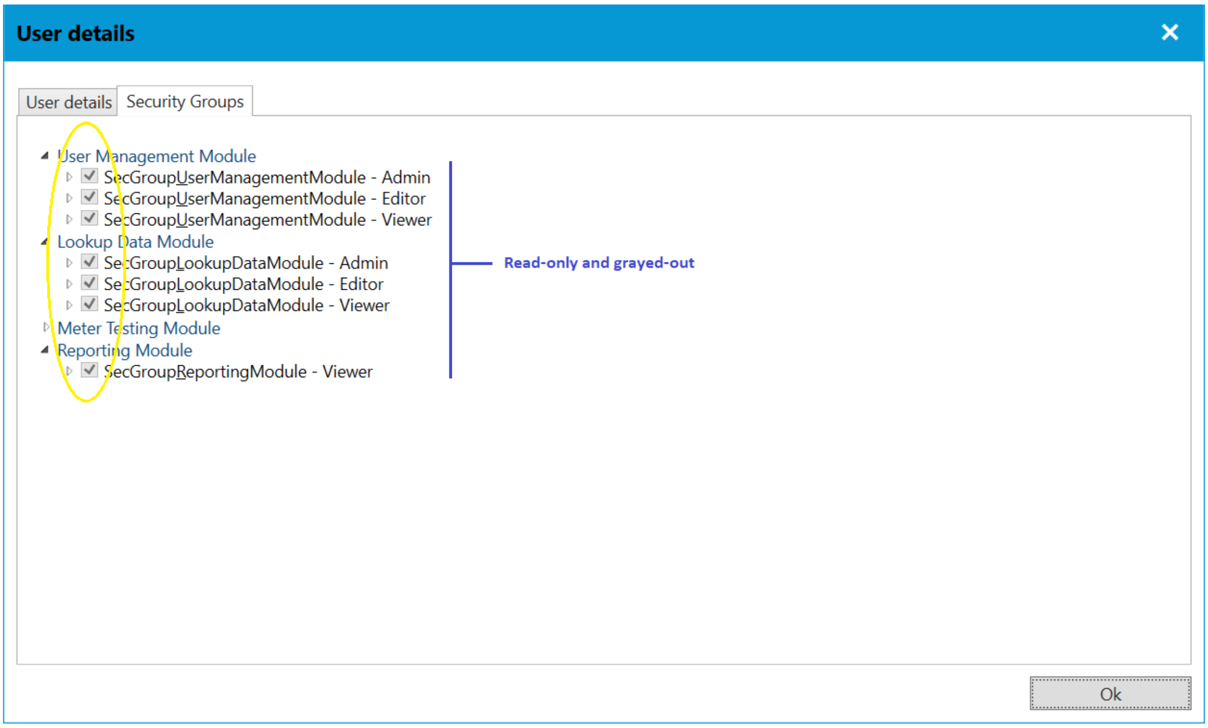


- *[A]* - name of a Module, *[B]* - Security Group, *[E]* – Security Group permissions.

9.2.2 Viewing user details in read-only mode

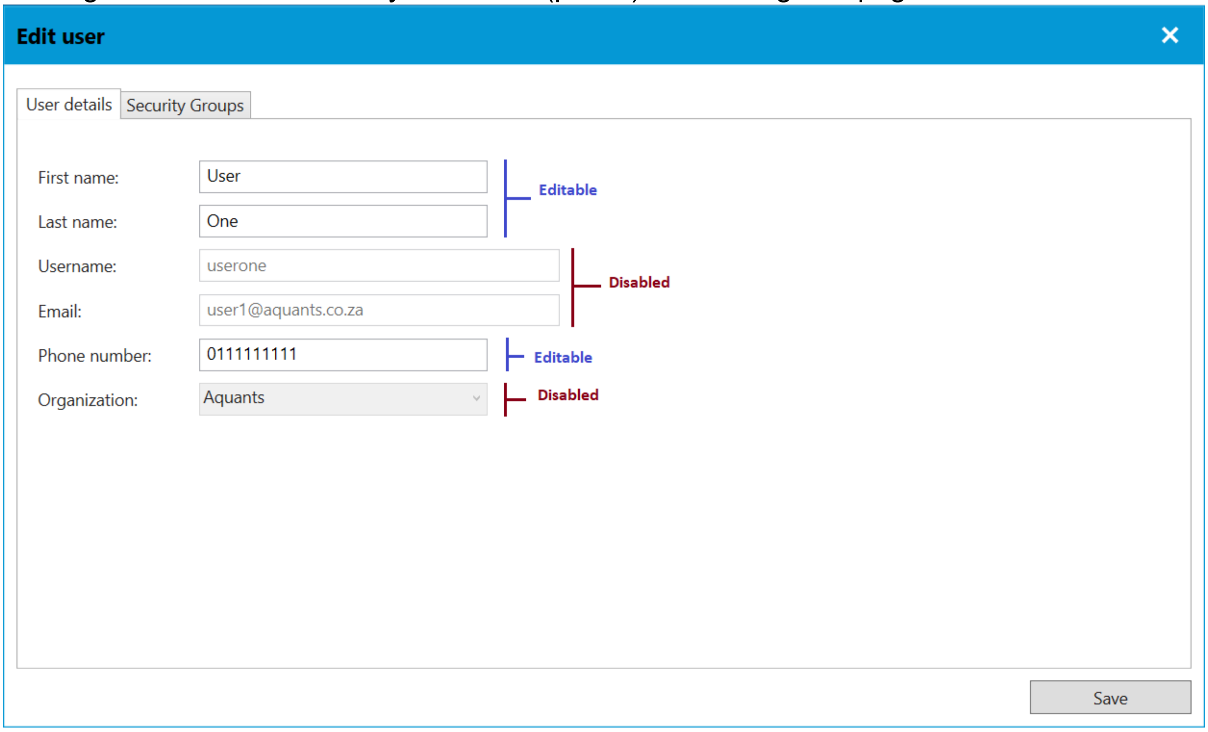
- For each user record, it is possible to see a read-only version of the user details by clicking the button identified with the magnifying glass in the image on page 5. In this case the TextBoxes in the *User details* tab will be readonly. The CheckBoxes in the *Security Groups* tab will be disabled and grayed-out.



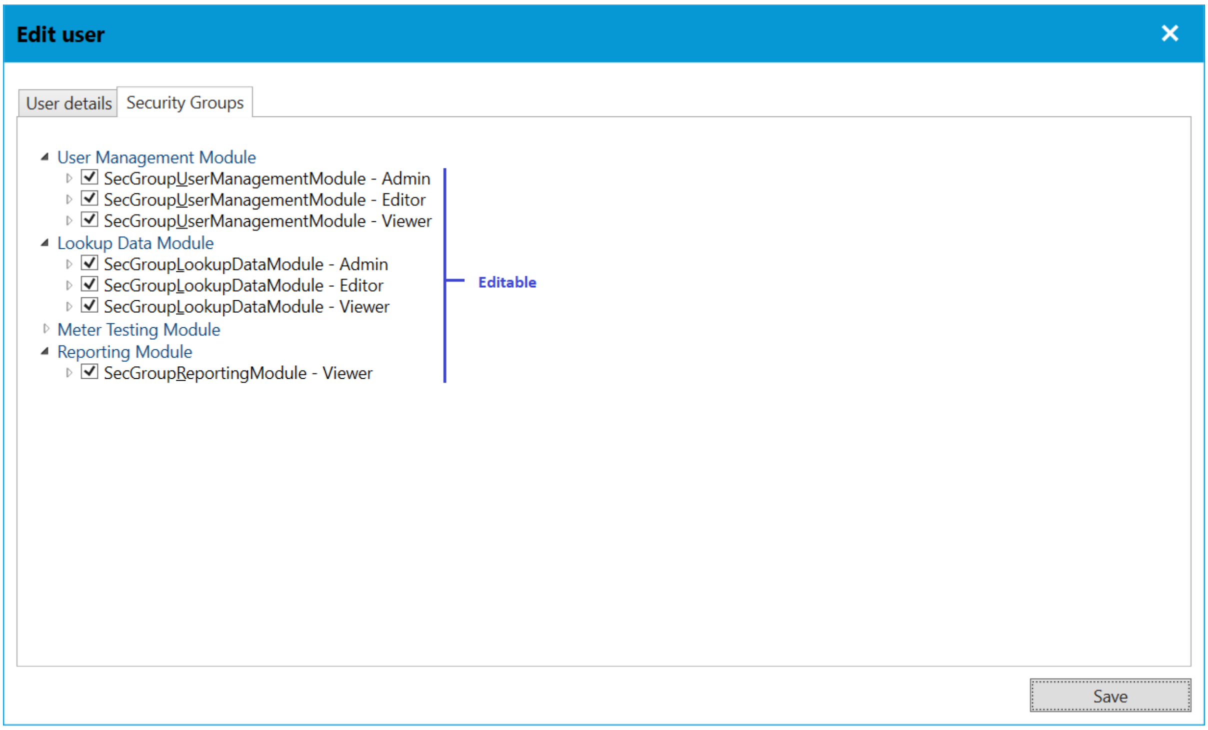


9.2.3 Viewing user details in edit mode

- For each user record, it is possible to view an editable version of the user details by clicking the button identified by the Editor (pencil) in the image on page 5.



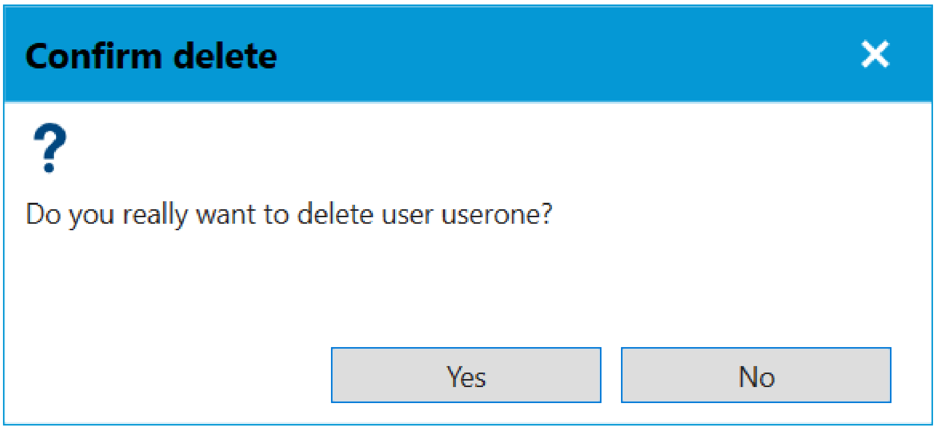
  - The disabled fields are disabled because once set at registration, the system does not allow them to be changed.



  - The user's Security Group assignment may now be changed effectively changing the permissions that the user has.

9.2.4 Deleting a use record

- For each user record, it is possible to delete the record by clicking the button identified by the rubbish bin icon in the image on page 5. In this case the user will be prompted to confirm the action as shown below:



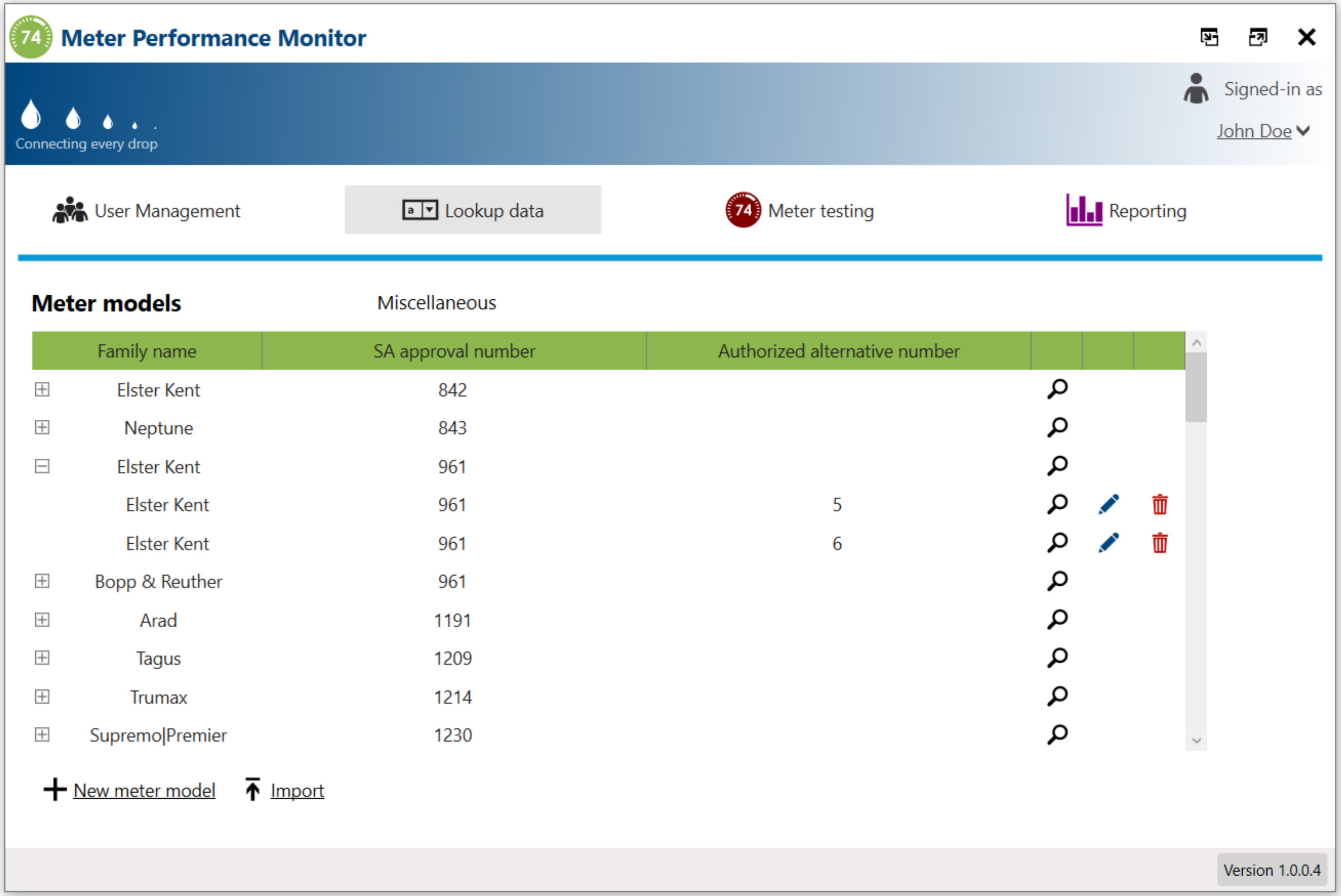
  - Clicking *Yes* deletes the user record while clicking *No* cancels the delete operation.

9.3 LOOKUP DATA MODULE

- Consists of two tabs, a *Meter Models* tab and a *Miscellaneous* tab.

9.3.1 Meter Models Tab

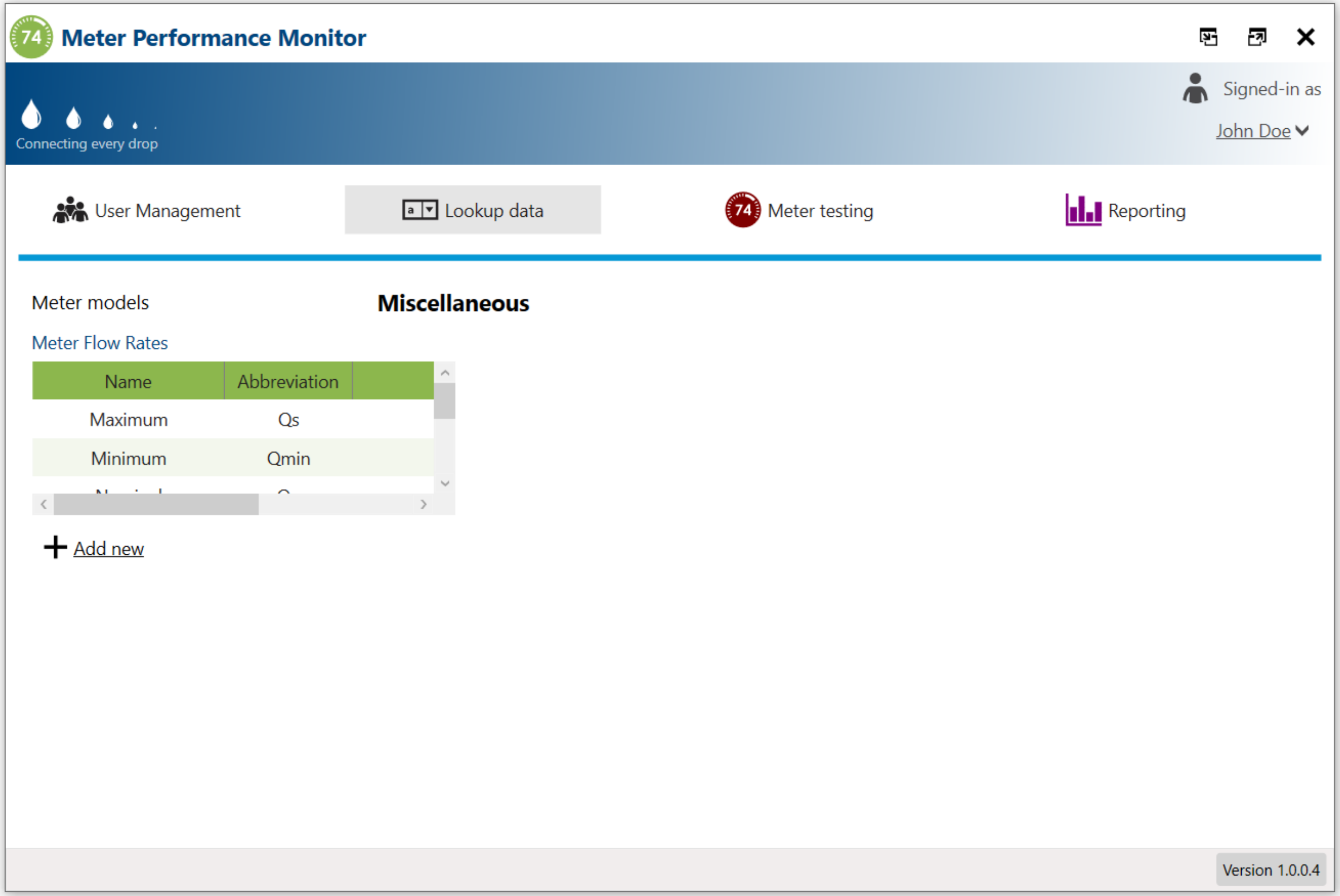
- Shows a breakdown of the different Meter Models as well as their associated SA Approval Numbers and the Authorized Alternative Numbers:


Meter Performance Monitor
Signed-in as
John Doe
Connecting every drop
User Management
Lookup data
Meter testing
Reporting
Meter models
Miscellaneous
Family name
SA approval number
Authorized alternative number
Elster Kent 842
Neptune 843
Elster Kent 961
Elster Kent 961 5
Elster Kent 961 6
Bopp & Reuther 961
Arad 1191
Tagus 1209
Trumax 1214
Supremo|Premier 1230
New meter model
Import
Version 1.0.0.4

- From this tab, new meter models may be created, either one at a time, or via bulk import using a csv file.
- Details of meter models may also be viewed or edited or a meter model may be deleted altogether.

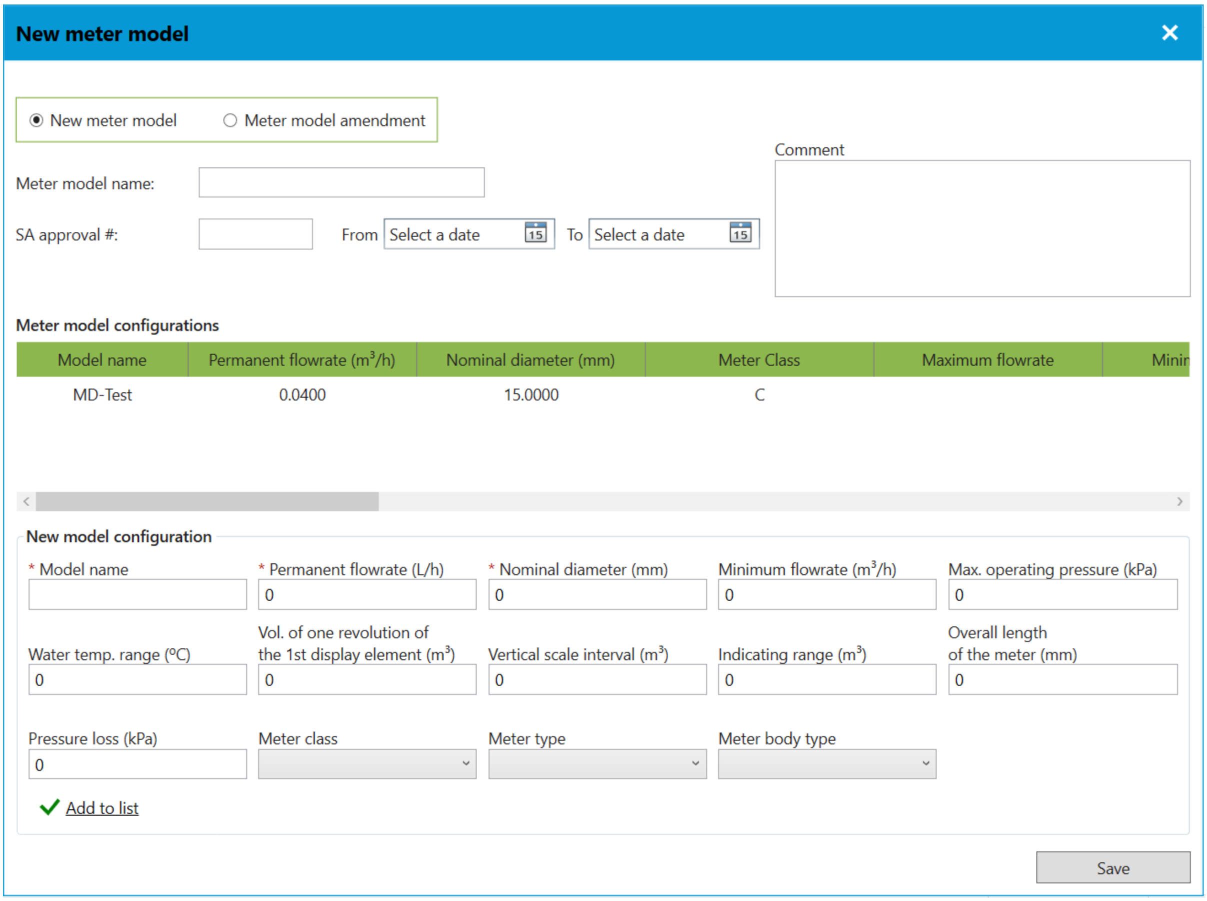
9.3.2 Miscellaneous Tab

- This tab will allow various look-up data items to be created. Currently, only additional Flow Rates may be captured.


Meter Performance Monitor
Signed-in as
John Doe
Connecting every drop
User Management
Lookup data
Meter testing
Reporting
Meter models
Miscellaneous
Meter Flow Rates
Name
Abbreviation
Maximum
Qs
Minimum
Qmin
Add new
Version 1.0.0.4

9.3.3 Creating a new meter model

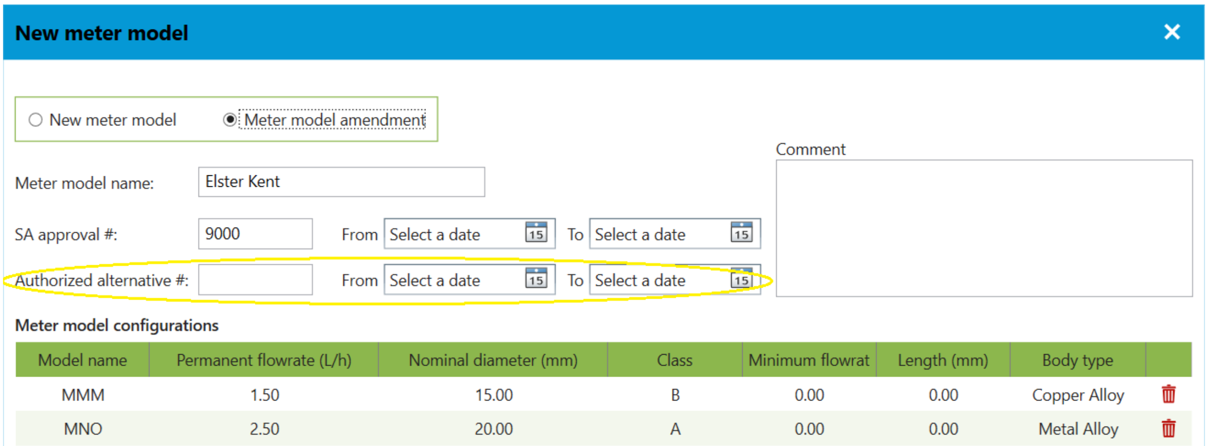
- Achieved by clicking the *New meter model* button in the diagram above:



  - The *New model configuration* section has the TextBoxes and ComboBoxes which capture the details of a configuration of a meter model. Clicking the *Add to list* button adds the configuration to the list of configurations associated with the meter model.
  - Saving the data saves a single meter model with its multiple configurations.

9.3.4 Making a meter model amendment

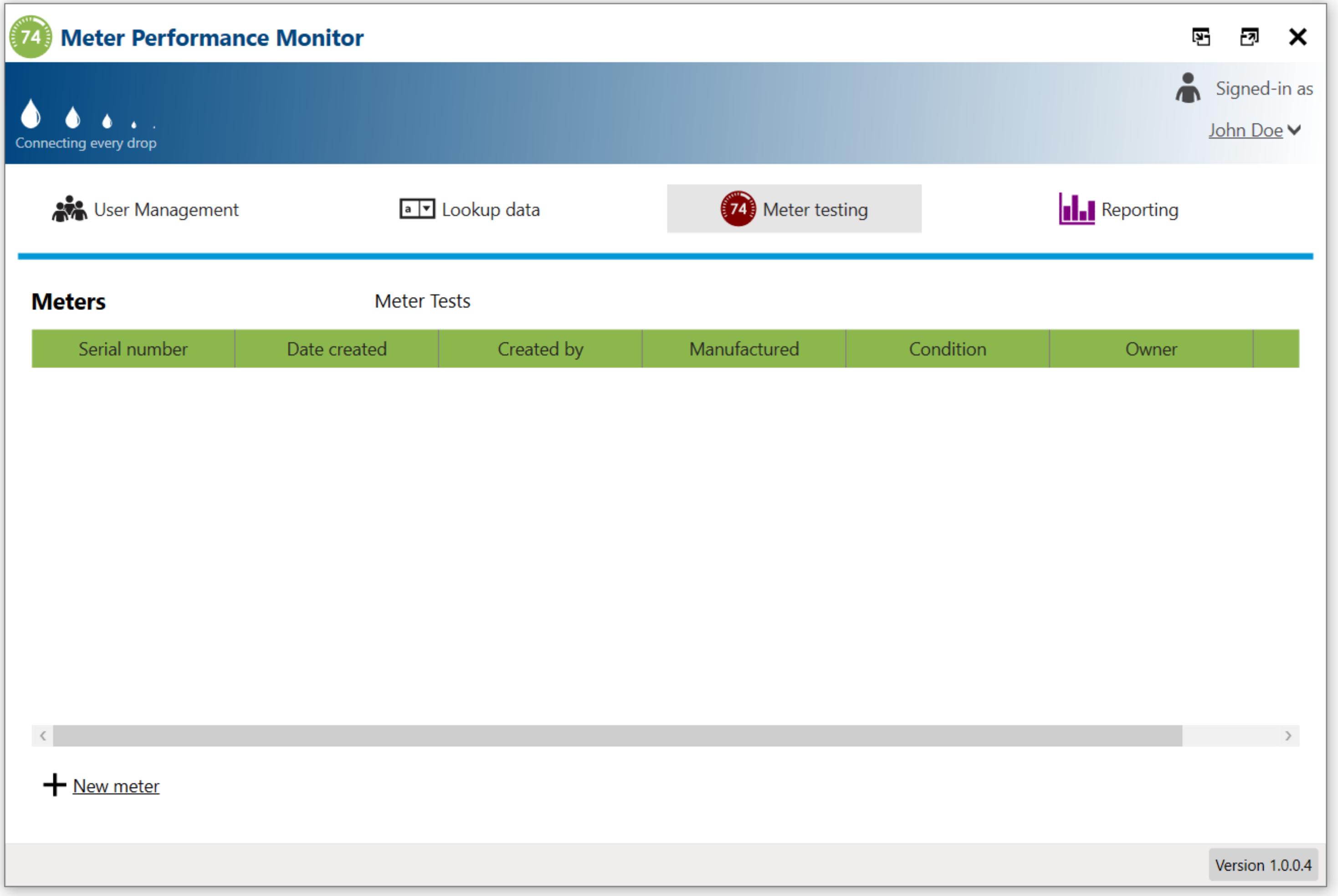
- In this case the Authorized Alternative number associated with the change is required, while everything else remains the same as for new meter model capture:


New meter model
New meter model
Meter model amendment
Comment
Meter model name:
Elster Kent
SA approval #:
9000
From
Select a date
To
Select a date
Authorized alternative #:
From
Select a date
To
Select a date
Meter model configurations
Model name
Permanent flowrate (L/h)
Nominal diameter (mm)
Class
Minimum flowrat
Length (mm)
Body type
MMM 1.50 15.00 B 0.00 0.00 Copper Alloy
MNO 2.50 20.00 A 0.00 0.00 Metal Alloy

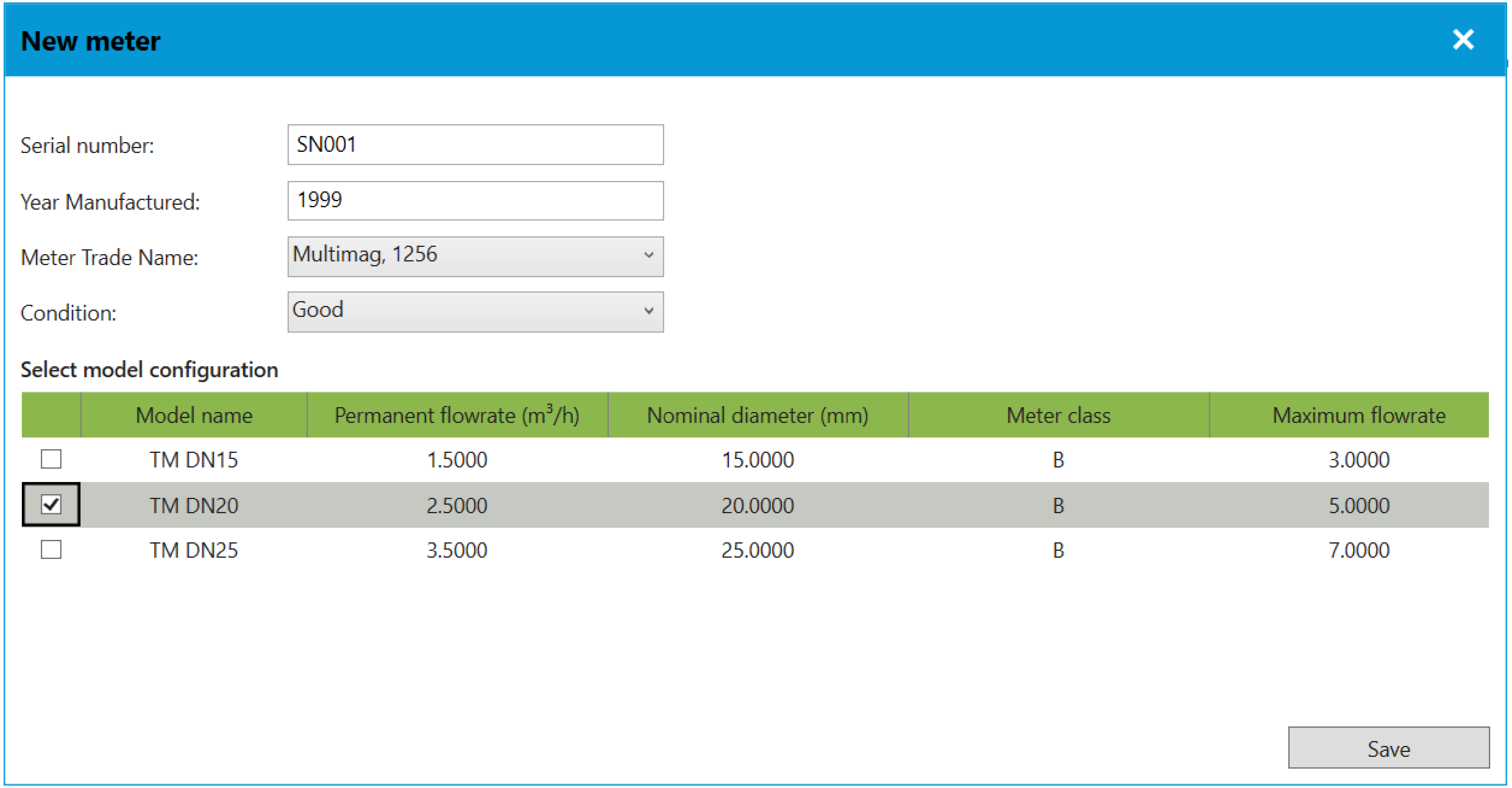
9.4 METER TESTING MODULE

9.4.1 Meters Tab

- Shows the existing physical meters and allows the user to manage the physical meters.


Meter Performance Monitor
Signed-in as
John Doe
Connecting every drop
User Management
Lookup data
Meter testing
Reporting
Meters
Meter Tests
Serial number
Date created
Created by
Manufactured
Condition
Owner
New meter
Version 1.0.0.4

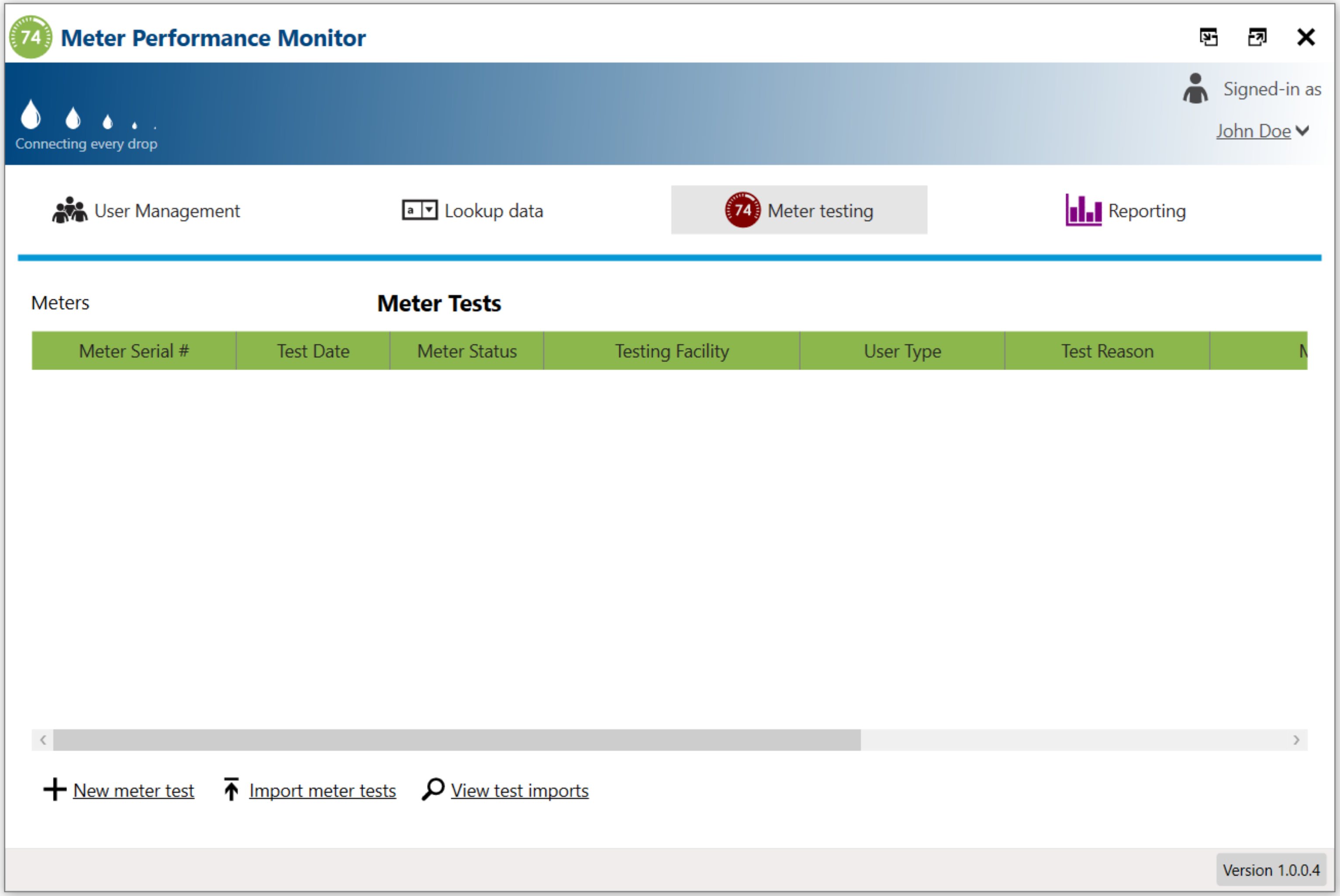
9.4.1.1 *Creating a new meter*



- Selecting a Meter Trade Name, which is the *Model Family Name + SA Approval Number*, fetches all the meter model configurations for that SA Approval Number.
- Meters may also be viewed, edited and deleted using the appropriate buttons in the top-most image.

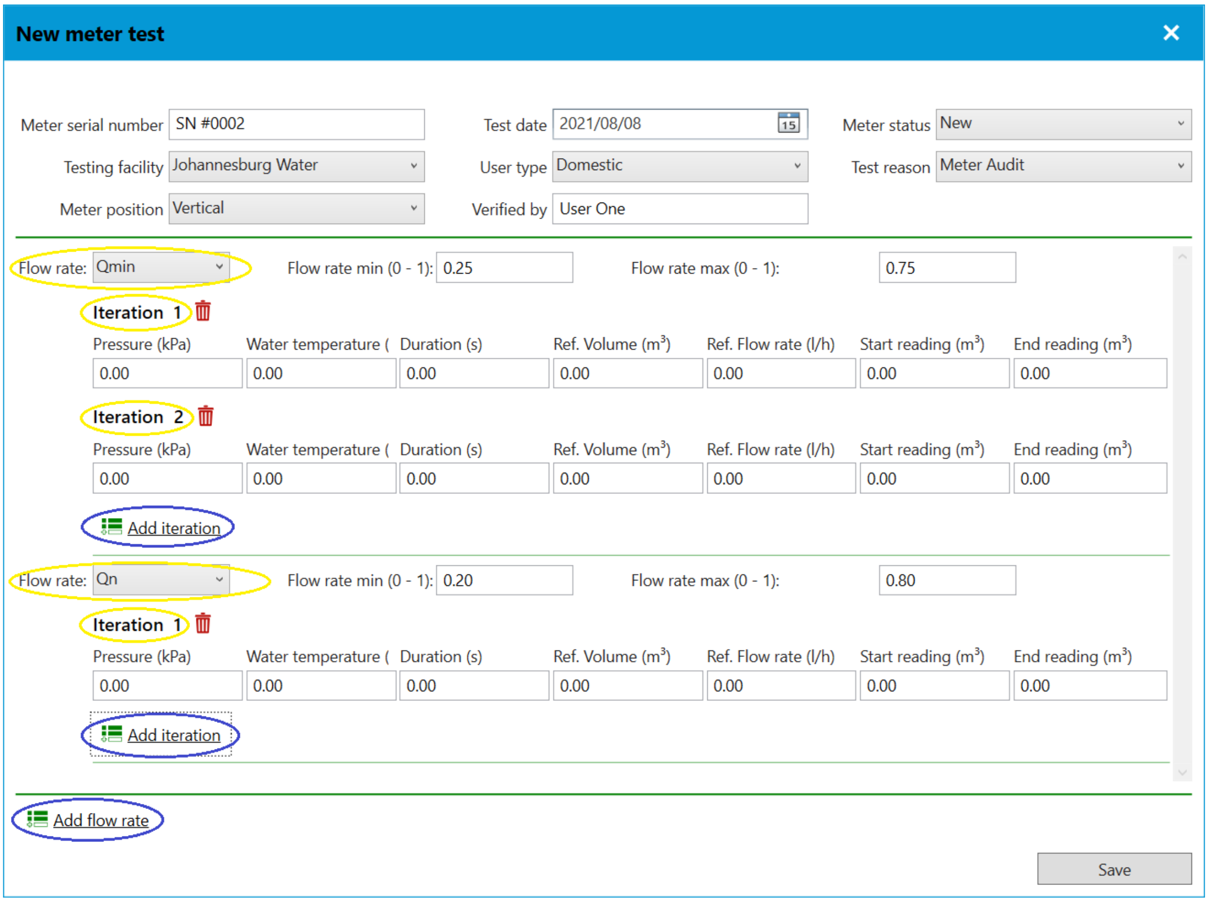
9.4.2 Meter Tests Tab

- Lists the meter tests recorded using the MeterPerformanceMonitor system.
- These tests may be viewed in read-only mode, edit mode, or deleted.


Meter Performance Monitor
Signed-in as
John Doe
Connecting every drop
User Management
Lookup data
Meter testing
Reporting
Meters
Meter Tests
Meter Serial #
Test Date
Meter Status
Testing Facility
User Type
Test Reason
New meter test
Import meter tests
View test imports
Version 1.0.0.4

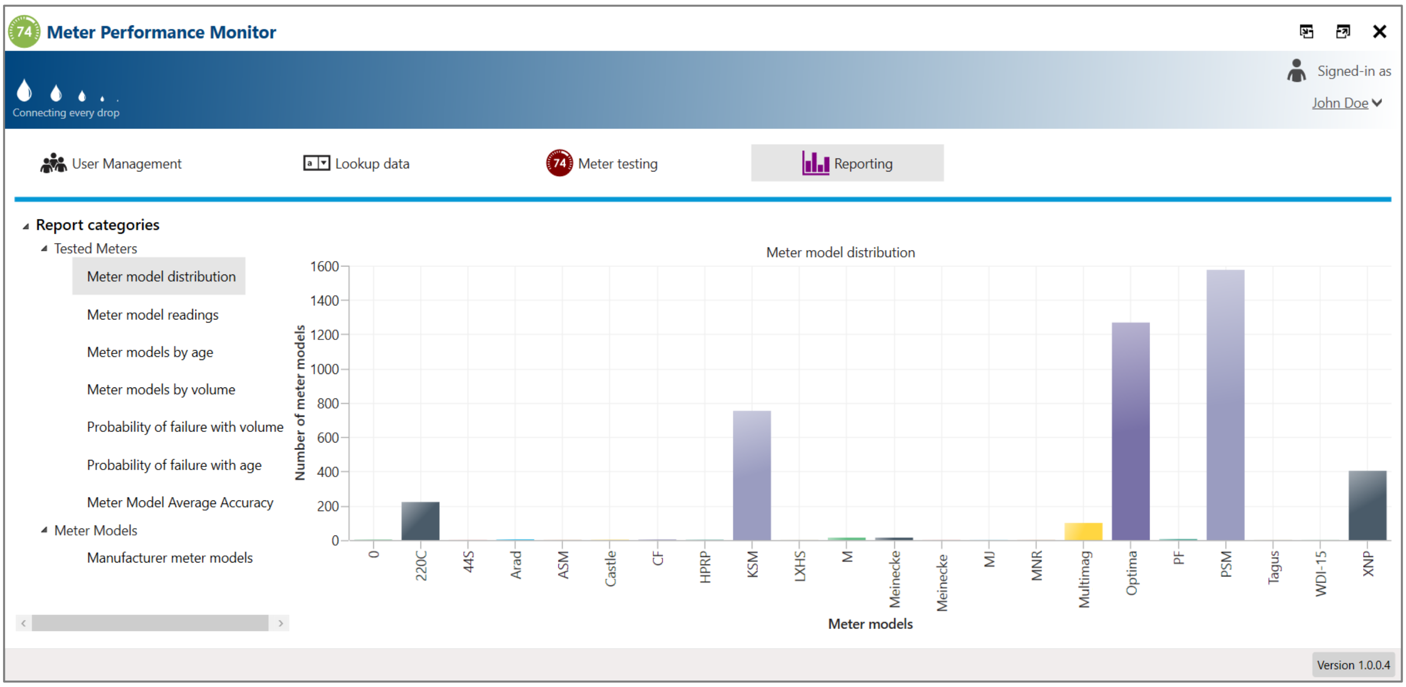
9.4.2.1 Adding a new meter test

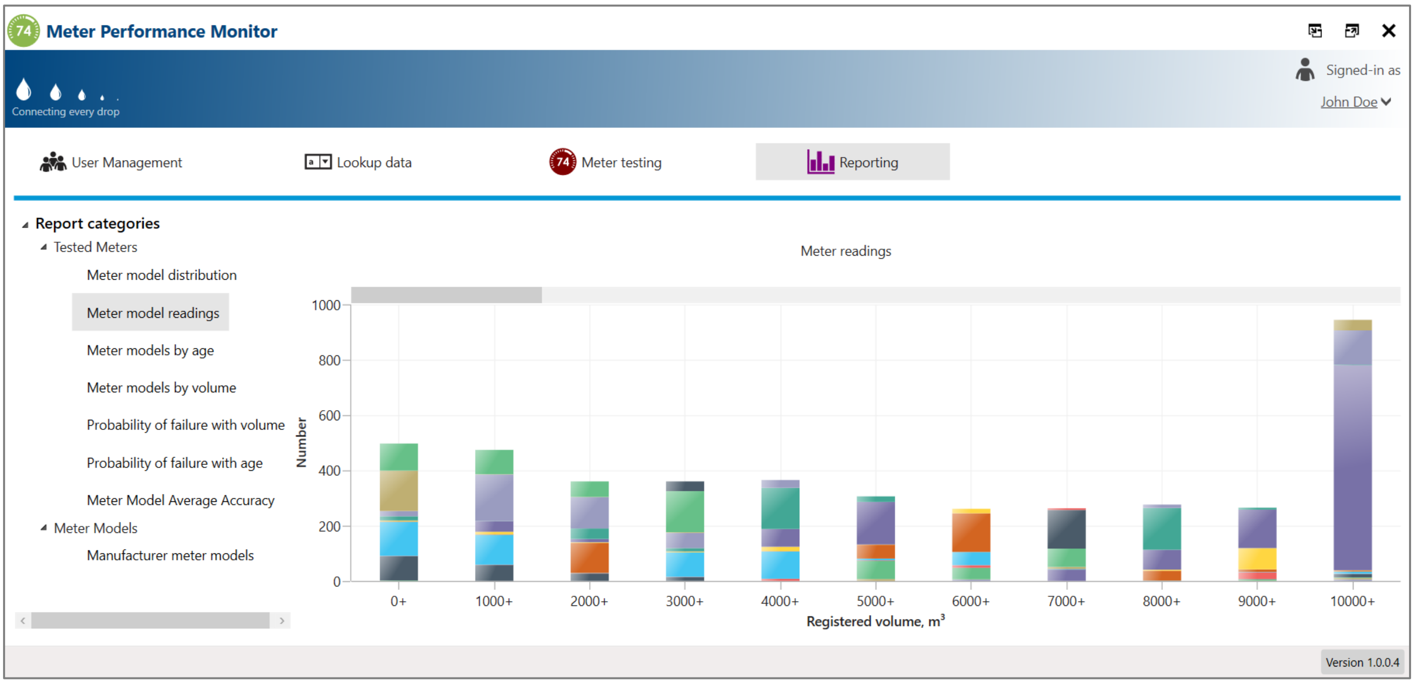
- For a given meter test, multiple flow rates may be recorded, and for each flow rate multiple iterations may also be recorded.
- During edit operations the flow rates and the iterations may be amended.

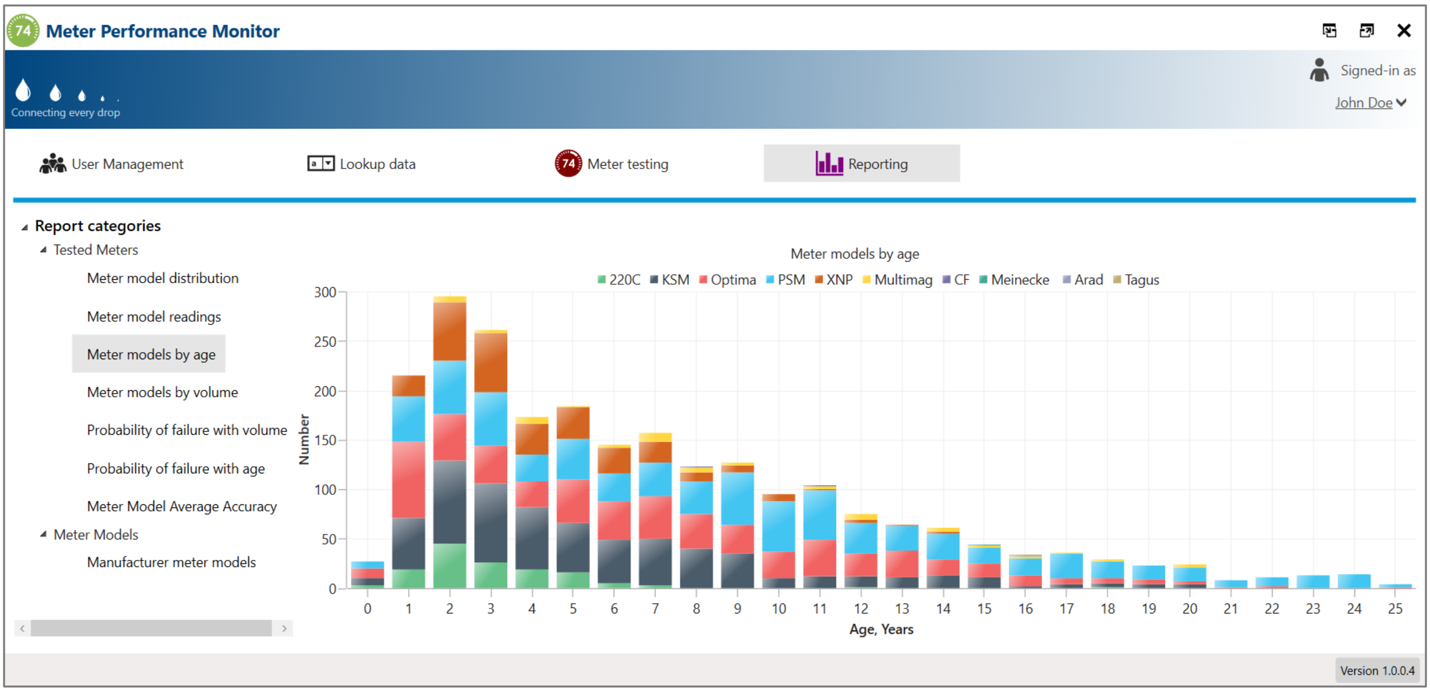


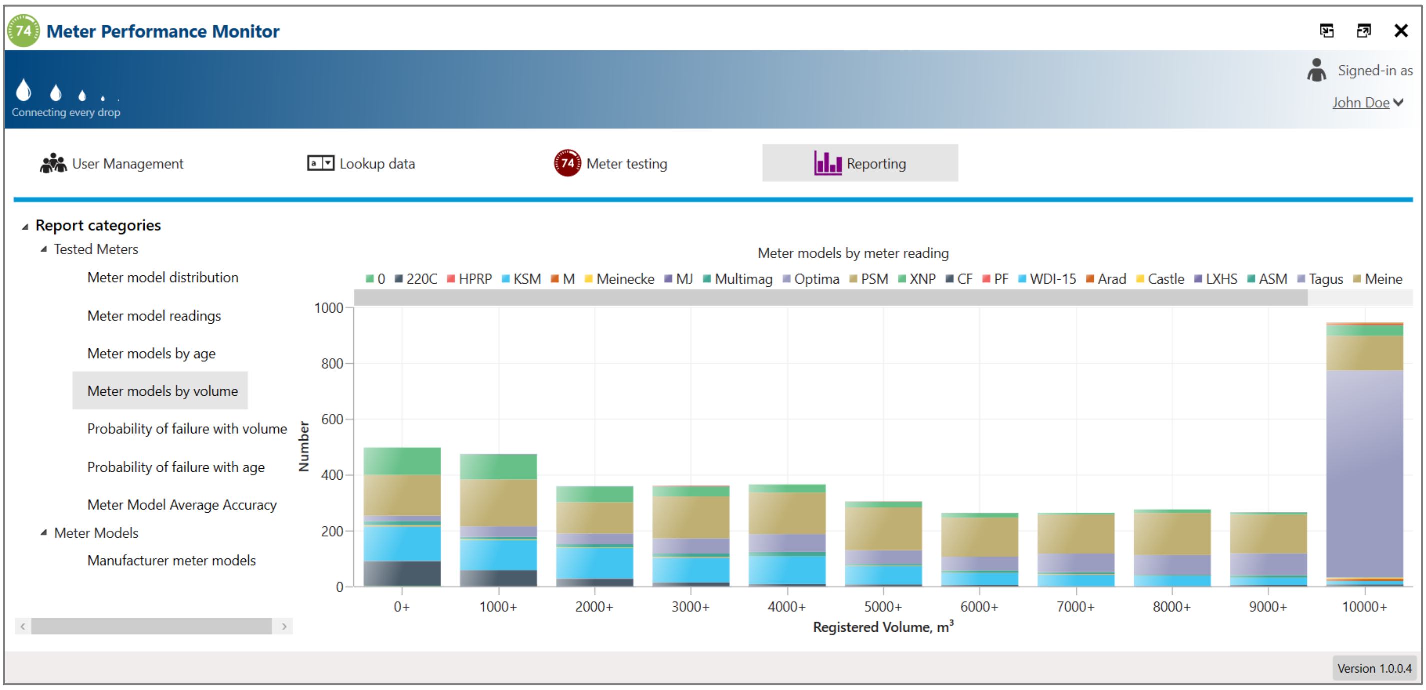
9.5 REPORTING MODULE

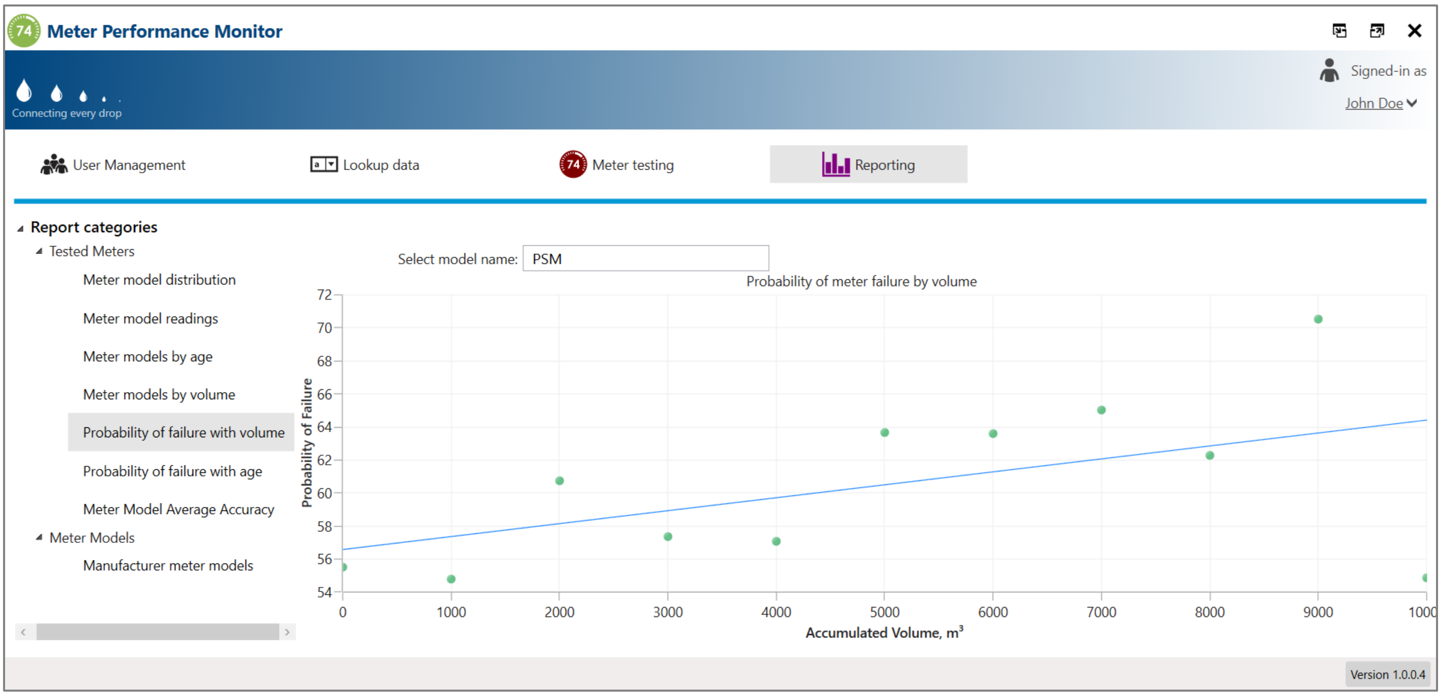
- Shows various reports on various aspects of the data stored within the MeterPerformanceMonitor system.

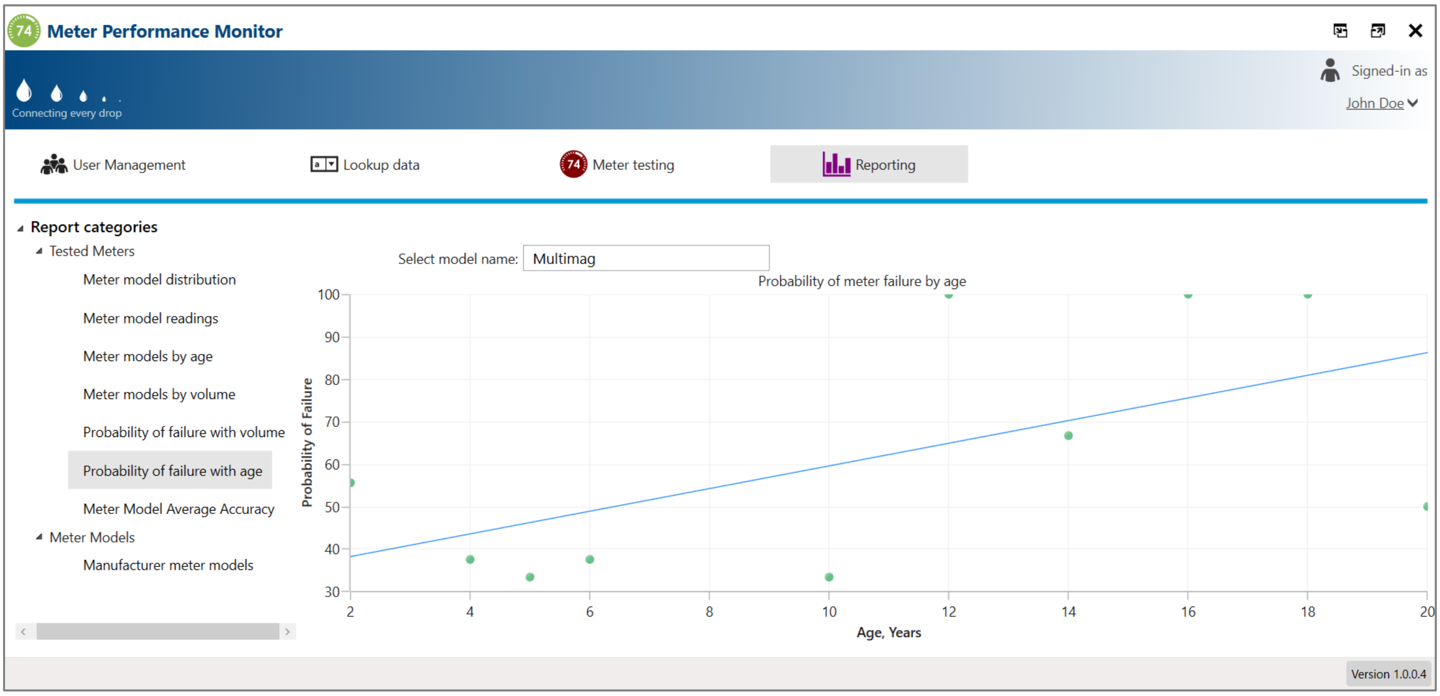


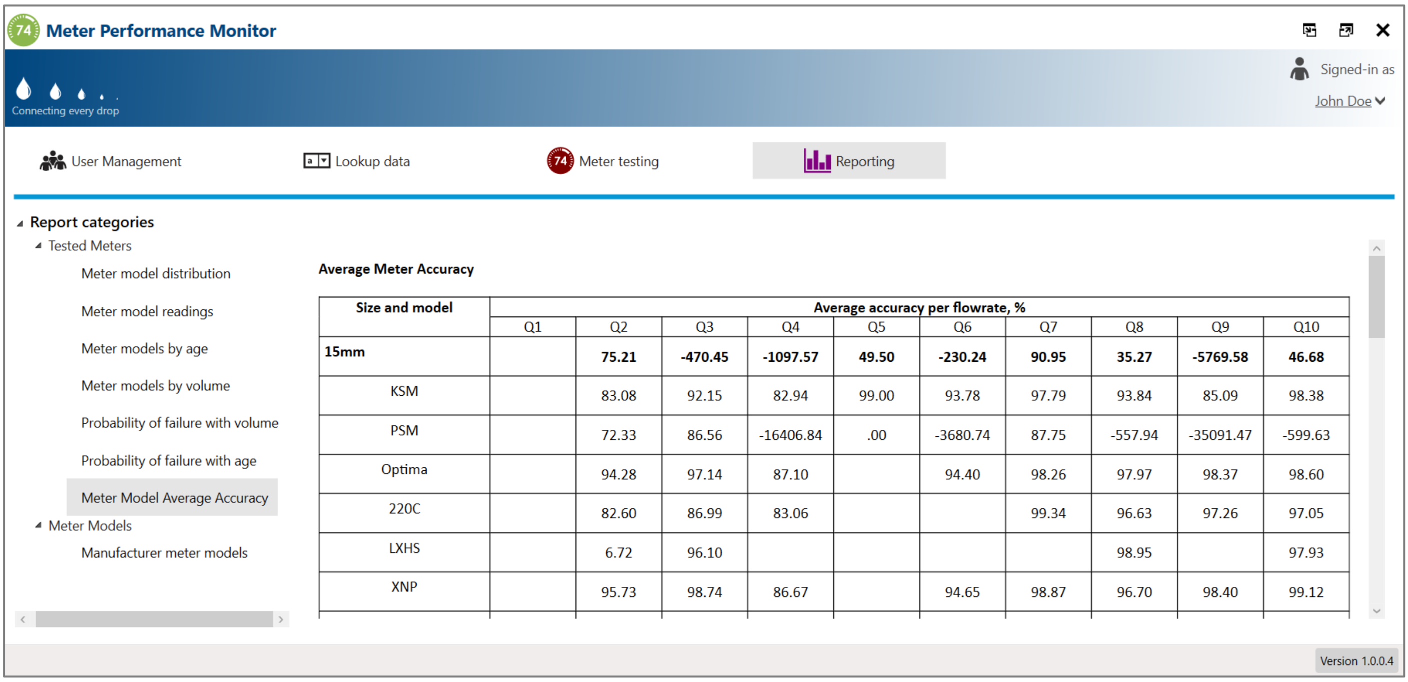



Meter Performance Monitor
Connecting every drop
Signed-in as
John Doe
User Management
Lookup data
Meter testing
Reporting
Report categories
Tested Meters
Meter model distribution
Meter model readings
Meter models by age
Meter models by volume
Probability of failure with volume
Probability of failure with age
Meter Model Average Accuracy
Meter Models
Manufacturer meter models
Meter models by age
220C KSM Optima PSM XNP Multimag CF Meinecke Arad Tagus
Number
Age, Years
Version 1.0.0.4


Meter Performance Monitor
Connecting every drop
Signed-in as
John Doe
User Management
Lookup data
Meter testing
Reporting
Report categories
Tested Meters
Meter model distribution
Meter model readings
Meter models by age
Meter models by volume
Probability of failure with volume
Probability of failure with age
Meter Model Average Accuracy
Meter Models
Manufacturer meter models
Meter models by meter reading
0 220C HPRP KSM M Meinecke MJ Multimag Optima PSM XNP CF PF WDI-15 Arad Castle LXHS ASM Tagus Meine
Number
Registered Volume, m³
Version 1.0.0.4


Meter Performance Monitor
Connecting every drop
Signed-in as
John Doe
User Management
Lookup data
Meter testing
Reporting
Report categories
Tested Meters
Meter model distribution
Meter model readings
Meter models by age
Meter models by volume
Probability of failure with volume
Probability of failure with age
Meter Model Average Accuracy
Meter Models
Manufacturer meter models
Select model name:
PSM
Probability of meter failure by volume
Probability of Failure
Accumulated Volume, m³
Version 1.0.0.4


Meter Performance Monitor
Connecting every drop
Signed-in as
John Doe
User Management
Lookup data
Meter testing
Reporting
Report categories
Tested Meters
Meter model distribution
Meter model readings
Meter models by age
Meter models by volume
Probability of failure with volume
Probability of failure with age
Meter Model Average Accuracy
Meter Models
Manufacturer meter models
Select model name:
Multimag
Probability of meter failure by age
Probability of Failure
Age, Years
Version 1.0.0.4



Size and model	Average accuracy per flowrate, %									
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
15mm		**75.21**	**-470.45**	**-1097.57**	**49.50**	**-230.24**	**90.95**	**35.27**	**-5769.58**	**46.68**
KSM		83.08	92.15	82.94	99.00	93.78	97.79	93.84	85.09	98.38
PSM		72.33	86.56	-16406.84	.00	-3680.74	87.75	-557.94	-35091.47	-599.63
Optima		94.28	97.14	87.10		94.40	98.26	97.97	98.37	98.60
220C		82.60	86.99	83.06			99.34	96.63	97.26	97.05
LXHS		6.72	96.10					98.95		97.93
XNP		95.73	98.74	86.67		94.65	98.87	96.70	98.40	99.12