University of Bahrain
College of Engineering **Department of Mechanical Engineering**



Investigation into Failure Phenomena of Water Meters in The Kingdom of Bahrain

A Thesis Submitted in Partial Fulfillment of the Requirements for the Master Degree in Engineering Management

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Defense Committee's Approval Page

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Dedication

I dedicate this work to my family and friends for their support and patience. I thank them for inspiring and for their continues encouragement.

Acknowledgments

I would like to thank my Prof, Ahmed Yusuf, for his contributions to this study, which include but are not limited to guiding my research and analysis of the investigation results, encouraging me to expand on my ideas for development of the project, and suggesting revisions all along the way. My sincere thanks also goes to Prof. Saad Suliman, coordinator of Engineering Management Master Program and Dr. Bader Mannai, Chairman of Mechanical Engineering Department, UOB for their insightful comments and encouragement.

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Jaber Al Ghannami

Abstract

EWA vision is “By 2017, EWA is a model of excellence in the provision of electricity & water services with minimum interruptions and timely revenue collection” and as stated in their objectives they are responsible for “Maintenance, development and improvement of the existing transmission and distribution network to achieve highest standards of operational efficiency and minimum energy waste”.

In 2015, there were around 140,000 domestic type revenue water meters existed in the Water Distribution System of The Kingdom of Bahrain. Most of those meters are flow displacement measurement type with size 15 and 25 mm. According to the water meter manufacturers, the estimated life span of those meters are in the range of seven years in service depending on operation and environmental conditions. However, Electricity and Water Authority (EWA) has set an annual program to replace the domestic water meters after every five years of services in order to minimize the administrative losses despite that, the water meters failed more frequently even in less than five years.

This study is intended to examine operation and environmental causes of domestic volumetric type water meter failures in most severe tank wise areas in the Kingdom of Bahrain, based on the analysis of statistical data and defective meter testing results. It has been found that the failure phenomena fall into three major category of defects. It has been observed that 60% of the selected samples stopped recording the flow, 34% failed to satisfy the accuracy test and 6% had physical body defects. Accordingly, the study has been diversified considering alternative metering technologies such as selection of single jet water meter and ultrasonic or electromagnetic water meters to suit operation and environmental parameters of Bahrain's water network.

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List of Abbreviations

AC	Asbestos Cement Pipe	RO	Reverse Osmosis
ADPWC	Al Door Power & Water Company	ROC	Rated Operation Condition
AWWA	American Water Works Association	QA	Quality Assurance
CED	Cause and Effect Diagram	QC	Quality Control
CSS	Customer Services System	WCC	Water Control Centre
DI	Ductile Iron Pipe		
EWA	Electricity and Water Authority		
FF	Frequent Failure		
FTA	Fault Tree Analysis		
HPC	Hidd Power Company		
IMM	International Monetary Market		
ISO	International Standard Organization		
KPI	Key Performance Indicator		
MED	Multi Effect Desalination		
MG	Million Gallon		
MMM	Metering Management Module		
MPE	Maximum Permissible Error		
MSF	Multi Stage Flashing		
NRW	Non-Revenue Water		
OIML	Organization International Metrology Legal		

Chapter 1. Introduction

1.1 Background

Before 1925, water supply in Bahrain depended on natural freshwater springs, which used to flow freely in the northern part of the country. In 1957, the water supply network was inaugurated to serve some 3000 customers. However, during the 1980's, most of the springs ceased flowing and demand for water continued to increase leading to a shortage in Bahrain's water supply.

Today, Bahrain relies greatly on non-conventional sources of water. This include four desalination plants with total production of desalinated and groundwater in Bahrain reached up to 160 million imperial gallons/day. The total consumption of blended water reached up to 154 million imperial gallons/day supplied to distribution network via 29 storage tanks situated over the Kingdom of Bahrain is shown in appendix B - Bahrain Water Network Map, EWA, (March 2016).

As strategic objective of Electricity and Water Authority (EWA) is to supply high quality, sustainable potable water to all sectors in The Kingdom of Bahrain, without interruption according to the international standards and at the possible lowest cost.

Indeed in a country located in an arid region with scarcity of natural water resources and mainly relies on desalination to meet its water demands, there is mandatory requirement to reduce the water losses. Especially water production unit cost is relatively high compared to countries that possess natural water resources.

Hence, water losses due to meter inaccurate measurements are considered to be one of the main challenges that prevent achieving EWA strategic aim.

According to AWWA (2009), water losses in the distribution system are categorized into real losses and apparent losses. Real losses are leakages in the water supply system while apparent (commercial) losses occur due to illegal usage, inaccurate measurement of meters, erroneous readings, data handling and billing errors. In comparison with International percentage of apparent losses, Bahrain has large apparent losses relatively in the water distribution network, recorded at about 10% as illustrated in appendix A - IWA and EWA Water Balance, EWA, 2011. The percentage cause EWA revenue losses and also lead to unnecessary financial burdens and wastage.

1.2 Thesis Scope and Structure

The establishment of this thesis targets to analyze volumetric water meter failure phenomena major causes, and propose solution to overcome the issue. It comprises of five chapters;

Chapter one: Introduction

This chapter intends to elaborate the framework of study by presenting background information of the research, statement of the problem, main objectives of the research, methodology.

Chapter two: Literature Review

This chapter discusses some of the previous studies that are related to the subject of this research such as: involvement of water meter in water commercial losses, meter basis, types and classes, factors effecting water meter performance, operational and environmental parameters involve in water meter failures.

Chapter three: Failure Phenomena Investigation

This chapter deals with methodology and tools used to collect and gather data using available historical data and laboratory test results enable to quantify domestic water meter failures.

Chapter four: Result Analysis and Discussion

This chapter analyzes and discusses the results using quality control tools.

Chapter five: Conclusion & Recommendation

This chapter presents conclusion and recommendations.

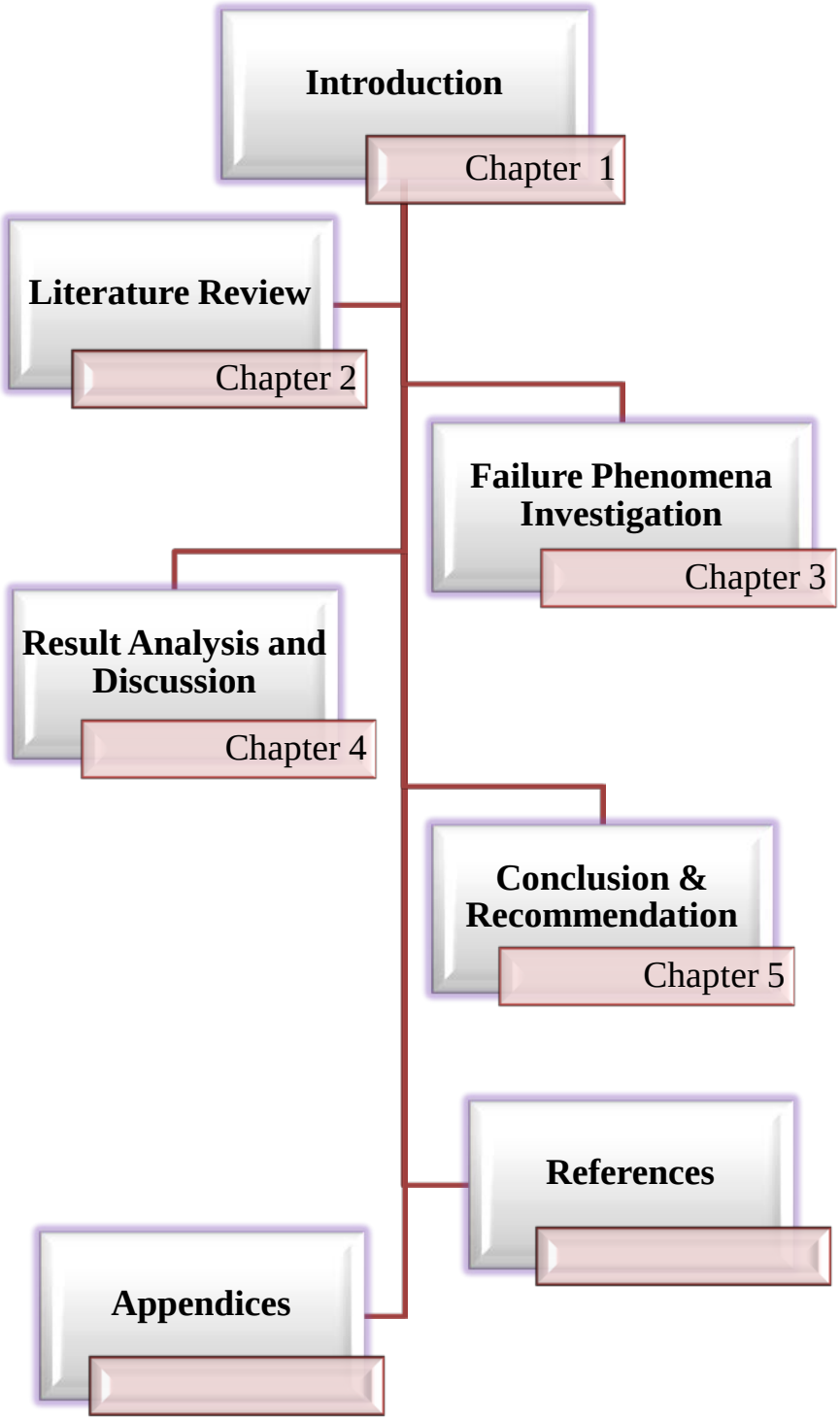


Figure 1-A: Thesis Structure

1.3 Problem Statement

Approximately, 140,000 domestic water revenue meters existed in The Kingdom of Bahrain's Water Distribution System in the year 2015. Majority of those meters are of flow displacement measurement type with size 15 mm and 25 mm. According to the water meter manufacturers, the estimated life cycle of those meters are about seven years in service depending on water quality and operation environmental conditions.

However, EWA has set an annual program to replace the domestic water meters after five years of services in order to enhance performance of EWA services through minimizing the administrative losses.

Despite that, the water meters failed more frequently in less than five years due several operational issues, average of 18% of existing water meters failed annually due to drop in accuracy, stoppage and other issues.

The early frequent failures of domestic water meters has dramatically increased EWA NRW losses level "Apparent Loss" thus lid to interrupted EWA provided services and consequently badly affected on EWA revenue.

1.4 Research Objective

The main objectives of this study are to:

1. Identifying the major causes of domestic water meter failure in the Kingdom of Bahrain Water Distribution System.
2. Establishing a logic relationship between domestic water meter metrological technology and failure causes.
3. Establish a logic relationship between life of the meter and failure causes.
4. Recommending method and procedure or other alternatives to reduce the rate of domestic meter failures in the water network.

1.5 Research Methodology

As there are many environmental and operational factors contribute to water meter failure phenomena, such as water quality, pressure, flow rate, meter accuracy, age and installation method. The quantitative research method would be used to identify the merit of order behind the failure phenomena and the data collected will be analyzed using groups of Quality Control Tools namely:

1. Histogram for summarizing and presenting most frequent meter failures.
2. Pareto Chart for identifying the most causes of meter failures.
3. Fault tree analysis (FTA) for analyzing the interrelation among the meter failures and their causes.
4. Cause and Effect Diagram (CED) for identifying relationships between meter failure element and their causes.

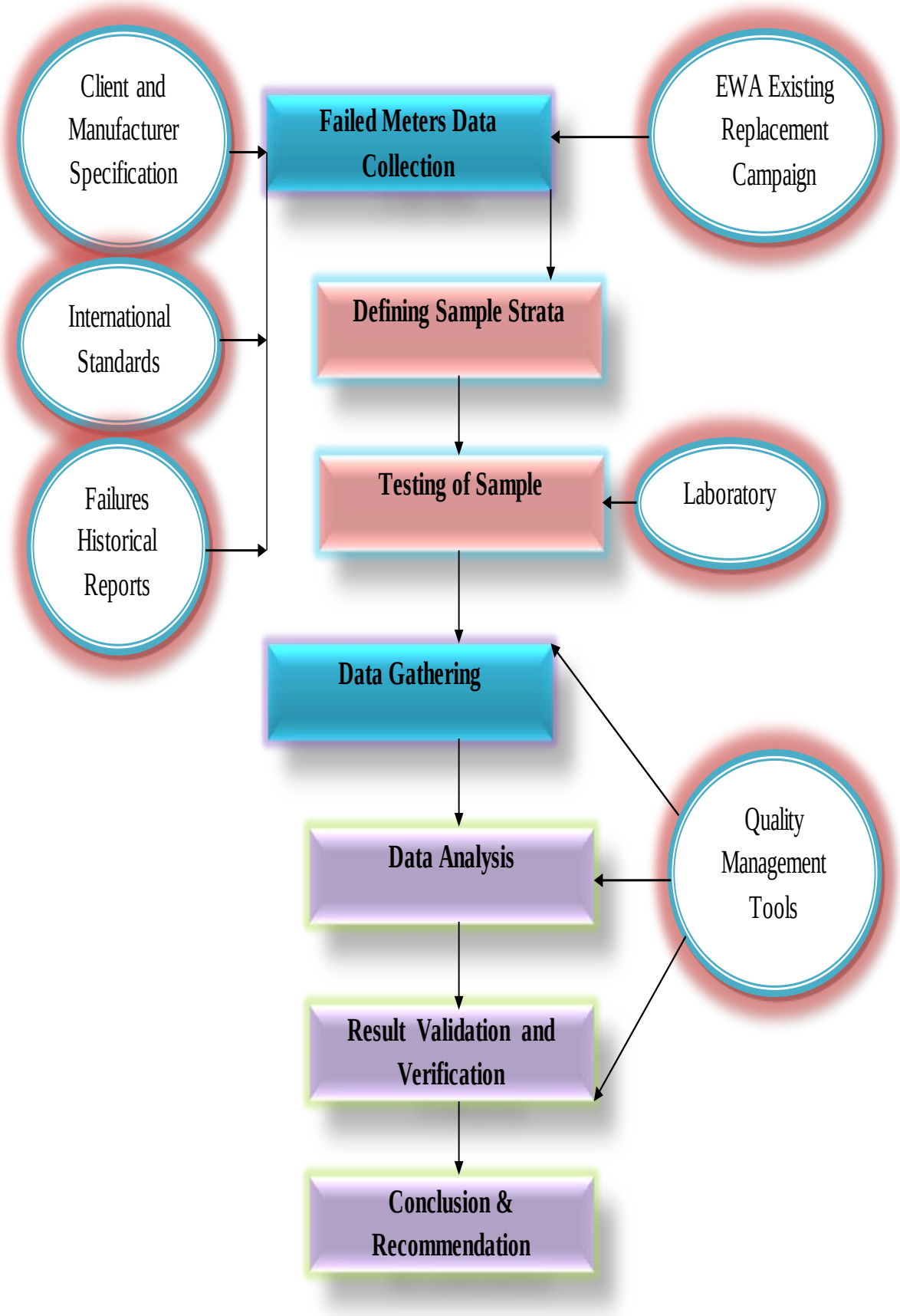


Figure 1-B: Research Methodology Process

1.6 Research Data Collection

Since this study will be based on the analysis of statistical data and testing results, multiple data of failed meters from most severe areas for this analysis such as:

1. Meter accuracy tests with low, medium and high flow for meters removed from system regardless of service life.
2. Operation flow rate.
3. Percentage of each customer consumption.
4. Nominal replacement cost.
5. Water quality in tank / area wise.
6. Water network pressure.
7. Network components and age.

Chapter 2. Literature Review

2.1 Background

Non-Revenue Water (NRW) has a simple precise definition. It is the difference between the volume of water pumped into water distribution system and the volume billed to consumers. NRW comprises of three components as follows, (Frauendorfer & Liemberger, 2010):

- Physical (or real) losses which are due to leakages in all parts of the water supply system. This could be caused by poor operation and maintenance, lack of active leakage control and poor quality of underground assets.
- Commercial (or apparent) losses are caused by under registration of consumer meters, data handling errors and illegal use of water in various forms including theft.
- Unbilled authorized consumption include the water that is used by the utility for operational purposes, water used for firefighting and water provided free for certain consumer groups.

2.2 Commercial Losses

Commercial losses are nearly always less in volume than physical losses, but this does not mean that commercial loss reduction is of less important. Commercial loss reduction has the shortest possible payback time, as any action immediately results in an increase in billed volume and an increase in revenues. Minimizing customer meter under-registration requires substantial technical expertise, managerial skills, and upfront funding. Customer meter management should be undertaken holistically, best described by the term ”IMM”, (Frauendorfer & Liemberger, 2010).

Water utilities face various challenges throughout the world. Those challenges are the issues of water loss accountability and subsequent revenue recovery due to meter accuracy, (Mutikanga, 2012).

2.3 Water Meters Basis

The water meter is a device used to measure the volume of water sold to the consumers. Water meter serve as both yardstick and cash register for water-conscious modern water utilities. Besides providing information on water usage, which is the basis for water user fees, water meter helps to determine potential losses in the system, (Davis, 2005).

In order to understand the field of water metering, it is important to start with the following basics, (Zyl, 2011).

- The classes of water meters that are used to classify water meters in terms of their performance.
- Water meter types and what components it consists of. While many different types of meters are available, they all have the same basic components.
- Legislation and standards that water meters typically have to comply with.
- Water Meter Metrology. Metrology deals with water meter accuracy, including the definition of terms and standards.

2.4 Water Meter Classes

The International Standards ISO 4064 (2005) provides a generic definition of this accuracy envelope from the minimum flow rate (q_{min}) up to their maximum or overload flow rate (q_s) for various metrological classes of water meters, (Johnson, 2001). Meter classes are used to classify meters according to their accuracy performance. Conventionally, four classes of meters are defined and

denoted by the letters A, B, C and D. The accuracy requirements are the same for all four classes, namely a maximum permissible error of 5% in the lower flow zone and 2% in the upper flow zone. The difference between the classes lies in how high the transitional and minimum flow rates are allowed to be in relation to the permanent flow rate. Class A has the lowest performance and class D the highest performance.

Conventional meter standards are being replaced in many countries by new standards that use a completely different approach for defining meter classes. However, the conventional standards will still be in use for many years even in those countries that adopt the new standards, (Zyl, 2011).

2.5 Water Meter Types

Water meters are generally classified based on the mechanism used by the meter to measure the flow passing through it, (Zyl, 2011).

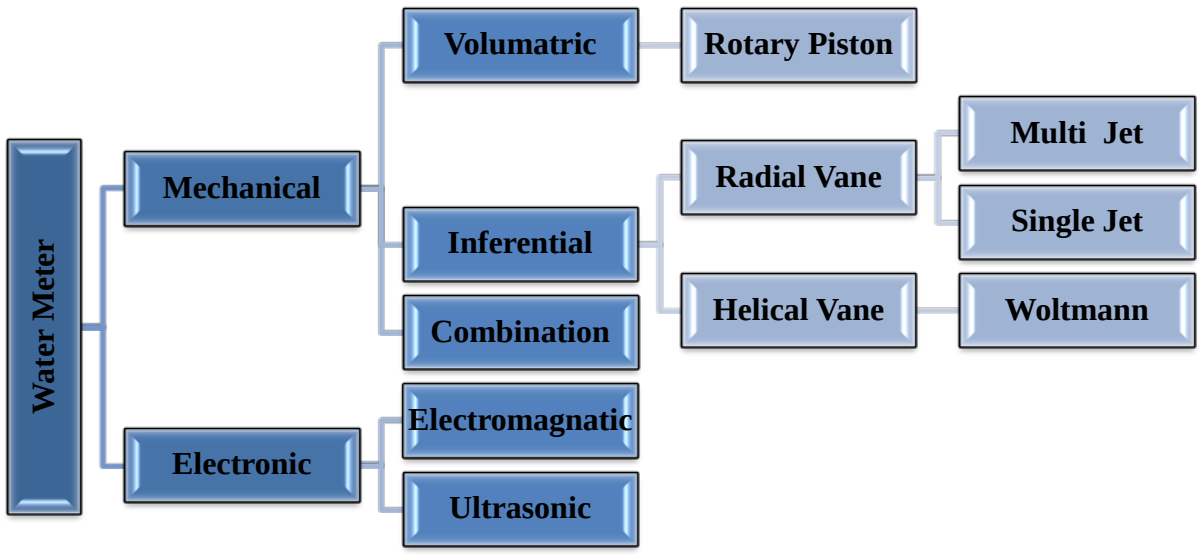


Figure 2-A: Classification of Water Meters

2.5.1 Mechanical Water Meter

Mechanical metering dominates the world water meter market with a share of 90-95%. Mechanical metering is divided into two categories; domestic (residential) and bulk (transmission, distribution large industrial) metering. In business revenue, the domestic segment represents 65-70% of the market and the bulk segment 30-35%. In units, the proportion is far higher for domestic and small commercial meters. Domestic meters are priced considerably lower in the large annual tenders issued by utilities, than the same meters, which are priced in small purchase volumes.

Class C (Class D in the United Kingdom) volumetric domestic water metering is used in the US, UK, France, Portugal, Taiwan and several other countries who have followed the British method are: Australia, Hong Kong and Cyprus. All other countries use Class A or B domestic velocity meters, single jet and multi jet, (ABS Energy Research, 2010).

2.5.1.1 Volumetric Meter (Rotary Piston)

Rotary piston meters are positive displacement meters that use a rotating cylindrical piston to measure ‘packets’ of water moving from the inlet to the outlet of the meter.

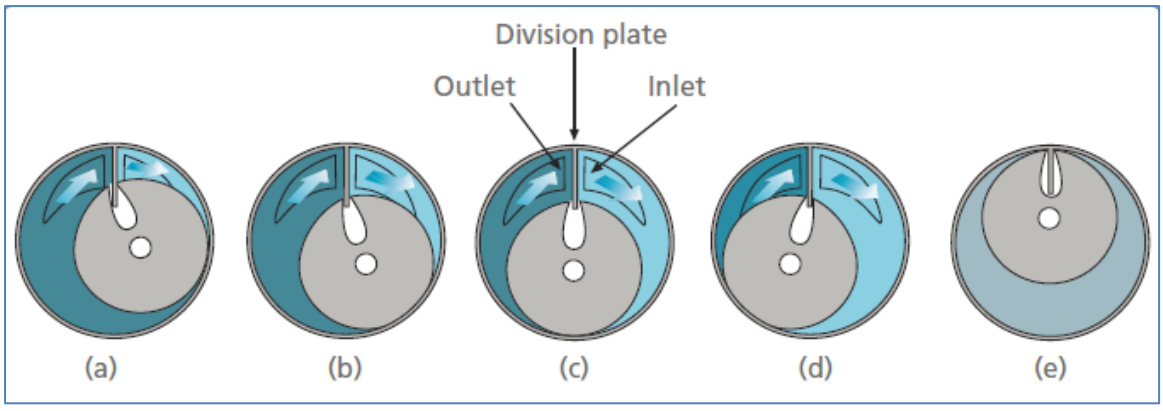


Figure 2-B: A simplified illustration of the mechanism of rotary piston meter

It is significant to note that plastic body meters have to be installed in chambers to protect them from direct sun light. Rotating piston meters are sensitive to sand or other suspended solids in the water that can be stuck between the piston and chamber wall, jamming the meter. Thus, it is important that these meters should only be installed in systems with very good water quality, and they should always be provided with built-in strainers.

A rotating piston meter in good working order is highly accurate, and it is the only type of domestic water meter available in Class D. These meters are very sensitive to low flows and are especially suitable for applications where low flow rates or on-site leakage frequently occur, such as domestic consumers. The accuracy of rotating piston meters dependent on waters not leaking through the piston from the inlet to the outlet compartment. It is therefore important that they are manufactured with strict tolerances.

As the rotary piston meters get age and wear with usage, water is possible to leak through the piston more easily, and thus the meters tend to become under register. If air is forced through the meter, the reading error can occur quite severe and the wear and tear on the moving parts of the meter can be increased substantially. It is recommended that an air valve is installed at an elevated point upstream of the meter to remove air from the system, (Zyl, 2011).

2.6 Key Factors affecting Water Meter Performance.

Nowadays there is a general lack of information, based on real data, about the actual effect of different parameters of the performance of water meters. Hence, technical staff in the water utility has to evaluate or estimate water meter accuracy, and analyze the factors that may have any influence on it, (Francisco et al., 2005).

It is not simple to generalize the deterioration of water meter accuracy with age since this depends on many factors, including the meter model, type of meter, water quality and characteristics of the water consumption pattern, (Zyl, 2011).

2.6.1 Water Quality

Volumetric water meters are insensitive to many of the influence factors that affect velocity meters. However, water quality and suspended particles greatly degrade the water meter accuracy curve and in some cases produce a definitive blockage of the meter, (Couvelis and Zyl, 2015).

2.6.2 Operation Pressure

By increasing residual pressure at the property master meter from 5 m to 20 m, the water under-registration (metering error) dropped to − 4%, implying that the sub-meters were actually over-registering by 4%. This confirmed the earlier assumption of over-registration for properties with booster pumps. This makes sense based on the analogy of pressure-leakage flow rate relationships used to minimize leakage in water distribution networks, (Thornton et al., 2008).

The pressure level of the network is not generally included amongst the causes affecting metrological performance, but such a factor is especially important for systems that include private tanks because the rate that water flows into these tanks is driven in part by network pressure and not only by user demand, (Fontanazza et al., 2013).

2.6.3 Consumption Flow Rate

Water consumption, expressed as a percentage of the total volume, is plotted against the flow rate at which it is consumed. This is usually called water consumption profile of a user and provides information on the percentage of

water consumed within each flow rate range. In statistical terms, it can be defined as the density function of water consumption with respect the consumption flow rate, (Bowen et al., 1991).

Water meters are subject to intrinsic systemic error depending on the actual flow rates pass through them. Furthermore, the moving parts of the meter are subject to wear and tear that progressively reduces meter accuracy. The increase in systemic error is especially evident at low flow rates because of growing friction in the rotating mechanism, which requires a higher flow to start the meter (starting flow), (Fontanazza et al., 2013).

Volumetric water meters having higher degradation rates with meter flow reading passing through the meter. Meter readings are also found to be better indicators for determining error degradation in both cases than meter age, (Ncube et al., 2015).

2.6.4 Selection and Installation

The selection of a water meter for a required duty is complex and the consequences of an incorrect selection are loss of performance, time and money, (BS 7405, 1991).

An incorrect mounting position of the water meter increases the friction of the moving parts. The effect is only noticeable at low flows for which this term is relevant in the effective drag torque. Another important consideration about the mounting position is that if it is not correct, according to the manufacturer recommendations, it may lead to a higher degradation rate of the meter.

The reason is that in such cases the moving parts or the meter are not working and standing properly, (Francisco et al., 2005).

2.6.5 Operation Life

It is now widely acknowledged that mechanical water meter's metrology becomes more and more inaccurate during their operating life due to 'wear and tear' of the measuring components, (Francisco et al., 2005 & Male et al., 1985).

Nominally, most water utilities have used a range of service between 10 and 20 years for meter replacement due to the perception of decreasing meter accuracy with length of service, (Davis, 2005).

2.6.6 Ambient Temperature

Meters installed outdoors are subject to extreme weather conditions. High temperatures may deteriorate plastic components and even deform them. On the other hand, low temperatures, below freezing, may increase the pressure inside the meter above the maximum allowable value, (Francisco et al., 2005).

2.7 Commentary in Literature Review

2.7.1 General

The water meter is an essential tool for effective utility revenue generation, equitable customer billing, water demand management, and generation data for network planning and management, when metering is inefficient, benefits associated with meter are reduced, (Mutikanga et al., 2011).

Water Meters one of most contributors in water apparent losses, while in many development countries water meters are used to measure the volume of water used by customer, which may hence considerable measuring limitations, (Couvelis and Zyl, 2015).

As elaborated in above literature reviews that, the water meter performance has badly effected by environmental and operational conditions. Such as water quality, pressure, temperature, metrology technology, installation and consumption Pattern, (Francisco et al., 2006 & Male et al., 1985), (Francisco et al, 2005), (Davis, 2005), (Johnson, 2001), (Bowen et al., 1991), (Fontanazza et al., 2013), (Mutikanga, 2012) and (Couvelis and Zyl, 2015).

2.7.2 Literature Review Summary

Table 2-1: Literature Review Summary

Subject	Finding	Reference
The Issues and Challenges of Reducing Non-Revenue Water.	Authors have highlighted the importance of NRW management as reflect water utilities performance and identified the NRW main elements and their impact in utility revenue.	Frauendorfer, & Liemberger, 2010
Water Loss Management tools and methods for developing countries.	Author has highlighted the importance of managing the level of NRW via develop a suite of appropriate tools, methodologies and recommendations to sustainably reduce water losses and improve urban water distribution system efficiency such as: • Performance assessment system for evaluating and improving water distribution system efficiency. • Integrated water meter management model to help address the problem of metering inefficiencies and improve utility revenues.	Mutikanga, 2012

Subject	Finding	Reference
	• Methodology for assessing apparent water losses in urban water distribution systems. • Pressure management planning decision support tool for leakage control. • Integrated MCDA framework methodology for evaluating and prioritizing water loss reduction strategy options.	
Residential Water Meter Replacement Economics.	Study has intended to analyze revenue loss in water utilities due to customer meter inaccuracy and due to meter service life. This paper clearly demonstrates that cumulative flow volume of the meter combined with the percentage of average water used by residential customers at low flow levels within the District is the driving factor for meter replacement.	Davis, 2005

Subject	Finding	Reference
Introduction to integrated water meter management.	This book covers all aspects of water meters and water metering in water utilities. It covers the theoretical principles of meters, legal and metrological requirements, meter types, best practice guidelines as well as practical aspects of water meter management (amongst others). It is anticipated that this book will serve as a training aid and a valuable tool for water utility managers, engineering technical staff, operations and maintenance, meter reading personnel and researchers.	Zyl, 2011
Optimal water meter selection system.	Study focus in comparison between particular meter accuracy envelope and a consumer's water demand/usage profile. Study elaborate that through weighted accuracies play a pivotal role in these comparisons with a common reference. Economic/financial analysis has been intended based on an income statement together with capital budgeting techniques assists in determining the financial suitability of the proposed investment in the replacement meter and its installation. Moreover, a sensitivity analysis	Johnson, 2001

Subject	Finding	Reference
	facilitated the identification of which variables influence the economic viability of installing a new water meter. Study concludes that the incorrect matching of a particular water meter performance with the demand characteristics of a consumer can result in the loss of revenue to a water authority.	
Key Factors Affecting Water Meter Accuracy.	Study is intended to highlight parameters that affect water meters accuracy and common problem registering non-domestic water meters. For domestic water meters, the following parameters are reviewed: mounting position, fatigue tests, depositions, partial blockage of the strainer or the water meter inlet and the presence of user's storage tanks. On the other hand, the main parameters that need to be taken into account when measuring non domestic users are velocity profile distortions that can modify the accuracy curve of the meter and meter sizing procedures.	Francisco et al., 2005

Subject	Finding	Reference
Apparent losses due to domestic water meter under-registration in South Africa.	Study are intended to estimate the extent of apparent losses due to water meter under-registration for middle- to high-income domestic consumers in South Africa. The approach of the study was to combine estimates of new meter under-registration due to on-site leakage and meter under- registration due to aging. The study concluded that apparent losses due to water meter under-registration are around 5% of consumption for domestic consumers.	Couvelis and Zyl, 2015
Water Loss Control.	Water Loss Control is a comprehensive guide to water auditing and hand-on reduction of water and revenue losses in water utility operations and management. The goal of the authors was to provide information on important innovations and technologies that have been developed water supply system such as: Climate issues, growing populations and deteriorating water supply infrastructure are exerting unprecedented pressure on water resources throughout the world. The book provides valuable information for water utility managers to select the correct tools and methodology for the water and revenue losses	Thornton et al., 2008

Subject	Finding	Reference
	encountered in their operations. The emphasis of the book is to promote the use of effective water loss control methods and tools as a cost-efficient means of controlling unchecked losses in water utilities.	
Effects of network pressure on water meter under registration.	The aim of this paper is to experimentally investigate metering error in an attempt to find a direct link between meter age, network pressure and apparent losses. The results of the laboratory experiments show that ageing and pressure are both relevant parameters for determining meter starting flow. The results are useful for understanding the effects of operating conditions on water meter under-registration, which can aid water managers in implementing effective replacement campaigns.	Fontanazza et al., 2013

Chapter 3. Research Methodology and Data Collection

3.1 Background

In this chapter, the research methodology techniques are introduced. Besides that procedure of collecting and investigating data of water meter failures for period of five years (2011-2015) is described in respect with failure phenomena rate, failure phenomena area of concentration and failure phenomena influence parameters.

3.2 Research Methodology

As discussed in Chapter 1, a quantitative research method is used to identify the merit of order behind the failure phenomena of water meter. It will be illustrated through data collection and analyzing via utilization and implementation of Quality Control Tools such as:

a. Histogram;

Histogram is a helpful tool, which visually represent the frequency of data related to a quality problem. Moreover, histogram provides the easiest way to evaluate the distribution of data, (**Russell and Taylor, 2011**).

b. Pareto Chart;

Pareto Chart is a method of identifying the causes of poor quality; it was devised in the earliest of 1950s. Pareto analysis can be applied by tallying the number of defects for each of the different possible causes of poor quality in a product or service and then developing a frequency distribution from the data. This frequency distribution, referred to as a Pareto diagram, is a useful visual aid for focusing on major quality problems, (**Russell and Taylor, 2011**). Thus, Pareto Chart will be used to visualize accumulation percentage of water meter defect frequency.

c. Fault Tree Analysis (FTA);

FTA method is primary a qualitative analysis can be pursued in a quantitative analysis expressing the probability of production of the top event or any other event in between. (**Rodica, 2014**)

P (A) = P (B) + P (C) + P (D) + P (E) + …P (n) **(Equation 3-1)**

Where;

P (A) = probability of the top event
P (B) - P(n) = probability of primary and secondary events

Quantitative assessment of probabilistic faults' tree based on determining the probability of producing top event, taking into account the probability of the event based in the fault tree. Fault Tree Method is done in four phases namely;

1. Identify the event/top event to be analyzed.
2. Identify events that contribute to the top event.
3. Build the fault Tree of the system using symbols.
4. Quantitative and qualitative assessment of fault tree based on data obtained in the graphic construction, using calculation to evaluate system reliability, (**Rodica, 2014**).

FTA model for the study of the foreseeable reliability of the complex devices such as water meter is based on the idea that the failure can be quantified at structural level so that any defect in the device is the result of a sequence of measured states of the fault. FTA method is based on binary logic to assess the probability of failure that use the properties of the logical gates AND, OR and NOT, (**Rodica, 2014**).

- OR Gate

Represent the union of events at the gate. For event Q with two input events A and B attached to the OR gate, the probability is obtained as;

$$P(Q) = P(A) + P(B) - P(A \cap B) \quad \textbf{(Equation 3-2)}$$

or

$$P(Q) = P(A) + P(B) - P(A)\,P(B|A) \quad \textbf{(Equation 3-3)}$$

If A and B are mutually exclusive events then $P(A \cap B) = 0$

$$P(Q) = P(A) + P(B) \quad \textbf{(Equation 3-4)}$$

If A and B are independent events then $P(B \mid A) = P(B)$

$$P(Q) = P(A) + P(B) - P(A)\,P(B) \quad \textbf{(Equation 3-5)}$$

If event B is completely dependent on event A then $P(B \mid A) = 1$

$$P(Q) = P(A) + P(B) - P(A)\backslash(1) = P(B) \quad \textbf{(Equation 3-6)}$$

Therefore, the approximation of

$$P(Q) = P(A) + P(B) \quad \textbf{(Equation 3-7)}$$

Always a conservative estimate for the probability of event Q because $P(A \cap B)$ is small compared with $P(A) + P(B)$ for very low probability events. Event Q will occur if any (at least) one of the input events to the OR gate occurs.

- AND Gate

Represents the intersection of events at the gate. For event Q with two input events A and B attached to the AND gate, the probability is obtained as;

$$P(Q) = P(A)\,P(B \mid A) = P(B)\,P(A \mid B) \quad \textbf{(Equation 3-8)}$$

If A and B are independent events then $P(B \mid A) = P(B)$ and $P(A \mid B) = P(A)$;

$$P(Q) = P(A)\,P(B) \quad \textbf{(Equation 3-9)}$$

If A and B are not independent, then Q may be significantly greater than P(A) P(B).

- NOT Gate

Represent that events at the gate not occur. For event Q with the NOT gate, the probability is obtained as

P (Q) = 1- P'(Q) **(Equation 3-10)**

d. Cause and Effect Diagram (CED);

Cause and Effect Diagram (CED) or Fish bone Diagram is a tool / technique used to analyze possible causes of a specific problem or condition, (**Russell and Taylor, 2011**).

Basically CED used to investigate a problem, exploring, identifying, and displaying the possible causes. Then it can be used to identify the relationship between the effects in a given situation and all of the possible causes in order to find problem sources/solutions.

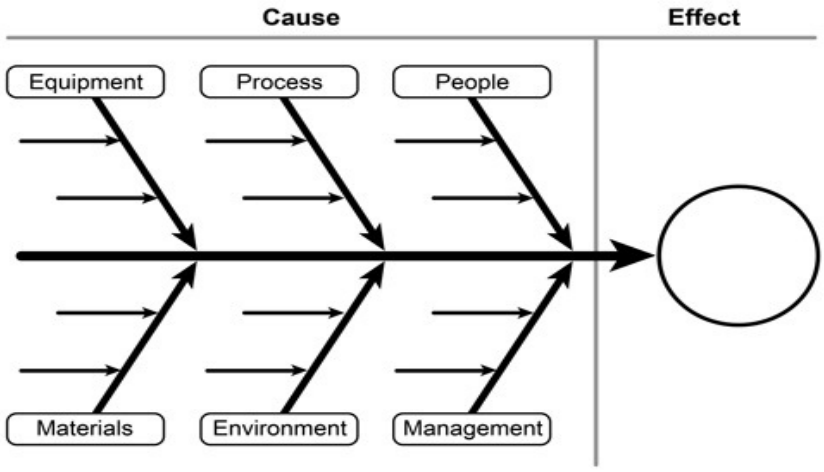


Figure 3-A: CED - Cause and Effect Diagram Template

Figure 3-A shows CED template, consists of Causes and Effects of the main problems, usually grouped into major categories to identify these sources of variation. The categories typically include:

People: Those involved with water meter process (client, user and manufacturer).

Methods: How the water meter process is performed and the specific requirements for doing it, such as policies, procedures, rules, regulations and laws.

Machines: Any requirement of equipment, tools and computers etc., required to test, install, remove and inspect the water meter.

Materials: Raw material requirement for manufacture body parts, internal components, needles and pens etc.. for the water meter.

Measurements: Data generated from the water meter that are used to evaluate meter quality; water volume flow rate.

Environment: Operating conditions of water meter such as; location, pressure, flow rate, time, temperature, and culture in which the meter operates.

Management: the individuals who set the strategy, policies of the organization and coordinate the efforts of employees to accomplish objectives by using available human, financial and other resources efficiently and effectively.

3.3 Failed Meter Data Collection

3.3.1 Water System Operation Characteristics

In 1957, the water supply network was inaugurated to benefit some 3,000 houses depending on natural freshwater springs.

Nowadays in Bahrain, EWA water distribution system feed via 81% MSF and MED Desalinated potable water from HPC and ADPWC and 19% Blended

Water (1.5% Ground Water and 17.5 % RO / MSF Desalinated Water from Ras Abu Jarjur RO Desalination Plant, ALBA and Sitra Power Station).

Through the influence of gravitational force, water is supplied to distribution network with fluctuating pressure range. The reason for that is to maintain, sustain and balance water supply during restricted and peak times of the day.

Moreover, Chart 3-1 shows pressure fluctuation of water supply tanks, which depend on the number of customer, quantity of supplied water and geographical nature of supplied area.

Twenty nine water storage stations distribute all over The Kingdom of Bahrain supplying water through water distribution network to EWA customers..

Water Distribution Network consists of the combination of two piping systems viz. main and sub-main network. The main network has been constructed from AC or DI pipes with DI fittings while sub-main network is constructed from polyethylene pipes and related fittings. Such complex combination of water production system, transmission and distribution systems (operation / environmental parameter) can be valid factor in increasing the water meter failure phenomena. The details of Bahrain Water Network Map are given in Appendix B.

3.3.2 Failure Phenomena

Five years (2011-2015) data of defective water meters have been collected, and reported yearly by EWA in relation to volumetric domestic water meter.

An average of 12% of water meters over last five years was failed more frequently in less than five years due several operational issues.

Such rate of water meter failure has been clearly indicated in year 2015 which led EWA to investigate the failure phenomena causes. The details are reported in Appendix C.

Table 3-1: Water Distribution Network Pressure

No.	Tank	Pressure (bar)		No. of Connections.
		High	Low	
1	Al Areen	1.0	1.0	38
2	BFH	1.3	1.0	801
3	Bokowa	1.2	0.8	3,367
4	Budaiya	1.4	0.9	6,641
5	Durat Al Bahrain	2.3	2.3	909
6	East Riffa	2.2	2.2	8,676
7	Hidd	1.9	1.0	7,874
8	Hoora	1.5	0.8	5,149
9	HTBG	1.0	0.8	9,185
10	HTBT	1.8	1.0	5,045
11	HTDG	0.8	0.8	5,588
12	Isa Town- East	1.5	0.8	5,091
13	Isa Town- R\R	1.8	1.8	3,894
14	Isa Town- West	1.5	0.8	7,705
15	Jannusan	2.8	1.0	4,242
16	Mahooz	2.5	2.5	4,806
17	Mmuharraq 'C'	1.9	1.0	9,108
18	Mussalla	1.1	0.8	4,968
19	North Muharraq	2.0	1.2	5,002
20	Saar	2.9	2.0	4,591
21	Salmaniya	1.5	1.0	7,261
22	Samahij	1.4	0.8	6,115
23	Sanabis	1.6	1.0	4,964
24	Sitra	1.4	0.8	4,468
25	SKBS	2.1	1.8	168
26	South Alba	2.8	2.8	1,451
27	Toubli	1.1	0.8	3,497
28	West Rifaa	1.9	0.9	3,107
29	WRBG	1.9	0.9	4,114
Average Pressure		1.7	1.2	

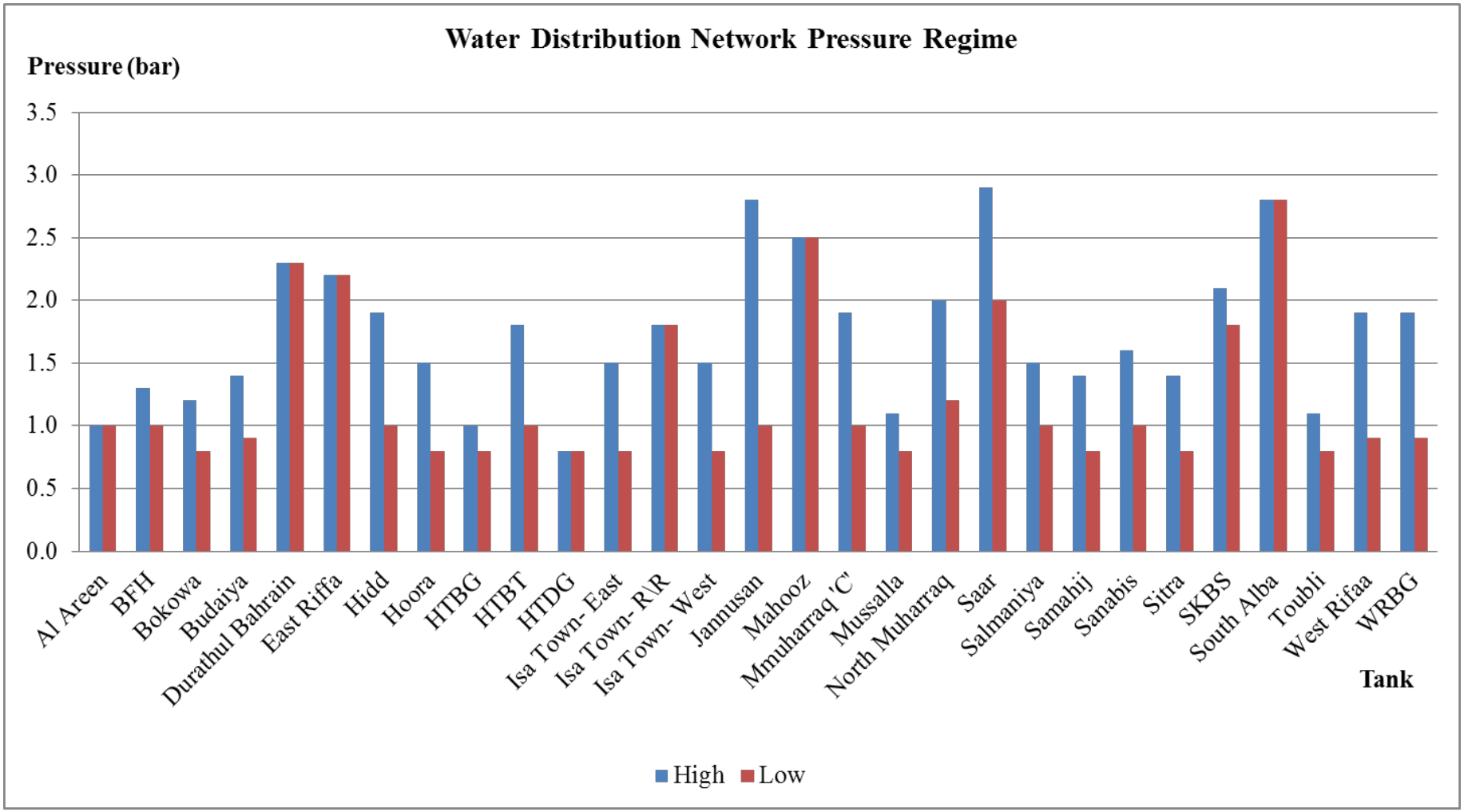


Chart 3-1: Water Distribution Network Pressure Regime

3.3.3 Volumetric Water Meter Characteristics

Volumetric Water Meter is most often used in residential and small commercial applications; the device has been introduced officially in EWA water system since 1998 as an upgrade version of velocity type water meter.

Volumetric water meter (rotating piston meter) is popular for their combination of accuracy and moderate cost, and are the meter of choice for most domestic applications. Rotating piston meter is sensitive to sand or other suspended solids in the water that can get stuck between the piston and chamber wall. It is highly accurate; the only type of domestic water meter available in Class D. The accuracy of rotating piston meters is dependent on water not leaking through the piston from the inlet to the outlet compartment. As it get aged and wear through usage, it is possible to leak through the piston more easily, and thus the meters tend to under register with age. The metering error can be quite significant and the wear on the moving parts of the meter is increased substantially, **(Zyl, 2011)**.

3.3.4 Manufacturer Specification

The manufacturer provides the users with performance specifications of the volumetric water meter which include the minimum and maximum measurable flow rate, operating pressure, and temperature range, maximum allowable material viscosity, meter body size, connection size, and meter accuracy class.

The meter housing and internal components are typically made from plastic. It is important to note that plastic body meters have to be installed in safe custody to protect them from tampering and direct sun light.

Volumetric water meters are sensitive to sand or other suspended solids in the water that can get stuck between the piston and chamber wall, which may cause meter blockage problem. Thus, it is important that these meters should only be

installed in systems with very good water quality, and they should always be provided with built-in strainers. Moreover, such meter types should have excellent sensitivity at low flow rates, and remain accurate irrespective of installation position, volumetric water meters are prone to relatively high pressure losses, and that they can be more bulky and expensive than other meter types. Figure 3-B illustrates an existing volumetric water meters in EWA network.



Figure 3-B: Volumetric Water Meter

3.3.5 EWA/WDD Specification

In order to assure the water consumption is being accounted accurately, meters need to be selected, installed, operated and maintained using generally accepted industrial standards. EWA/WDD have a comprehensive specification titled "Specification for domestic water meters S-4419-F", refer to **Appendix D**, based on internationally recognized standards such as ISO 4064 and OIML R49 .

The standard is clearly lays out what is expected from water meter manufacturers and suppliers in respect of meters design, construction, operational and environmental characteristics, accuracy, testing, handling and installation characteristics.

3.3.6 EWA/WDD Meters Replacement Program

Water meters tend to deteriorate with age, resulting in inaccurate readings, which impacts system audits and leak detection efforts.

Meters should be regularly calibrated and tested in accordance with the manufacturer's recommendations.

Implementation of meter replacement programs will show a decrease in apparent loss and increase in revenue, while yearly EWA replacement program cost more than (BD) 756,000.000 as illustrated in Table 3-2.

Table 3-2: (2011-2015) Average yearly Cost of EWA Replacement Program

Description	Calculations	Total Amount (BD)
Average yearly No. of replaced meter (EA)	25,200.000	
Capital Cost (BD)	12* 25,200.000	302,400.000
Associated Cost of Replacing Water meters (BD) as per EWA MTC Rate	18*25,200.000	453,600.000
Total yearly Cost of Water Meter Replacement		**756,000.000**

Furthermore in 2007 EWA/WDD has been undertaking enhanced an Automated Water Meter Replacement Program to replace the domestic water meters every five years. EWA Replacement Program manages via Customer Services Software CSS – Meter Management Module MMM, based on meter operation service life of water meter. Figure 3-C illustrates EWA Water Meter Replacement Program process.

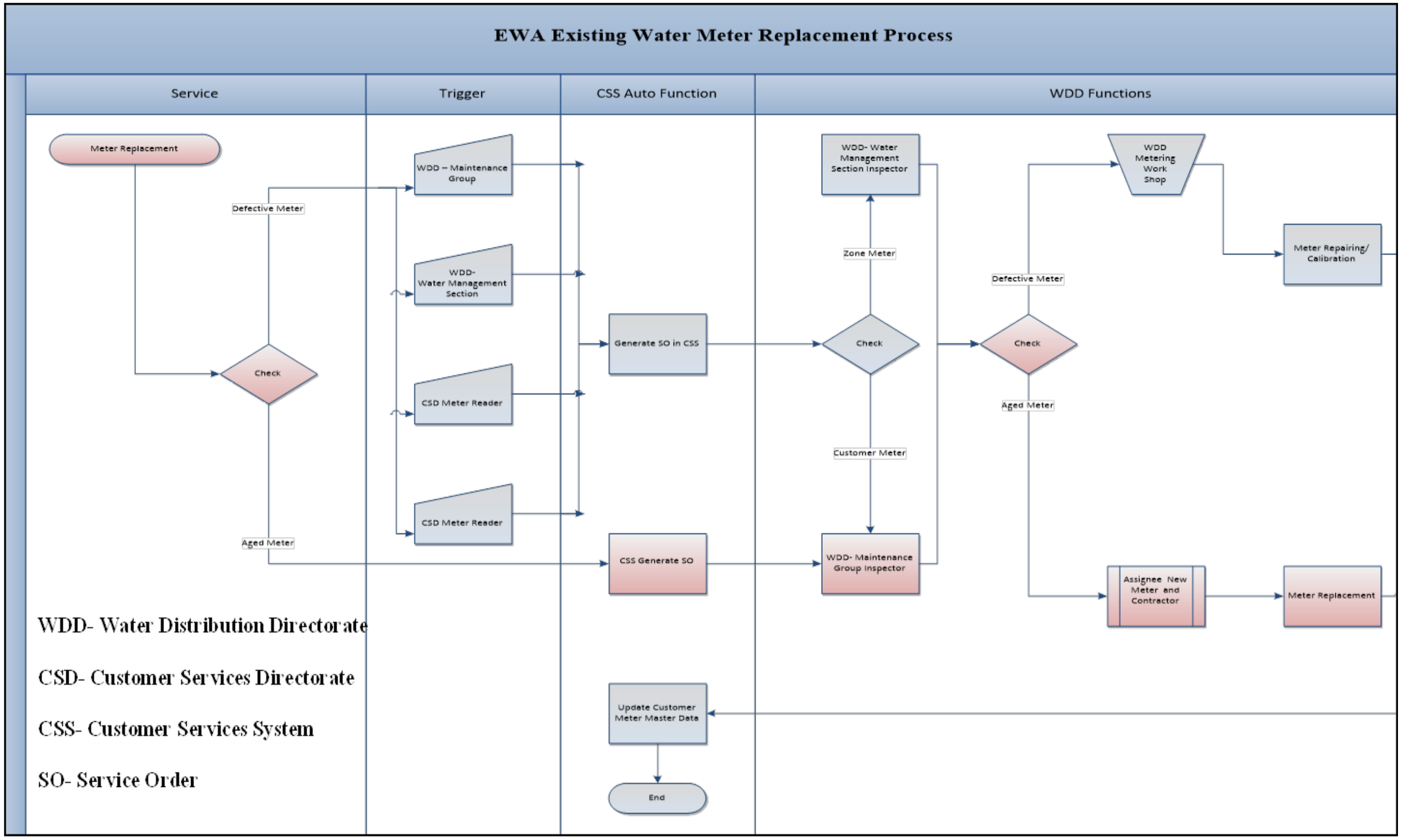


Figure 3-C: EWA Water Meter Replacement Program Process

3.4 Study Area of Investigation

Area of investigation has been selected based on deep analysis of five years collected historical data of tanks supplied area volumetric domestic water meter failures over EWA/WDD Water Network, reported in Appendix C.

The area of investigation has been carefully selected based on the most frequent average percentage defects occurrences over last five years (2011-2015) in each water distribution tank.

Table 3-3 and chart 3-3 illustrate five year data gathering and analysis of water meter failures in water distribution tanks area, which elaborated that the highest percentage average defect occurred in Salmanyia tank area.

Therefore, Salmaniya tank area has been selected as study area due to consistency of yearly defects comparing to other tank areas to ensure investigation feasibility.

Table 3-3: Yearly Water Meter Failures

Tank Name	No. of Water Connection	2011		2012		2013		2014		2015		% Average
		Defect	% Defect	Defect	% Defect	Defect	% Defect	Defect	% Defect	Defect	% Defect	
Al Areen	38	2	5%	2	5%	0	0%	1	3%	2	5%	4%
BFH	801	19	2%	51	6%	115	14%	158	20%	233	29%	14%
Bokowa	2641	292	11%	270	10%	428	16%	344	13%	486	18%	14%
Budaiya	6641	434	7%	1152	17%	1959	29%	1501	23%	1540	23%	20%
Durathul Bahrain	909	4	0%	33	4%	284	31%	307	34%	324	36%	21%
East Riffa	8676	598	7%	958	11%	1249	14%	1865	21%	2260	26%	16%
Hidd	7874	1021	13%	930	12%	948	12%	1672	21%	1764	22%	16%
Hoora	5149	309	6%	1207	23%	1455	28%	1542	30%	1680	33%	24%
HTBG	9185	706	8%	1295	14%	1194	13%	1785	19%	1760	19%	15%
HTBT	5045	319	6%	1119	22%	914	18%	1479	29%	915	18%	19%
HTDG	8470	678	8%	1220	14%	1433	17%	1869	22%	2469	29%	18%
Isa Town- East	5091	667	13%	583	11%	738	14%	750	15%	1136	22%	15%
Isa Town- R\R	3941	292	7%	437	11%	497	13%	784	20%	1244	32%	17%
Isa Town- West	7705	762	10%	1049	14%	1050	14%	1649	21%	1946	25%	17%
Jannusan	4242	326	8%	631	15%	1005	24%	890	21%	824	19%	17%
Mahooz	4806	515	11%	744	15%	885	18%	900	19%	1520	32%	19%
Mmuharraq 'C'	9108	825	9%	1942	21%	2160	24%	2192	24%	2453	27%	21%
Mussalla	4968	532	11%	686	14%	769	15%	841	17%	1073	22%	16%
North Muharraq	5002	497	10%	549	11%	579	12%	792	16%	1008	20%	14%
Saar	4591	261	6%	652	14%	1091	24%	1019	22%	1162	25%	18%
Salmaniya	7261	683	9%	1564	22%	1650	23%	2272	31%	3031	42%	25%
Samahij	6115	716	12%	429	7%	374	6%	701	11%	1095	18%	11%
Sanabis	4964	290	6%	621	13%	992	20%	777	16%	1220	25%	16%
Sitra	4468	333	7%	481	11%	727	16%	947	21%	867	19%	15%
SKBS	168	7	4%	32	19%	38	23%	53	32%	66	39%	23%
South Alba	1458	89	6%	99	7%	122	8%	158	11%	544	37%	14%
Toubli	3497	340	10%	441	13%	475	14%	494	14%	812	23%	15%
West Rifaa	3109	176	6%	517	17%	537	17%	866	28%	815	26%	19%
WRBG	4114	291	7%	626	15%	1068	26%	1012	25%	1051	26%	20%
Total	**140,037**	**11,984**	**9%**	**20,320**	**15%**	**24,736**	**18%**	**29,620**	**21%**	**35,300**	**25%**	**12%**

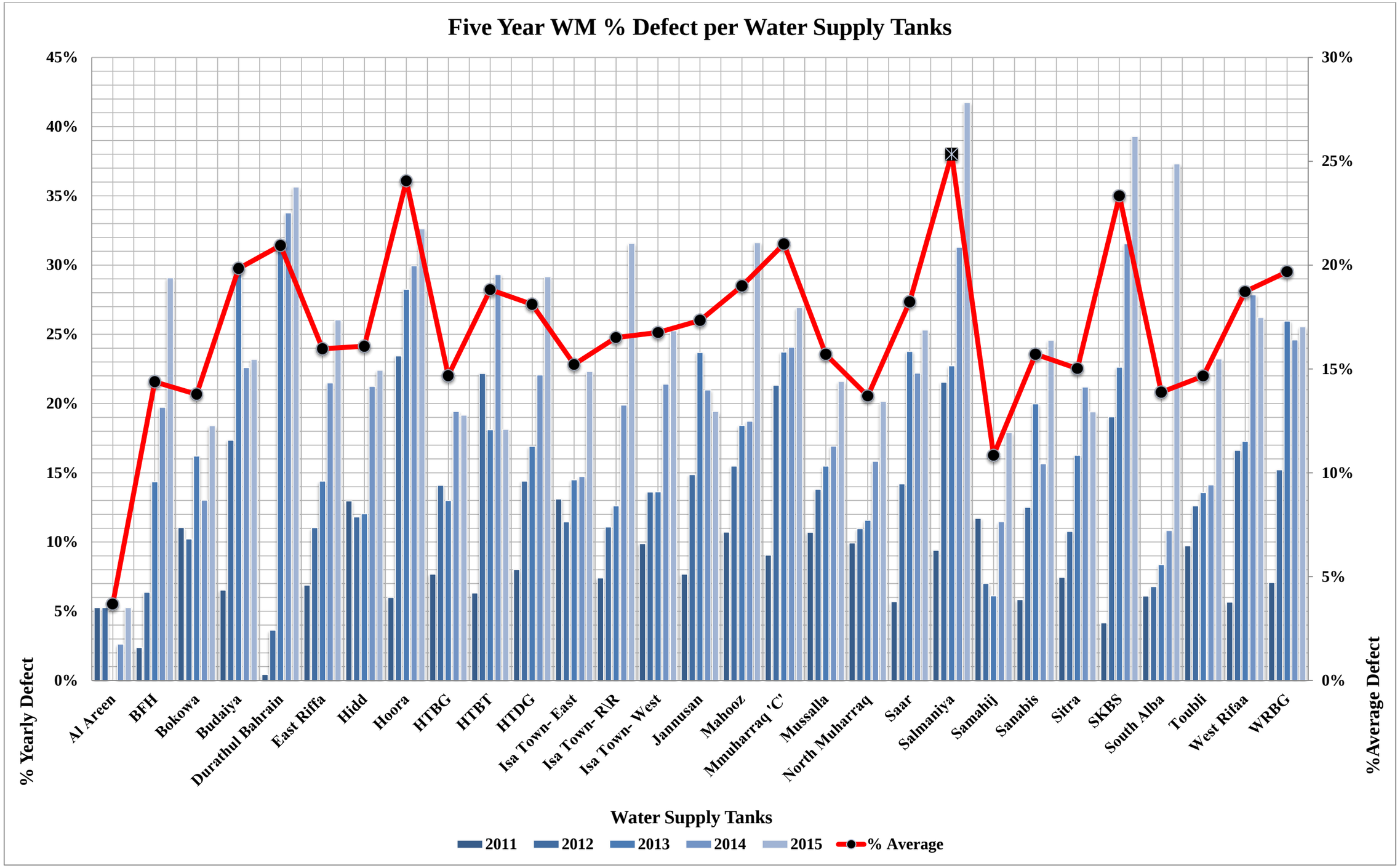


Chart 3-2: Tank wise Annual Defects Percentage of Water Meters

As demonstrated in Chart 3-3, Salmaniya tank supply area has the highest average water meter defects. Salmaniya tank supplied potable water to 7,261 domestic customers, an average of 25% (1,840) water meter failures over five years (2011-2015) with annual percentage defect increment from year 2011 due to increase in number of water connections.

Most of failures have been occurred in the year 2015 with 3,031 failures. It equals to 42% of water tank supplied to 7261 domestic customer as illustrated in Table 3-4 and Chart 3-3.

Table 3-4: Salmaniya Tank Annual Water Meter Failures

Year	2011	2012	2013	2014	2015
Defect (%)	9	22	23	31	42
Annual average (%) (2011-2015)	25				
Yearly Defect Comparison (%) relative to year 2011	0	13	14	22	33

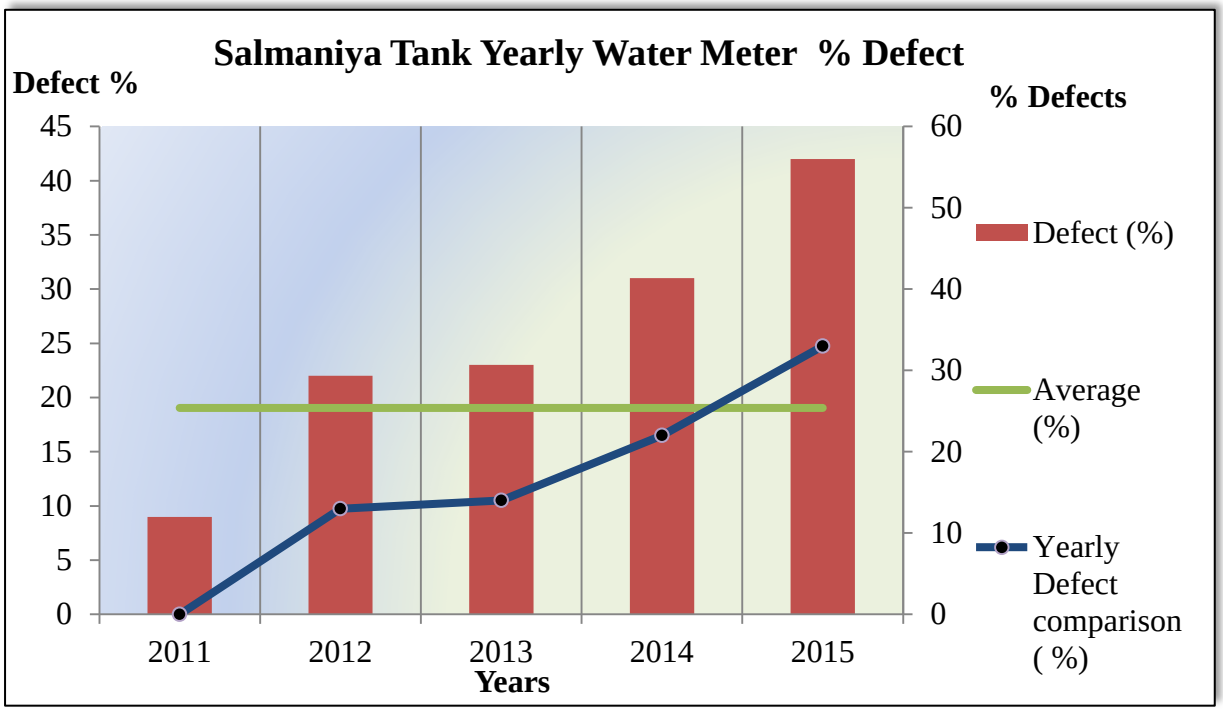


Chart 3-3: Salmaniya Tank Yearly Water Meter % Defects

3.4.1 Salmaniya Water Tank

Salmaniya storage tank was established in 1989 with storage capacity of 6 million gallons of blended water supplied from Sitra Power Station.

In 2013 EWA has signed contract to develop and rehabilitation of water transmission storage tanks, and Salmaniya storage tank has been rehabilitated to have storage capacity of 8 MG.

In the year 2015 Salmaniya storage tank feed 20 areas (blocks) containing 7,261 domestic customers in capital governorate with maximum supply pressure of 1.5 bar.



Figure 3-D: Salmaniya Water Supply Tank

3.4.2 Block 302 – Al Makarga

This study methodology has been implemented on area (block) that has the most frequent and worst domestic water meter failures. As Salmaniya water supply tank supplied potable water to several blocks.

The data collected in Table 3-5 has been clearly distinguished that block 302 – Al Maqarga area has most frequent and worst meter failures. The table below illustrate five year water meter failures data gathering and analysis of Salmaniya Tank area.

Table 3-5: Salmaniya Tank Block Wise Water Meter Failure

Tank Area	Blocks	No. of Water Connections	No. and % of Defective meters per year										% Average Defects
			2011		2012		2013		2014		2015		
Salmanyia	301	639	100	16%	125	20%	137	21%	214	33%	385	60%	30%
	302	1090	223	20%	194	18%	276	25%	358	33%	674	62%	32%
	303	502	16	3%	143	28%	130	26%	154	31%	315	63%	30%
	304	950	65	7%	239	25%	143	15%	579	61%	370	39%	29%
	307	46	4	9%	13	28%	12	26%	13	28%	20	43%	27%
	309	234	14	6%	57	24%	70	30%	75	32%	53	23%	23%
	310	72	2	3%	14	19%	13	18%	35	49%	15	21%	22%
	311	363	24	7%	112	31%	110	30%	94	26%	104	29%	24%
	312	370	31	8%	84	23%	102	28%	110	30%	136	37%	25%
	313	8	1	13%	2	25%	2	25%	3	38%	4	50%	30%
	314	411	49	12%	84	20%	122	30%	102	25%	121	29%	23%
	315	10	2	20%	2	20%	3	30%	4	40%	4	40%	30%
	327	648	53	8%	87	13%	108	17%	118	18%	188	29%	17%
	328	449	25	6%	153	34%	149	33%	109	24%	133	30%	25%
	329	254	23	9%	96	38%	106	42%	76	30%	87	34%	31%
	330	478	17	4%	70	15%	79	17%	95	20%	237	50%	21%
	331	84	7	8%	29	35%	17	20%	28	33%	19	23%	24%
	332	492	22	4%	39	8%	55	11%	72	15%	119	24%	12%
	333	44	3	7%	9	20%	3	7%	10	23%	19	43%	20%
	373	117	2	16%	12	10%	13	11%	23	20%	28	24%	13%

Table 3-6 and Chart 3-4 illustrate Block 302 percentage of annual defects, percentage of average annual defects and percentage of increase in annual defects, which shows that the peak meter defects has been occurred in the year 2015.

Table 3-6: Block 302 % of yearly Water Meter Failure

Year	2011	2012	2013	2014	2015
Defect (%)	20	18	25	33	62
Annual average (%) (2011-2015)	32				
Annual Defect Comparison (%) relative to year 2011	0	-2	5	13	42

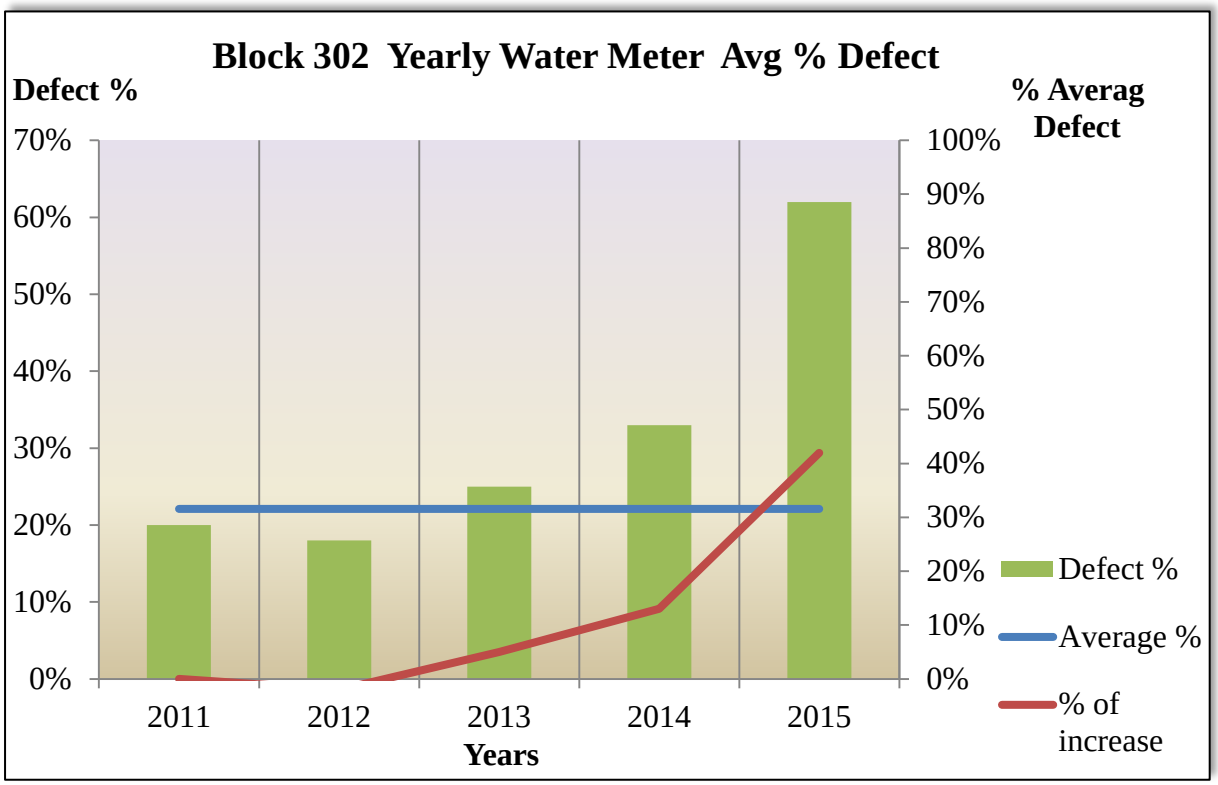


Chart 3-4: Block 302 Yearly Water Meter Average % Defect

The selected block/area where the methodology has implemented has different water supply characteristics such as network age, pipe materials, and supplied water type, figure 3-3 and table 3-2 illustrates study area features.

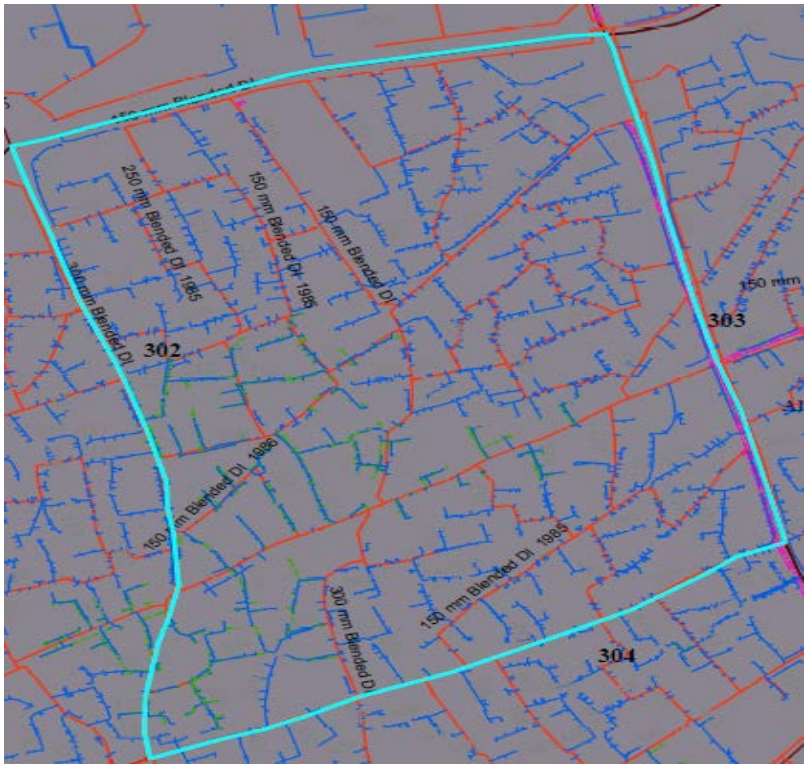


Figure 3-E: Block 302 Water Network map

Table 3-7: Block 302 Water Network Features

Main Pipes	Service Pipes	Water Type	Max. Pressure	No. of Meters	Avg. Water Meter Defects	Annual Avg.%
DI	LDPE/MDPE	Blended	1.5 bar	1,090	345	32

3.4.3 Failed Meter Sample Size and sample list

There are about 1,090 installed customer meter size 15 mm in selected study area with an average 345 failed meters annually (2011-2015), while the investigation and testing of all those meters can only be realized by defining and establishing representative samples. The methodology used in this study for sampling is implemented using Yamane Formula, (Taro, 1973).

The sample size of this study is calculated by using Taro Yamane (Yamane, 1973) formula with 86% confidence level due to huge amount of collected data from multiple sources and to maintain an acceptable sample size. The calculation formula of Taro Yamane is presented as follows;

$$n=N / (1+Ne^2) \qquad \textbf{(Equation 3-11)}$$

Where;

n = Sample size

N = Population (total number of defects)

e = error

CL = 86% due to huge amount of collected data from multiple sources and to maintain acceptable sample size.

e = 1-CL = 0.14

All Population, N = 1,725

$n=N / (1+Ne^2) = 1725/ (1+1725*0.14^2) = 50$

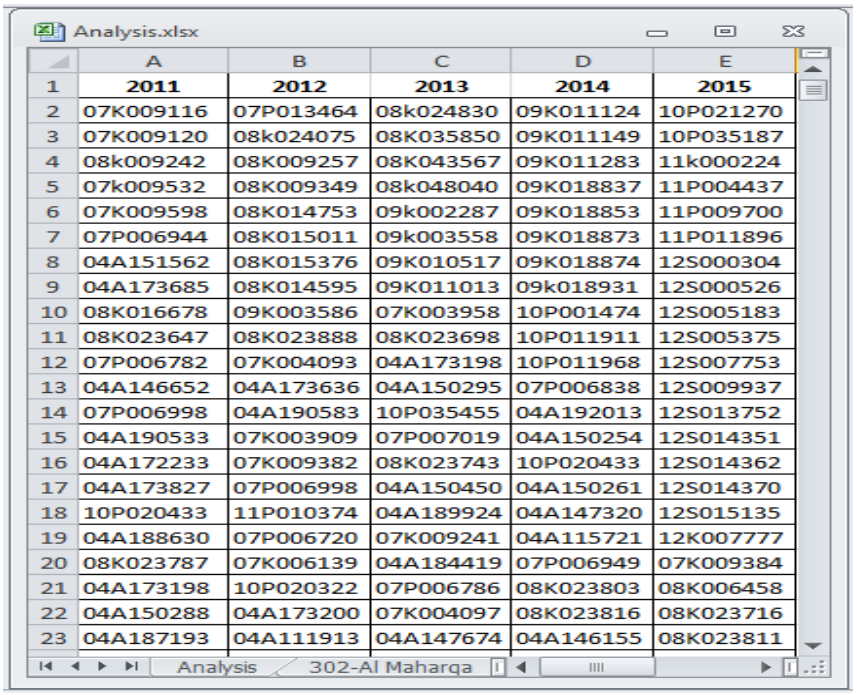
Sample Size, n= 50

Table 3-8: Sample Size of Failed Meters - Block 302

Year	Total No. of Meters	No. of Defect	Percentage	Sample Size
2011	1,090	194	11%	6
2012		223	13%	7
2013		276	16%	8
2014		358	21%	10
2015		674	39%	19
Total		1,725	100%	50

Samples have been selected randomly using excel data sheet by implementing the following steps;

1. Get your data set ready in Excel.



Analysis.xlsx

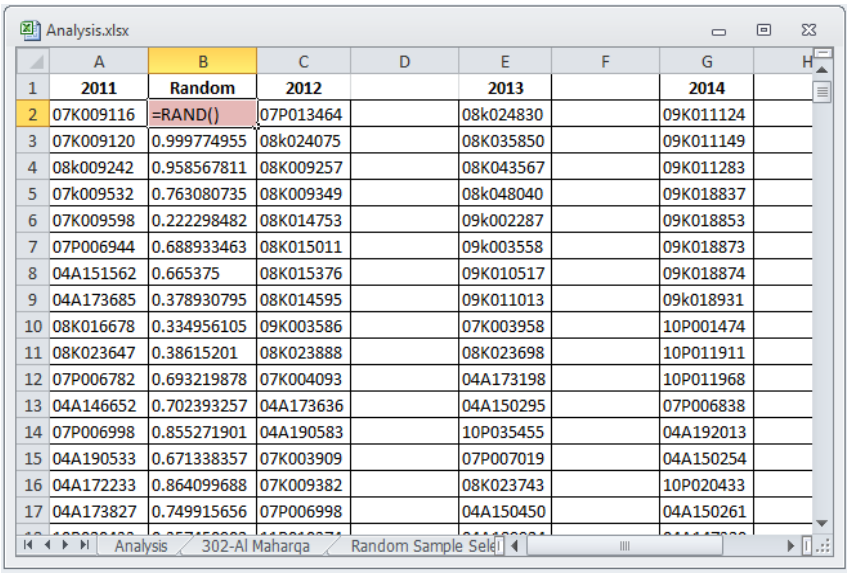
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3	07K009120	08k024075	08K035850	09K011149	10P035187
4	08k009242	08K009257	08K043567	09K011283	11k000224
5	07k009532	08K009349	08k048040	09K018837	11P004437
6	07K009598	08K014753	09k002287	09K018853	11P009700
7	07P006944	08K015011	09k003558	09K018873	11P011896
8	04A151562	08K015376	09K010517	09K018874	12S000304
9	04A173685	08K014595	09K011013	09k018931	12S000526
10	08K016678	09K003586	07K003958	10P001474	12S005183
11	08K023647	08K023888	08K023698	10P011911	12S005375
12	07P006782	07K004093	04A173198	10P011968	12S007753
13	04A146652	04A173636	04A150295	07P006838	12S009937
14	07P006998	04A190583	10P035455	04A192013	12S013752
15	04A190533	07K003909	07P007019	04A150254	12S014351
16	04A172233	07K009382	08K023743	10P020433	12S014362
17	04A173827	07P006998	04A150450	04A150261	12S014370
18	10P020433	11P010374	04A189924	04A147320	12S015135
19	04A188630	07P006720	07K009241	04A115721	12K007777
20	08K023787	07K006139	04A184419	07P006949	07K009384
21	04A173198	10P020322	07P006786	08K023803	08K006458
22	04A150288	04A173200	07K004097	08K023816	08K023716
23	04A187193	04A111913	04A147674	04A146155	08K023811

Analysis | 302-Al Maharqa

2. Insert empty column to the right of your data.

3. Type random ( ) in your empty cell.

4. Copy the random formula and paste it all the way down.



Analysis.xlsx

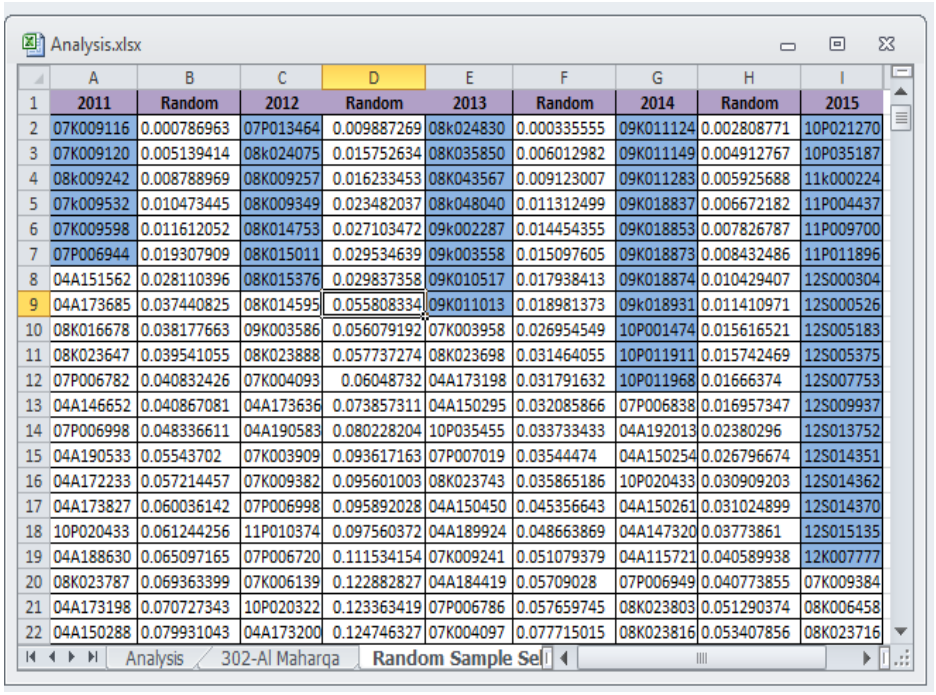
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3	07K009120	0.999774955	08k024075		08K035850		09K011149	
4	08k009242	0.958567811	08K009257		08K043567		09K011283	
5	07k009532	0.763080735	08K009349		08k048040		09K018837	
6	07K009598	0.222298482	08K014753		09k002287		09K018853	
7	07P006944	0.688933463	08K015011		09k003558		09K018873	
8	04A151562	0.665375	08K015376		09K010517		09K018874	
9	04A173685	0.378930795	08K014595		09K011013		09k018931	
10	08K016678	0.334956105	09K003586		07K003958		10P001474	
11	08K023647	0.38615201	08K023888		08K023698		10P011911	
12	07P006782	0.693219878	07K004093		04A173198		10P011968	
13	04A146652	0.702393257	04A173636		04A150295		07P006838	
14	07P006998	0.855271901	04A190583		10P035455		04A192013	
15	04A190533	0.671338357	07K003909		07P007019		04A150254	
16	04A172233	0.864099688	07K009382		08K023743		10P020433	
17	04A173827	0.749915656	07P006998		04A150450		04A150261	

Analysis | 302-Al Maharqa | Random Sample Sele

5. Highlight the whole column of random numbers.

6. Paste the random values in the B column.

7. Sort your random values, your selected data will be sorted according to sorted random value.



	A	B	C	D	E	F	G	H	I
1	2011	Random	2012	Random	2013	Random	2014	Random	2015
2	07K009116	0.000786963	07P013464	0.009887269	08k024830	0.000335555	09K011124	0.002808771	10P021270
3	07K009120	0.005139414	08k024075	0.015752634	08K035850	0.006012982	09K011149	0.004912767	10P035187
4	08k009242	0.008788969	08K009257	0.016233453	08K043567	0.009123007	09K011283	0.005925688	11k000224
5	07k009532	0.010473445	08K009349	0.023482037	08k048040	0.011312499	09K018837	0.006672182	11P004437
6	07K009598	0.011612052	08K014753	0.027103472	09k002287	0.014454355	09K018853	0.007826787	11P009700
7	07P006944	0.019307909	08K015011	0.029534639	09k003558	0.015097605	09K018873	0.008432486	11P011896
8	04A151562	0.028110396	08K015376	0.029837358	09K010517	0.017938413	09K018874	0.010429407	12S000304
9	04A173685	0.037440825	08K014595	0.055808334	09K011013	0.018981373	09k018931	0.011410971	12S000526
10	08K016678	0.038177663	09K003586	0.056079192	07K003958	0.026954549	10P001474	0.015616521	12S005183
11	08K023647	0.039541055	08K023888	0.057737274	08K023698	0.031464055	10P011911	0.015742469	12S005375
12	07P006782	0.040832426	07K004093	0.06048732	04A173198	0.031791632	10P011968	0.01666374	12S007753
13	04A146652	0.040867081	04A173636	0.073857311	04A150295	0.032085866	07P006838	0.016957347	12S009937
14	07P006998	0.048336611	04A190583	0.080228204	10P035455	0.033733433	04A192013	0.02380296	12S013752
15	04A190533	0.05543702	07K003909	0.093617163	07P007019	0.03544474	04A150254	0.026796674	12S014351
16	04A172233	0.057214457	07K009382	0.095601003	08K023743	0.035865186	10P020433	0.030909203	12S014362
17	04A173827	0.060036142	07P006998	0.095892028	04A150450	0.045356643	04A150261	0.031024899	12S014370
18	10P020433	0.061244256	11P010374	0.097560372	04A189924	0.048663869	04A147320	0.03773861	12S015135
19	04A188630	0.065097165	07P006720	0.111534154	07K009241	0.051079379	04A115721	0.040589938	12K007777
20	08K023787	0.069363399	07K006139	0.122882827	04A184419	0.05709028	07P006949	0.040773855	07K009384
21	04A173198	0.070727343	10P020322	0.123363419	07P006786	0.057659745	08K023803	0.051290374	08K006458
22	04A150288	0.079931043	04A173200	0.124746327	07K004097	0.077715015	08K023816	0.053407856	08K023716

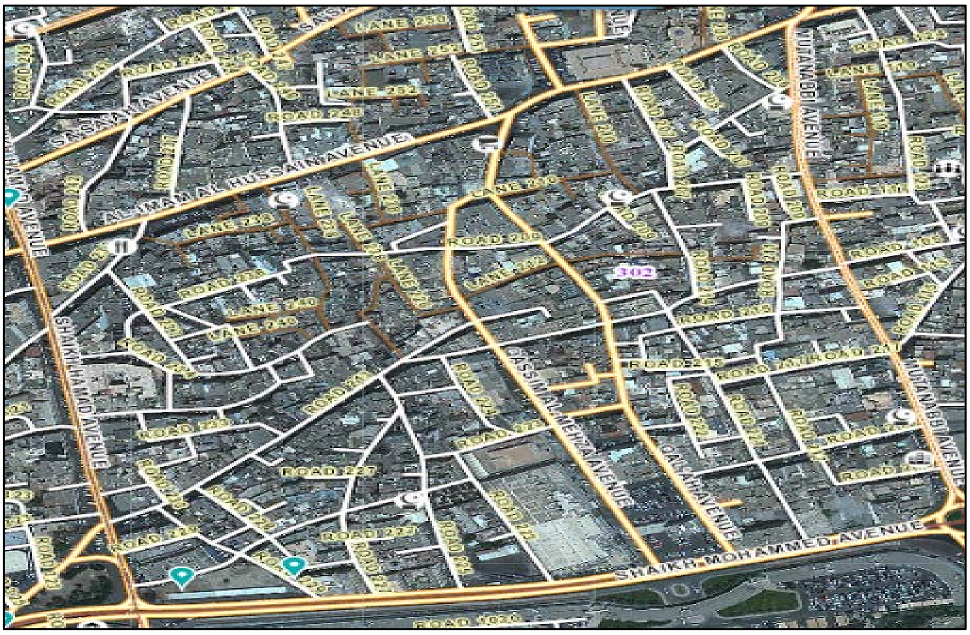
Accordingly, the randomly selected defective water meters found during the last five years in block 302 contain service point number, meter number; initial causes of defect and meter manufacturer are illustrated in table 3-9

Table 3-9: Sample Size Details of Block 302 Failed Meters

SN	Service Point No.	Meter No.	Defect Year	Defect	Manufacturer / Country or origin
1	1064083	07K009116	2011	Meter Stop	Kent - UK
2	1060897	07K009120	2011	Meter Stop	Kent - UK
3	1061132	08k009242	2011	Meter Stop	Kent - UK
4	1059462	07k009532	2011	Meter Stop	Kent - UK
5	1066572	07K009598	2011	Meter Stop	Kent - UK
6	1078719	07P006944	2011	Meter Stop	Kent - UK
7	1073472	07P013464	2012	Meter Stop	Kent - UK
8	1057888	08k024075	2012	Drop in Accuracy	Kent - UK
9	1058753	08K009257	2012	Meter Stop	Kent - UK

SN	Service Point No.	Meter No.	Defect Year	Defect	Manufacturer / Country or origin
10	1082012	08K009349	2012	Drop in Accuracy	Kent - UK
11	1059187	08K014753	2012	Drop in Accuracy	Kent - UK
12	1070779	08K015011	2012	Drop in Accuracy	Kent - UK
13	1081176	08K015376	2012	Drop in Accuracy	Kent - UK
14	1092912	08k024830	2013	Drop in Accuracy	Kent - UK
15	1070842	08K035850	2013	Meter Stop	Kent - UK
16	1057888	08K043567	2013	Drop in Accuracy	Kent - UK
17	1075474	08k048040	2013	Drop in Accuracy	Kent - UK
18	1070314	09k002287	2013	Drop in Accuracy	Kent - UK
19	1058769	09k003558	2013	Drop in Accuracy	Kent - UK
20	1062074	09K010517	2013	Drop in Accuracy	Kent - UK
21	1000166	09K011013	2013	Meter Stop	Kent - UK
22	1062614	09K011124	2014	Meter Stop	Kent - UK
23	1070435	09K011149	2014	Meter Stop	Kent - UK
24	1066592	09K011283	2014	Meter Stop	Kent - UK
25	1067773	09K018837	2014	Meter Stop	Kent - UK
26	1066482	09K018853	2014	Meter Stop	Kent - UK
27	1064800	09K018873	2014	Meter Stop	Kent - UK
28	1062908	09K018874	2014	Meter Stop	Kent - UK
29	1069120	09k018931	2014	Drop in Accuracy	Kent - UK
30	1063226	10P001474	2014	Meter Stop	Actaris - UK
31	1069923	10P011911	2014	Meter Stop	Actaris - UK
32	1059171	10P011968	2015	Meter Stop	Actaris - UK
33	1072260	10P021270	2015	Meter Stop	Actaris - UK
34	1068912	10P035187	2015	Meter Stop	Actaris - UK
35	1284219	11k000224	2015	Drop in Accuracy	Kent - UK
36	1052711	11P004437	2015	Meter Stop	Actaris - UK
37	1063270	11P009700	2015	Meter Stop	Actaris - UK
38	1071799	11P011896	2015	Meter Stop	Actaris - UK

SN	Service Point No.	Meter No.	Defect Year	Defect	Manufacturer / Country or origin
39	1067452	12S000304	2015	Meter Stop	Sensus - Germany
40	1071914	12S000526	2015	Meter Stop	Sensus - Germany
41	1060386	12S005183	2015	Meter Stop	Sensus - Germany
42	1057867	12S005375	2015	Meter Stop	Sensus - Germany
43	1082201	12S007753	2015	Meter Stop	Sensus - Germany
44	1058747	12S009937	2015	Meter Stop	Sensus - Germany
45	1099311	12S013752	2015	Meter Stop	Sensus - Germany
46	1066783	12S014351	2015	Meter Stop	Sensus - Germany
47	1066851	12S014362	2015	Meter Stop	Sensus - Germany
48	1060228	12S014370	2015	Meter Stop	Sensus - Germany
49	1000262	12S015135	2015	Meter Stop	Sensus – Germany
50	1000264	12K007777	2015	Meter Stop	Kent -Malaysia



<u>Figure 3-F: Block 302 Locations of Defective Water Meter</u>

3.4.4 Failed Meter - Sample Testing

In order to assure water is being accounted accurately, meters need to be selected, installed, operated and maintained using generally accepted industrial standards. Selected meters samples have been visually inspected in EWA metering workshop and found that the meter failures has failures into three main categories as shown in Figure 3-G.



Meters have stopped recording flow | **Meter's body failure** | **Meters have dropped in Accuracy**

Figure 3-G: Water Meter - Failures Categories

Water meters samples that have dropped in accuracy (performance) has been tested via EWA water meter testing rig in accordance with the International Standards (ISO 4064-1;2005, **Appendix E**) using the relative error formula:

$$\epsilon = \frac{Vi - Va}{Va} \times 100 \qquad \textbf{(Equation 3-12)}$$

Where;

ϵ = Relative Error

Vi = Indicated Volume

Va = Actual Volume

The acceptances range of water meter has been identified in ISO 4064-1; 2005, **Appendix E**, Maximum Permissible Error (MPE) as follows;

1. **MPE lower range:** MPE, positive or negative, on volumes delivered at flow rates between the minimum flow rate (Q_1) and the transitional flow rate (Q_2) (excluded) is 5 % for water having a temperature within ROC.
2. **MPE upper range:** MPE, positive or negative, on volumes delivered at flow rates between the transitional flow rate (Q_2) (included) and the overload flow rate (Q_4) is:

   ±2 % for water having a temperature $\leq$ 30 ^{o}C

   ±3% for water having a temperature > 30 ^{o}C

Figure 3-H demonstrates an illustration of standard MPE upper and lower range whereas Figure 3-I demonstrate the application of form of Water meter test result extracted from EWA Water Meter Testing Rig Software.

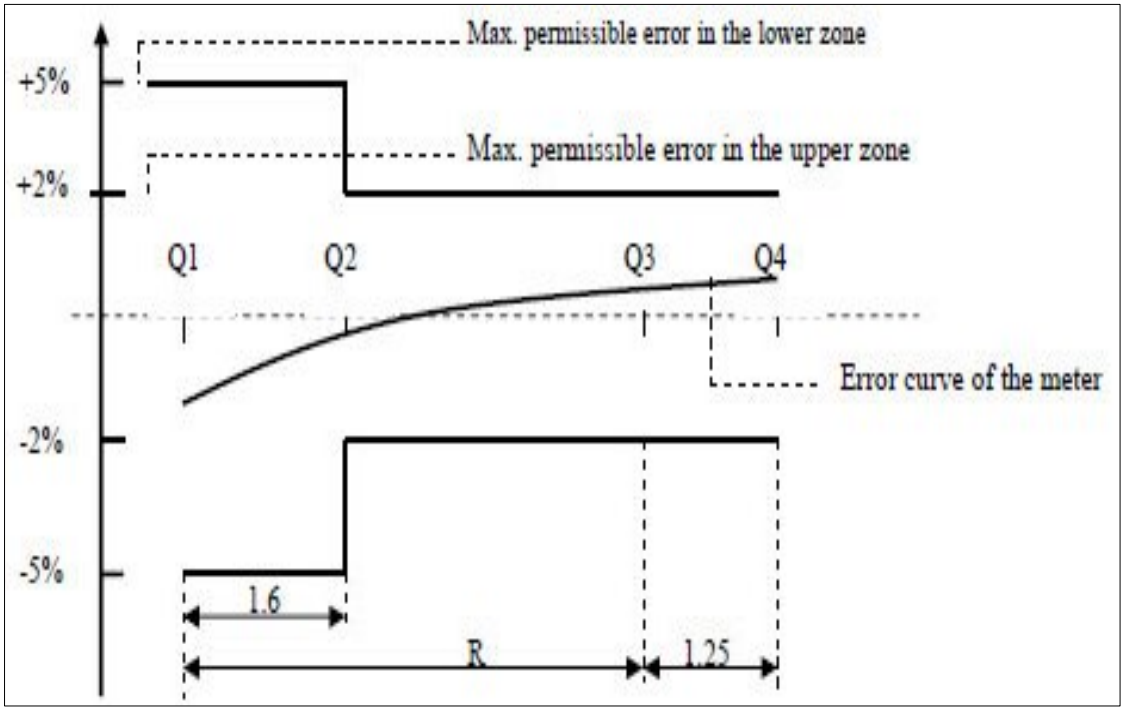
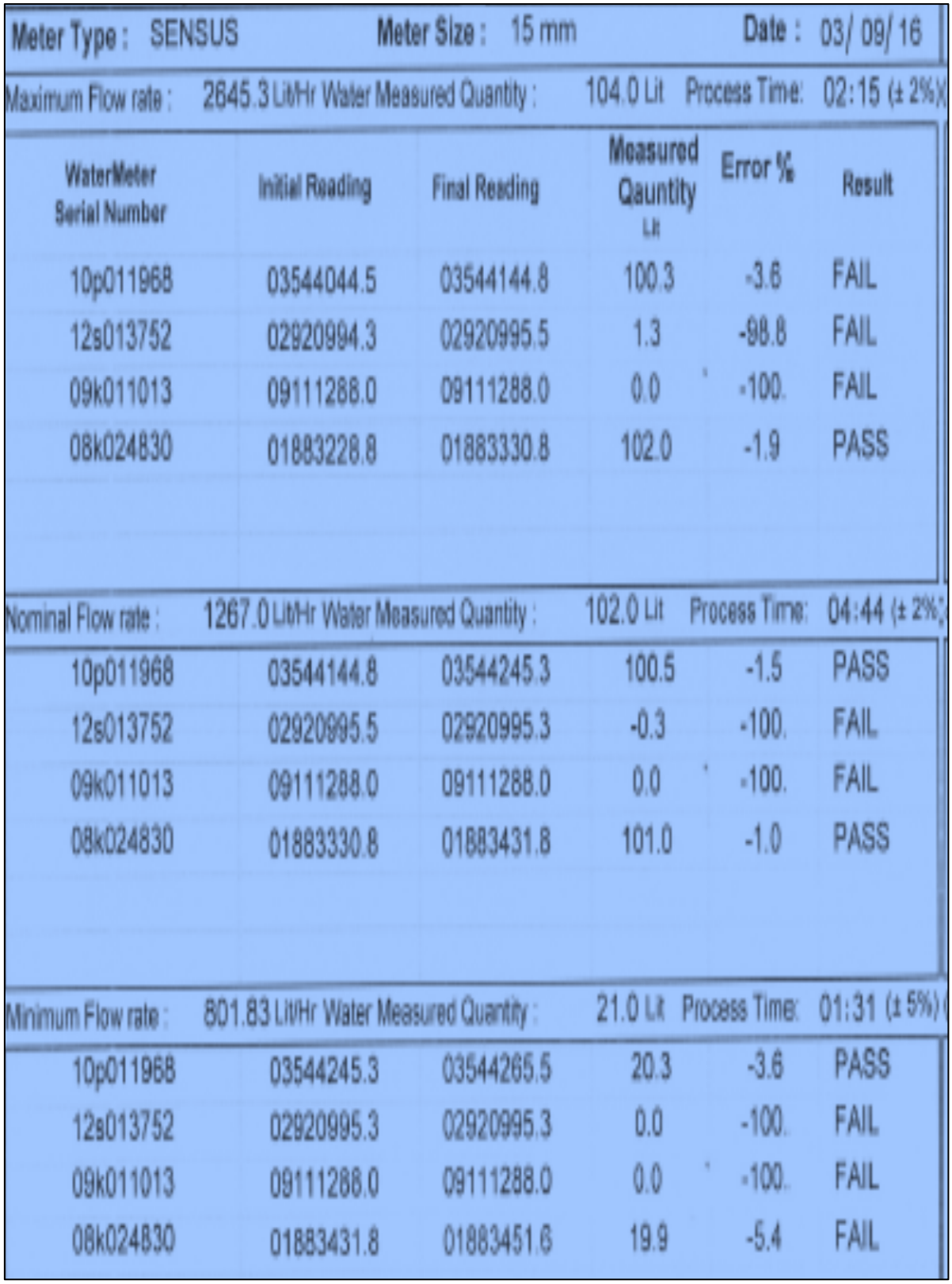


Figure 3-H: Standard Water Meter Error Curve - ISO 4064-1;2005



Meter Type : SENSUS Meter Size : 15 mm Date : 03/ 09/ 16

Maximum Flow rate : 2645.3 Lit/Hr Water Measured Quantity : 104.0 Lit Process Time: 02:15 (± 2%)

WaterMeter Serial Number	Initial Reading	Final Reading	Measured Qauntity Lit	Error %	Result
10p011968	03544044.5	03544144.8	100.3	-3.6	FAIL
12s013752	02920994.3	02920995.5	1.3	-98.8	FAIL
09k011013	09111288.0	09111288.0	0.0	-100.	FAIL
08k024830	01883228.8	01883330.8	102.0	-1.9	PASS

Nominal Flow rate : 1267.0 Lit/Hr Water Measured Quantity : 102.0 Lit Process Time: 04:44 (± 2%)

10p011968	03544144.8	03544245.3	100.5	-1.5	PASS
12s013752	02920995.5	02920995.3	-0.3	-100.	FAIL
09k011013	09111288.0	09111288.0	0.0	-100.	FAIL
08k024830	01883330.8	01883431.8	101.0	-1.0	PASS

Minimum Flow rate : 801.83 Lit/Hr Water Measured Quantity : 21.0 Lit Process Time: 01:31 (± 5%)

10p011968	03544245.3	03544265.5	20.3	-3.6	PASS
12s013752	02920995.3	02920995.3	0.0	-100.	FAIL
09k011013	09111288.0	09111288.0	0.0	-100.	FAIL
08k024830	01883431.8	01883451.6	19.9	-5.4	FAIL

Figure 3-I: Sample Accuracy Test Report "Appendix - E"

Table 3-9: Failed Meter Visual inspection and Testing Result - Block 302

SN	Meter No.	Fixing Year	Defect Year	Life (Year)	Initial Defect Investigation	Visual inspection and Testing Result	Observation
1	07K009116	2007	2011	4	Meter Stop	Drop in Accuracy	Operation life
2	07K009120	2007	2011	4	Meter Stop	Meter Stop	Meter Blocked
3	08k009242	2008	2011	3	Meter Stop	Meter Stop	Meter Blocked
4	07k009532	2007	2011	4	Meter Stop	Meter Stop	Meter Blocked
5	07K009598	2007	2011	4	Meter Stop	Meter Stop	Meter Blocked
6	07P006944	2007	2011	5	Meter Stop	Drop in Accuracy	Operation life
7	07P013464	2007	2012	5	Meter Stop	Drop in Accuracy	Operation life
8	08k024075	2008	2012	4	Drop in Accuracy	Body Failure	Tampering in meter housing
9	08K009257	2008	2012	4	Meter Stop	Meter Stop	Meter Blocked
10	08K009349	2008	2012	4	Drop in Accuracy	Meter Stop	Meter Blocked
11	08K014753	2008	2012	4	Drop in Accuracy	Meter Stop	Meter Blocked
12	08K015011	2008	2012	4	Drop in Accuracy	Meter Stop	Meter Blocked
13	08K015376	2008	2012	5	Drop in Accuracy	Drop in Accuracy	Operation life
14	08k024830	2008	2013	5	Drop in Accuracy	Drop in Accuracy	Operation life
15	08K035850	2008	2013	5	Meter Stop	Meter Stop	Internal mechanical parts defect
16	08K043567	2008	2013	5	Drop in Accuracy	Meter Stop	Internal mechanical parts defect

SN	Meter No.	Fixing Year	Defect Year	Life (Year)	Initial Defect Investigation	Visual inspection and Testing Result	Observation
17	08k048040	2008	2013	5	Drop in Accuracy	Drop in Accuracy	Operation life
18	09k002287	2009	2013	4	Drop in Accuracy	Drop in Accuracy	Operation life
19	09k003558	2009	2013	4	Drop in Accuracy	Meter Stop	Meter Blocked
20	09K010517	2009	2013	4	Drop in Accuracy	Meter Stop	Meter Blocked
21	09K011013	2009	2013	5	Meter Stop	Drop in Accuracy	Operation life
22	09K011124	2009	2014	5	Meter Stop	Meter Stop	Internal mechanical parts defect
23	09K011149	2009	2014	5	Meter Stop	Meter Stop	Internal mechanical parts defect
24	09K011283	2009	2014	5	Meter Stop	Meter Stop	Meter Blocked
25	09K018837	2009	2014	5	Meter Stop	Drop in Accuracy	Operation life
26	09K018853	2009	2014	5	Meter Stop	Meter Stop	Meter Blocked
27	09K018873	2009	2014	5	Meter Stop	Meter Stop	Meter Blocked
28	09K018874	2009	2014	5	Meter Stop	Meter Stop	Meter Blocked
29	09k018931	2009	2014	5	Drop in Accuracy	Body Failure	Water Quality
30	10P001474	2010	2014	4	Meter Stop	Meter Stop	Meter Blocked
31	10P011911	2010	2014	4	Meter Stop	Drop in Accuracy	Operation life
32	10P011968	2010	2014	5	Meter Stop	Drop in Accuracy	Operation life
33	10P021270	2010	2015	5	Meter Stop	Drop in Accuracy	Operation life
34	10P035187	2010	2015	5	Meter Stop	Meter Stop	Meter Blocked

SN	Meter No.	Fixing Year	Defect Year	Life (Year)	Initial Defect Investigation	Visual inspection and Testing Result	Observation
35	11k000224	2011	2015	4	Drop in Accuracy	Meter Stop	Meter Blocked
36	11P004437	2011	2015	4	Meter Stop	Drop in Accuracy	Operation life
37	11P009700	2011	2015	4	Meter Stop	Meter Stop	Meter Blocked
38	11P011896	2011	2015	4	Meter Stop	Drop in Accuracy	Operation life
39	12S000304	2012	2015	3	Meter Stop	Meter Stop	Meter Blocked
40	12S000526	2012	2015	3	Meter Stop	Drop in Accuracy	Operation life
41	12S005183	2012	2015	3	Meter Stop	Meter Stop	Meter Blocked
42	12S005375	2012	2015	3	Meter Stop	Meter Stop	Meter Blocked
43	12S007753	2012	2015	3	Meter Stop	Meter Stop	Meter Blocked
44	12S009937	2012	2015	3	Meter Stop	Drop in Accuracy	Internal mechanical parts defect
45	12S013752	2012	2015	3	Meter Stop	Drop in Accuracy	Internal mechanical parts defect
46	12S014351	2012	2015	3	Meter Stop	Meter Stop	Meter Blocked
47	12S014362	2012	2015	3	Meter Stop	Meter Stop	Meter Blocked
48	12S014370	2012	2015	3	Meter Stop	Meter Stop	Meter Blocked
49	12S015135	2012	2015	3	Meter Stop	Meter Stop	Meter Blocked
50	12K007777	2012	2015	3	Meter Stop	Body Failure	Tampering in meter housing

Chapter 4. Results Analysis and Discussion

4.1 Background

As known, the major cornerstone of the commitment to quality improvement prescribed by Deming and the other early gurus, who introduced number of tools called magnificent seven or quality tools.

Quality management tools intended to identify and prevent the causes of quality problems or defects. In this chapter it is intended to focus on research result analysis and discuss on collected and generated data of volumetric domestic revenue water meter failure phenomena in The Kingdom of Bahrain through gathered and collected data and validate testing results using the following Quality Management / Control Tools.

1. Histogram to visualize failure distributions.
2. Pareto Chart to identifying most causes of meter failures.
3. Fault tree analysis (FTA) to analyzing the interrelation among the meter failures and their causes.
4. Cause and Effect Diagram (CED) to identifying relationship between meter failure element and their causes.

4.2 Results Analysis

4.2.1 Histogram

Histogram is a helpful tool, which visually represents the frequency of data related to quality problems. Moreover, Histogram provides the easiest way to evaluate the distribution of data.

As resulted from testing of the collected samples, the volumetric water meter defects categorized into three major defects (stopped meter defects, accuracy

defects and body defects). Those defects has been categorized into classes as elaborated in Table 4-1 where 52% of defects found to be due to meter blockage, 12% due to defective internal mechanical parts, 30% due meter operation life (aging) and 6% due to meter body degradation.

Table 4-1 and Chart 4-1 illustrate that the failures of the volumetric water meters concentrate in blockage and aging problem respectively.

Table 4-1: Frequency of Water Meter Defect Types

Major Defect	Defect Classification	Frequency	Percentage Defect (%)
Stopped Meter	Blockage	26	52%
	Internal Mechanical Parts	4	12%
Accuracy Failure	Internal Mechanical Parts	2	
	Aging	15	30%
Body Failure	Body degradation	3	6%
Total		**50**	

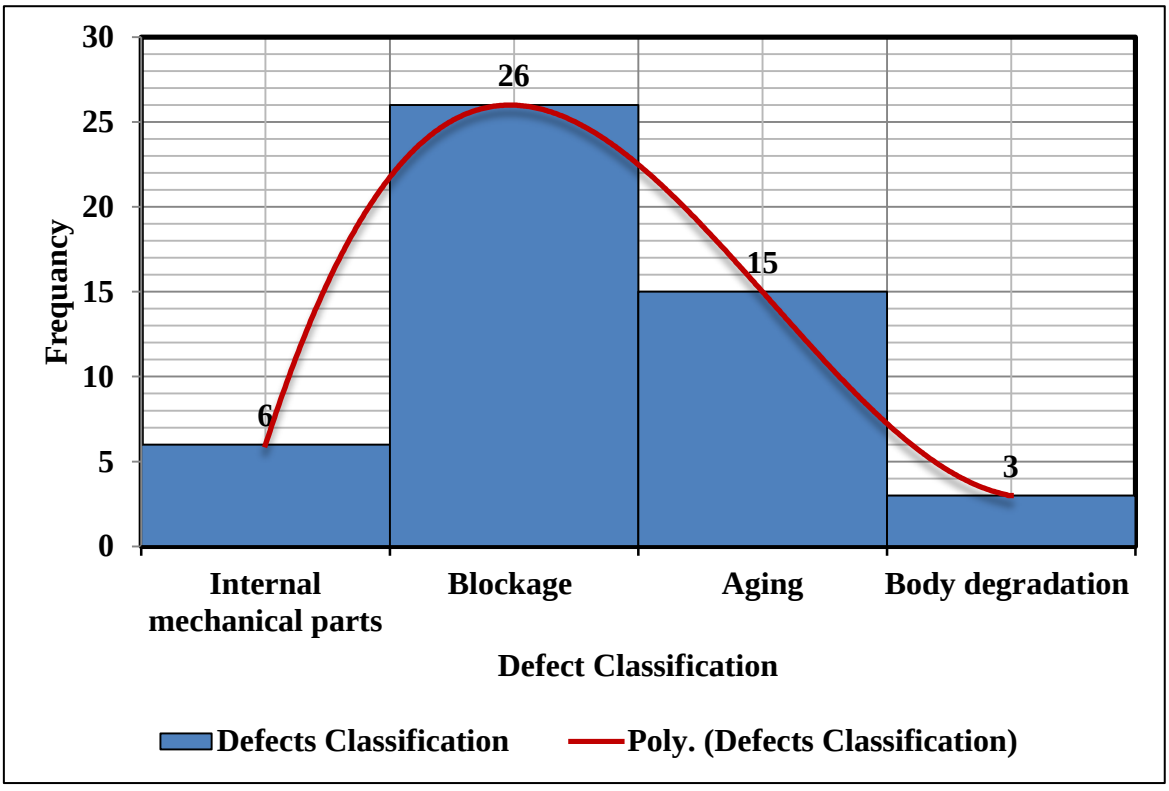


Chart 4-1: Sample selected frequency of meter defects

4.2.2 Pareto Chart.

Pareto Chart is a method of identifying the causes of poor quality and the principle of Pareto Chart states that 20% of the defects are responsible for 80% of all the defects. By putting it in another way, it states that 80% of consequences start from 20% of the causes.

Table 4-2: Frequency Cumulative of Water Meter Defect Types

Defect	Frequency	Cumulative	% Cumulative
Blockage	26	26	52%
Aging	15	41	82%
Internal Mechanical Parts	6	47	94%
Body degradation	3	50	100%
Total	**50**		

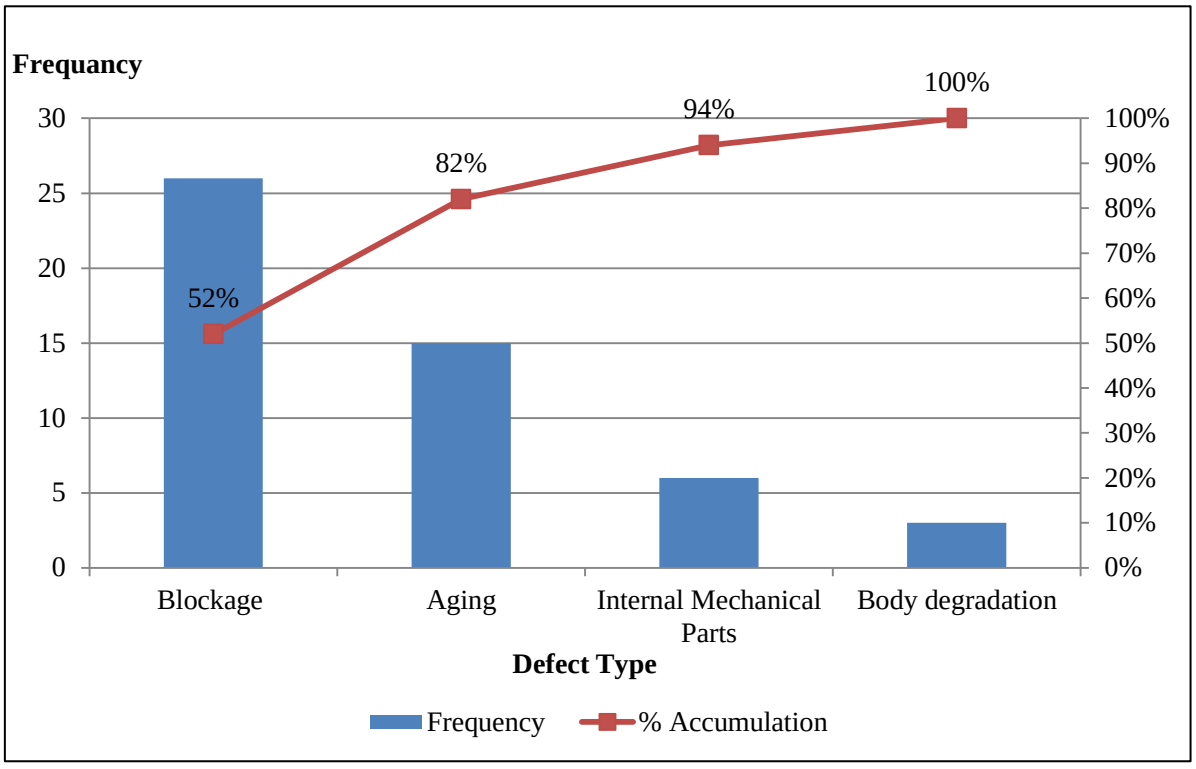


Chart 4-2: Pareto Chart – Water Meter Failures

Using principle of 80/20, Pareto chart illustrate that the 80% of accumulative defects due to blockage and aging problems. The frequency of data elaborate that the vast majority defects has been found in selected samples of study area is blockage and aging defects, which represent 52% and 30% respectively.

Table 4-3 illustrates the number of defective meters against operation life. The data indicate that the vast major of defect of water meter is due to blockage which is 60% of the selected samples, 21 samples of blocked meters have failed prior to the recommended life of 5 years, operation life (70%) and the rest of the 9 blocked meters represented 30% and have failed within recommended operation life.

The majority of blocked meters have occurred due to operation environment such as water quality, pressure rate or flow rate. While 34% of selected samples represent accuracy failures, 100% of such failures have occurred within recommended operation life. The third defect has been found is body failure, which represents 6% of the selected samples 67% of such meter failures has be failed prior to the recommended operation life.

Table 4-3: Meters Defects vs. Operation Life

Defect	Operation Life (Year)	No. of Defects	% Defect	Failure vs. Operation Life
Blockage	3	9	60	Prior Operation Life
	4	12		Prior Operation Life
	5	9		within Operation Life
Accuracy	5	17	34	within Operation Life
Body	4	2	6	Prior Operation Life
	5	1		within Operation Life
Total		**50**		

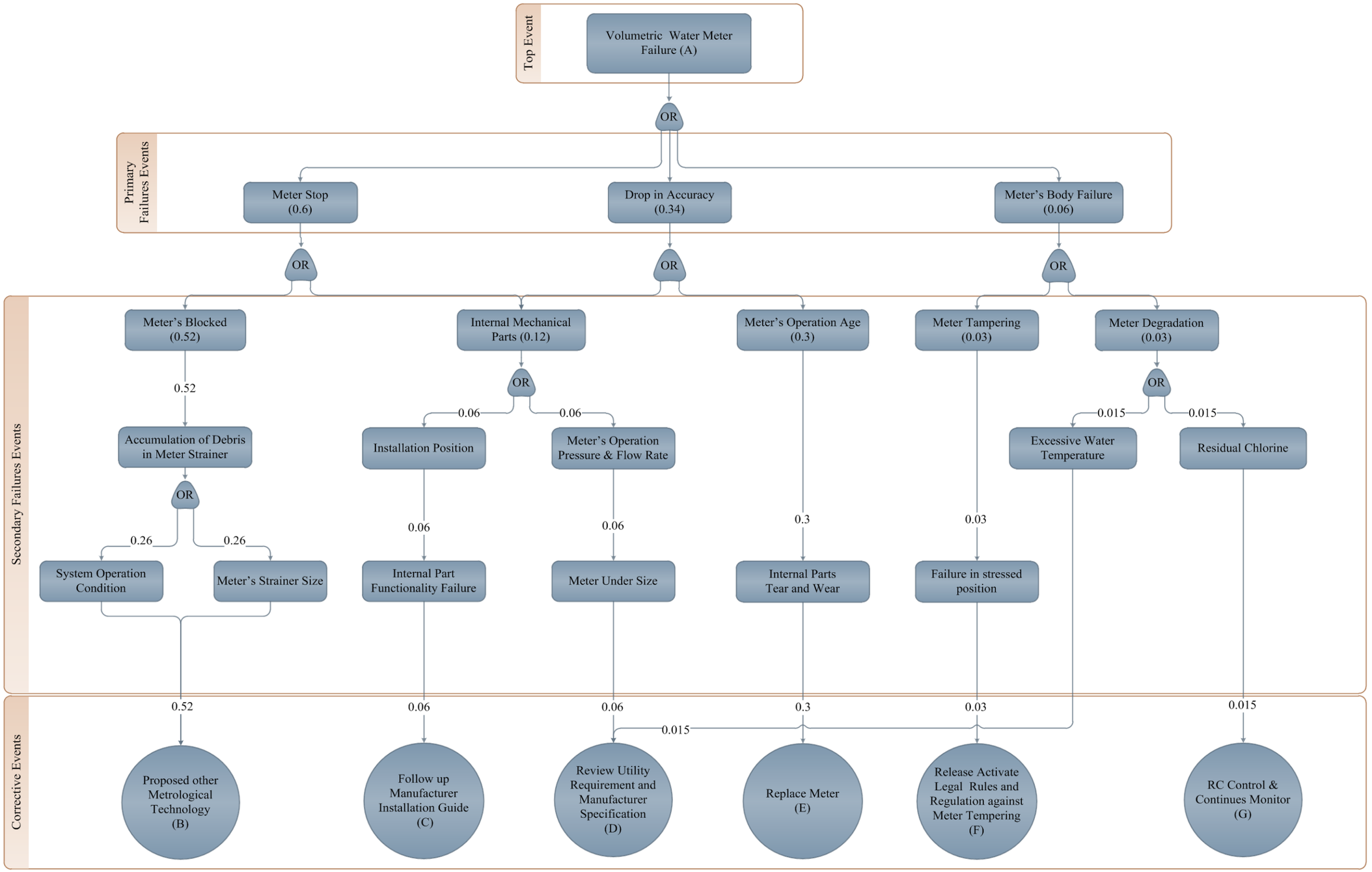
4.2.3 Fault Tree Analysis (FTA)

The methodology of a fault tree analysis graphically involves presenting the major fault associated with a water meter, along with the identified causes of each faults and the possible corrective measures.

Implementation of FTA in this study has been started by identifying the top event cause the failure of the volumetric water meters. This has been divided into three primary events (meter blockage, drop in accuracy and body failures) contribute in occurrence of the top event (water meter failures) as investigated from selected samples.

As result, the most frequent defect are meter stopped 60%, drop in accuracy 34% and body failure 6%, which considered as primary event. As illustrated in histogram analysis, stop meter failures divided into defects occurred due to meter blockage (52%) and defects occurred due to internal mechanical parts (8%). The drop in meter accuracy failures can be divided into defects due to meter internal mechanical parts (4%) and defects due to incorrect operation principle (30%). Meter body failure can be divided into defects due to meter tempering (3%) and defects due to meter degradations.

The quantitative and qualitative assessment of fault tree take place based on data obtained in the graphic construction, using calculation to evaluate system reliability using binary logic equations 3-2 and 3-3 and assessment assuming that all the events are depended and the probability of primary events has been distributed into corrective events equally. Table 4-4 illustrates corrective event probability calculation in Volumetric Water Meter FTA.



1. OR Gate
   $P(Q) = P(A)+P(B)-P(A \cap B)$
   Assumption 1: Events are completely dependent, $P(A \cap B) = 1$
   $P(Q) = P(A)+P(B)$

2. AND Gate
   $P(Q) = P(A)P(B/A)=P(B)P(A/B)$
   Assumption 2: Occurrence of all events is necessary for the occurrence of the top event, $P(A/B) = 1$
   $PQ = P(A)P(B)$

Figure 4-A: FTA -Volumetric Water Meters

Table 4-4: Probabilities of Corrective Event

Symbol	Corrective Event	Probability
B	Proposed other Metrological Technology	0.52
C	Folow up Manufacturer Installation Guide	0.06
D	Review Utility Requirement and Manufacturer Specification	0.075
E	Replace Meter	0.3
F	Release Activate Legal Rules and Regulation against Meter Tempering	0.03
G	RC Control & Continues Monitor	0.0015

P (A) = P (B) + P (C) + P (D) + P (E) + …P (n) (Equation 3-1),

P (A) = 0.52 + 0.06 + 0.075 + 0.3+ 0.03 + 0.015 = **1**

Where;

P (A) Probability of volumetric water meter failure.

P (B) to P (G) Probabilities of corrective events.

Volumetric Water Meter FTA Diagram, which has been created based on collected data to elaborate the interrelation between meter failures and their causes, which clearly illustrate the prevalent Volumetric Water Meter Failure roots and how to be tackled.

FTA elucidated, the volumetric water meter defects categorized into three categories; meters stop failures, accuracy failures and body failures. Therefore, FTA has been conducted accordingly to detail graphically the interrelation between water meter failures, their causes and how to tackle and elaborate the following:

- The vast majority of water meter failure is meter stop registration, representing 60% of the selected samples, which could be either blockage of water meter (52%) or defects of water meters internal mechanical parts (8%).

- Blockage of water meters failures constitutes 52% of selected samples failures, which occurred because of accumulation of debris on the meter strainer due to either strainer size or water distribution system operation conditions. As investigated, some of the debris found to be sand and the other was fibrous type of materials.
- Internal mechanical part failures constitute 12% of selected samples failures, which occurred due to either meter installation position 6% or meters operation pressure and flow rate 6%.



Figure 4-B: Accumulation of Debris on Meter Strainer

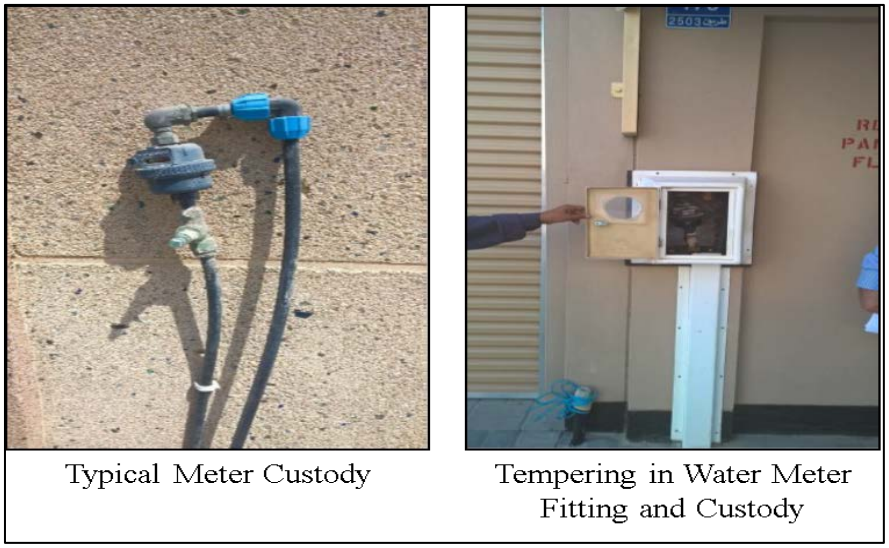
- The second major volumetric water meter failure is the accuracy failure, which represents 34% of the selected samples. This could be either meter internal parts 4% or meter operation life (age) 30% .



Figure 4-C: Occurrence of Tears and Wears in Meter Chamber

- Meter body failure, represents 6% of selected samples, which could be either because of water meter tampering or water meter body degradation problem.

1. Water meter tampering constitute 3% of selected samples, which could be in meter custody or water meter fittings may have exposed to direct sunlight and application of stress at weak point especially in water meter threads.



Typical Meter Custody

Tempering in Water Meter Fitting and Custody

Figure 4-D: Typical Installation and Tampering Installation

2. Meter degradation problem constitutes 3% of the selected samples occurred due to elevated level of residual chlorine 1.5% , direct exposure to sun light and excessive ambient temperature 1.5% as the meter housing made from polypropylene plastic which may have been subjected to ultra violet deterioration, (Compo,2007).



Figure 4-E: Meter Degradation

4.2.4 Cause and Effect Diagram

Cause and Effect Diagram (CED) or Fishbone Diagram is a tool / technique used to analyze possible causes of a specific problem or condition.

Basically CED used to investigate a problem, exploring, identifying, and displaying the possible causes to identify the relationship between the effects in a given situation and all of the possible causes in order to find problem sources/solutions.

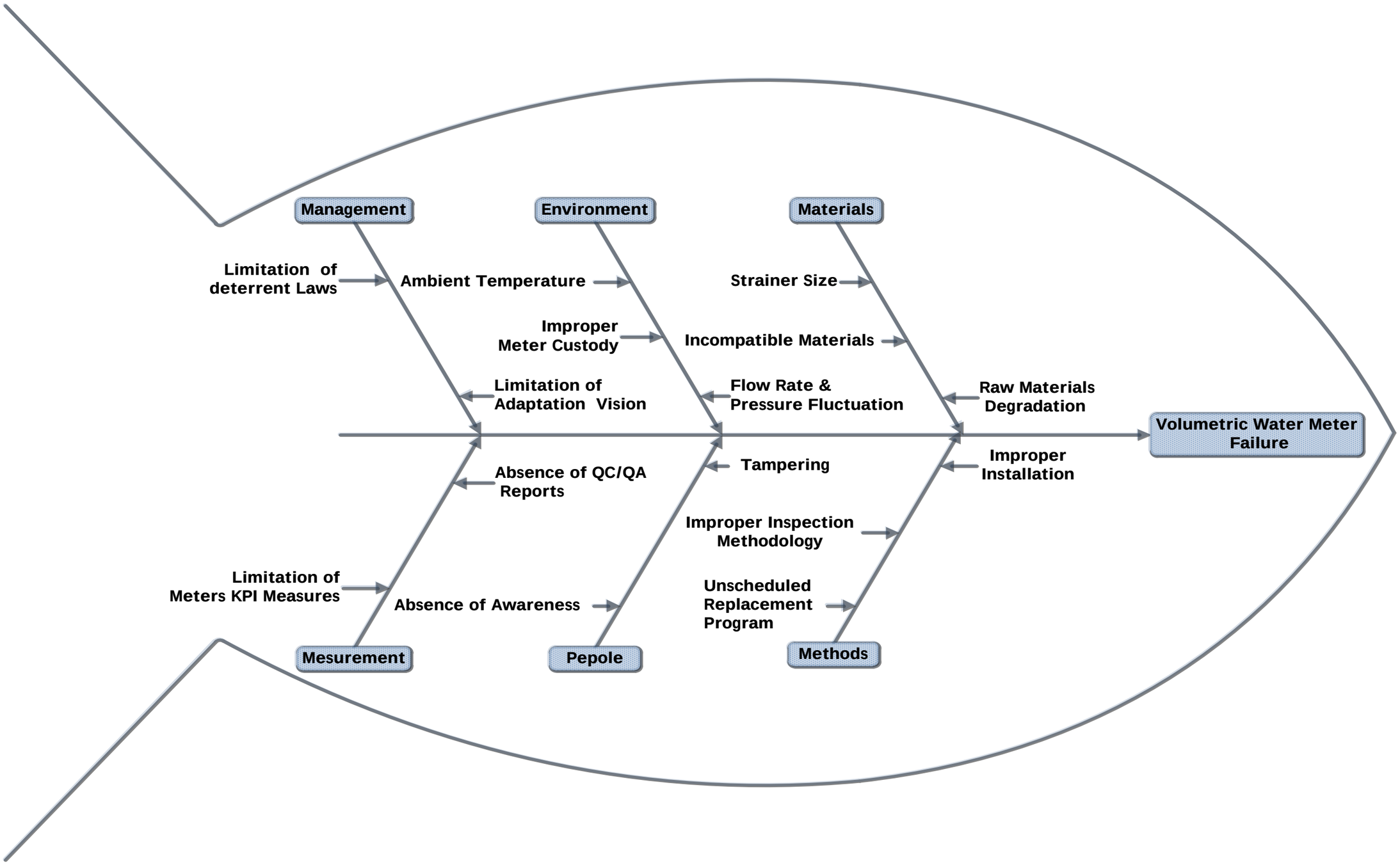


Figure 4-F: Volumetric Water Meter Failure – Cause and Effect Diagram

Six categories have been detailed in the above Cause and Effect Diagram, Fig. 4F, to elaborate the causes and effect of volumetric water meter failures.

- Utility Management;

1. The effect of limitation in setting deterrent rule and law against meter tampering will cause irresponsible stakeholder actions.
2. Limitation in availability of alternatives adaptations of water meter technologies will cause delayed in technology transformation stage thus increase water meter defects.

- Performance Measurement;

1. Limitation of Water Meter Performance reports (QA/QC) will cause delay in identifying sources of water meters failure.
2. Limitation in assigning KPI for meter installation, maintenance, inspection and all other activities related to water meter will cause losing in activates monitoring and control.

- Operation Environment;

1. The excessive ambient temperature (50 ^{o}C and above) will badly affect Meter internal plastic parts.
2. Improper water meter custody will allow irresponsible tampering.
3. Fluctuation of pressure and flow rate in water supplied system may stirs up dust and particulates deposited in the water network systems, which cause meter blockage problem.

- Users / People;

1. Tampering in water meter and related accessories may cause meter body failure.

2. Absence of knowledge and awareness in meter functions and technology may allow incorrect installation, which lead to accuracy failure.

- Meter Materials ;

1. Nonstandard strainer size will allow meter blockage.
2. Using incompatible materials in water meter installation allow body failure.
3. Degradation of meter raw materials will cause weak points in water body especially in connection point, which lead to body failure.

- Operation / installation methods;

1. Improper inspection methodology such as network flushing before meter installation lead to improper meter blockage with debris.
2. Improper meter installation leads to accuracy and body failures.
3. Improper implementation of replacement program lead to accuracy failure.

4.3 Results Discussion

The result analysis in section 4.2 elaborated the major defects occurred in volumetric domestic water meter of water distribution system in The Kingdom of Bahrain. Related defects have been investigated and analyzed using Quality Control tools adds in order to identify the water meter failures phenomena parameters. This section is intended to discuss major defects of domestic water meters comparing with previous experimental studies.

4.3.1 Water Meter Blockage Failures

Accumulation of debris in meter strainers is formed 60% of water meter defects, out of 30 blockage cases in investigation area, 21 cases are failed prior recommended operation life, which formed 70% of water meter blockage. Result analysis of selected samples elaborate that the highest percentage failures of the volumetric water meters are resulted due to meter blockages, which have been caused due to unsuitability of water meter construction characteristics water system operation environment. Thus volumetric water meters are sensitive to water quality and suspended particles that may produce a definitive blockage of the water meters.

4.3.2 Water Meter Accuracy Degradation

Accuracy degradation formed 34% of selected samples. Such failure is attributed to over-age operation life, operation flow rate and installation position. Mechanical water meters, experience a degradation of accuracy over time. This degradation is a function of several factors, such as wear, water quality, water velocities, throughput volumes, installation and handling. The relationship between meter accuracy degradation and factors such as age, wear, and throughput for in-service water meters is intended to provide insight to water utility managers and decision-makers about meter replacement programs or proposing alternative technology.

4.3.3 Water Meter Body Degradation

Body degradation of the domestic water meters 6% of such failure has been investigated in selected samples result from meter custody tampering or excessive ambient temperature and quantity of residual chlorine in water distribution system.

4.4 Results Discussion Summary

Meter Failures	Result Analysis	Discussion
Meter Blockage	Accumulation of debris in meters strainers are formed 60% of water meter defects, out of 30 blockage cases in investigation area, 21 cases are failed prior recommended operation life, which formed 70% of blockage water meter.	Accumulation of debris on meter strainer could be occurred due to strainer size or network system operation parameter such as pressure fluctuation and flow rate, as discussed by Francisco et al. (2005) and Mutikanga et al. (2011) respectively. In order to tackle strainer size issue, EWA/WDD has to revise meter specification. However, such solution is not enough to solve blockage issue as witnessed in selected sample. Moreover, Francisco et al., 2005 have investigated such defect. Furthermore, pressure and flow rate fluctuation in water supply system considered contributes in meter blockage. Mutikanga et al., 2011 have discussed such failure. The fluctuated pressure may stir up dust and particulates, while most of blockage defects have occurred prior meter recommended operation life.

Meter Failures	Result Analysis	Discussion
Accuracy Degradation	34% of selected samples found to be with meter accuracy issues. It is attributed to over age operation life, operation flow rate and installation position.	As Specified in Manufacturer and WDD Specification, the operation life of mechanical volumetric meter is seven years. However, most of the meter accuracy failure cases have been investigated in the beginning of the fifth year and accordingly meters replacement program has been set. Operation flow rates of the domestic water meters are specified in manufacturer specification, WDD specification and International Standards (minimum flow rate is 15 l/h and maximum flow rate is 1,500 l/h). As discussed by Davis (2005), excessive flow rate will damage meter's internal parts, which may allow water passing through without registration, and meter could be considered as under register. The operation principle of the volumetric water meter is to account the volume of displaced water, which depends on vertical meter installation position. The meter accuracy could be dropped from one class to another due to horizontal or inclined installation.

Meter Failures	Result Analysis	Discussion
Body Degradation	6% of such failure has been investigated in selected samples result from meter custody tampering or water meter body degradation.	Tampering in water meter installation and related accessories by using incompatible materials and removing meter box may cause meter body failure. While Meter installation custody specified in WDD Specification. Elevated level of residual chlorine and high ambient water temperature lead to water meter body UV degradation, which may cause weak points in water meter body especially in connection point, which lead to body failure. Similar factors have been investigated by Campo (2007).

Chapter 5. Conclusions and Recommendations

5.1 Conclusions

Water losses due to meter inaccuracy are considered to be as one of the main challenges that prevent water utilities achieving future strategic aims. Due to lack of natural water resources, and to meet the water demands, The Kingdom of Bahrain depends on desalination techniques, which involve huge cost. Nevertheless, some of the produced water is lost (NRW). Amongst the NRW elements, apparent losses related to water meter have taken EWA concern. Accordingly, the circumstances of volumetric domestic water meters failure phenomena have been investigated.

Different analysis tools were applied in this study on random sample of the defected volumetric domestic water meters to identify the defect types. These help to decide on the most critical causes of the defect, putting into consideration the water quality, operational and environmental conditions.

The study found that the failure phenomena fall into three major categories;

- Meters stopped recording the flow due to accumulation of debris on water meter strainer. Those meters were carefully dismantled and found that some of the debris is sand, while other debris was observed such as fibrous type of material. Meter jam/blockage issue has been observed as well in other studies due to volumetric water meter operation principle. This type of failure had the major percentage (60%) compared to the other defect types.
- Meters had accuracy failures constitute 34% of the selected samples. Those meters have failed to pass laboratory accuracy test, the accuracy of volumetric water meter dependent on water not leaking through the piston from the inlet to the outlet compartment. Some of the meters have been

dismantled and found that the internal part has suffered wear and tear over-age operation life or over flow rate.

- Meters suffered terrible failures in meter body constitutes 6% of the selected samples. Those meters mainly failed in thread area (body failure). The threads on plastic body water meters are sensitive to direct sunlight, areas of the molding where some manufacturing process induced stresses will exist, and the wall thickness of the meter body wall will be reduced. Hence, EWA / WDD are strictly recommended to preserve water meter standard custody from tampering.

5.2 Recommendations

In conclusion, the vast majority of volumetric water meter failure has been found as blockages due to accumulation of debris on meter strainer. Consequently, the study is recommending the following points to be taken into consideration to ensure and enhance the study results.

- EWA/WDD recommends considering alternative metering technologies that would remove the issue of meters becoming blocked such as water meter without any moving parts such us ultrasonic or electromagnetic. As acknowledged in study that the volumetric water meter technology characteristics would have problems in such harsh supply environment.

  Furthermore, diverse meter models of the same technology present very different behaviors depending on the specific construction characteristics of each instrument. Consequently, to reduce the magnitude of the apparent losses and to guaranty an accurate water measurement, it is not only important to select the adequate metering technology but also the right construction that suits the specific characteristics of the water supply system.

- EWA/WDD recommends assessing installation procedures of water pipework and ensure adequate flushing of the pipeline before meter installation.
- EWA/WDD recommends revising specification of the volumetric domestic water meter, especially strainer holes size and meters allowable ambient water temperature.
- EWA/WDD recommends having more comprehensive reports for any water meter failure; this will support any future investigation. Proposal form/report for defective water meter collection is introduced in Appendix F.
- EWA/WDD recommends studying the workability and feasibility of existing meter replacement program. EWA/ WDD also recommends investigating the meter maintenance activities via introducing smart measures for each activity.

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APPENDICES

IWA Standard Water Balance

<table>
<tr><td rowspan="8">System Input Volume [corrected for known errors]</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="6">Non Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="4">Water Losses</td><td rowspan="2">Apparent (Commercial) Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling Errors</td></tr>
<tr><td rowspan="3">Real [physical] Losses</td><td>Leakage On Transmission And Distribution Mains</td></tr>
<tr><td>Leakage &Overflows at Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer Meter</td></tr>
</table>

Source: With Adopted. (Farley *et al.*, 2008).

EWA 2011 Water Balance

<table>
<tr><td rowspan="5">System Input Volume (m^3)

237,385,936
[100%]</td><td rowspan="2">Authorized consumption
[160143392]
[67.5%]</td><td>Billed authorized consumption</td><td colspan="2">Billed metered Consumption</td><td rowspan="2">Revenue Water

145,900,236
[61.5%]</td></tr>
<tr><td colspan="2">Billed un-metered Consumption</td></tr>
<tr><td rowspan="3">Water Losses

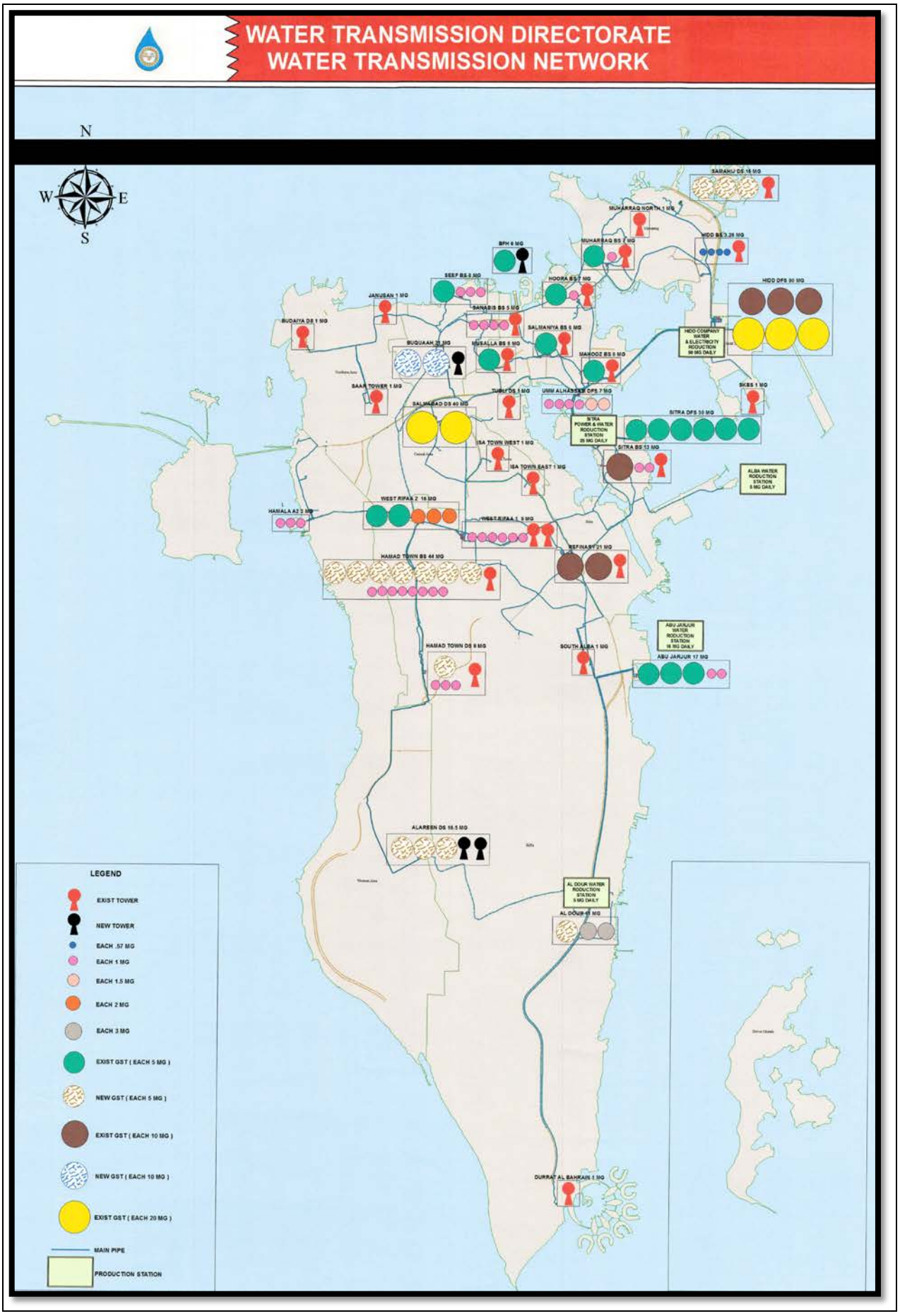
77,242,544

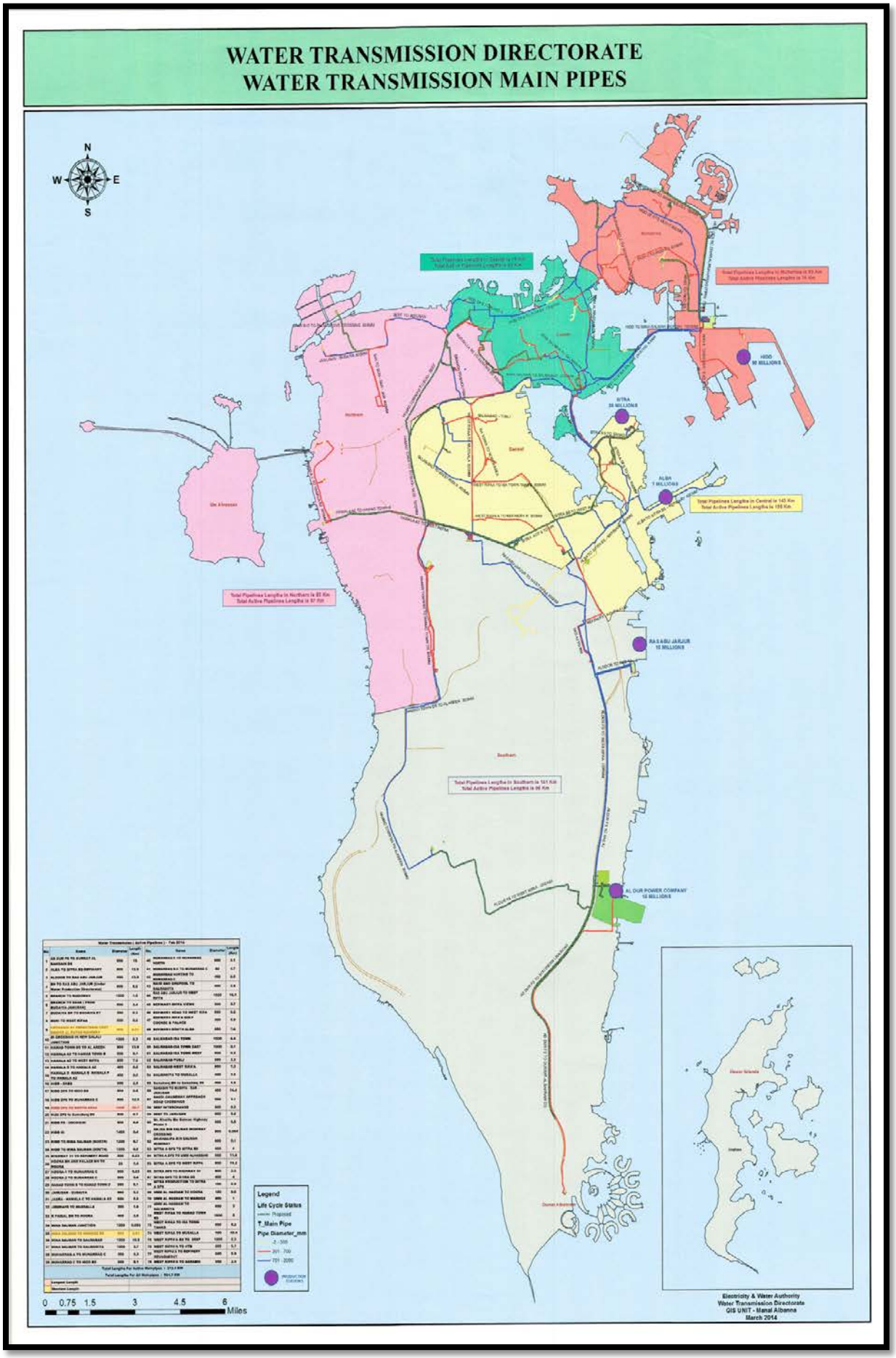
[32.5%]</td><td>unbilled authorized consumption</td><td>Unbilled Metered/ unmetered consumption</td><td>14,243,156
[6%]</td><td rowspan="3">Non Revenue Water [NRW]

91,485,700

[38.5%]</td></tr>
<tr><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td><td>2,373,859
[1%]</td></tr>
<tr><td>Customer Meter Inaccuracies</td><td>9,495,437
[4%]</td></tr>
<tr><td>Real Losses</td><td>Leakage from Distribution mains</td><td>65,373,248
[27.5%]</td></tr>
</table>

Source: EWA-WCC (2011).


WATER TRANSMISSION DIRECTORATE
WATER TRANSMISSION NETWORK
N
W
E
S
LEGEND
EXIST TOWER
NEW TOWER
EACH .57 MG
EACH 1 MG
EACH 1.5 MG
EACH 2 MG
EACH 3 MG
EXIST GST (EACH 5 MG)
NEW GST (EACH 5 MG)
EXIST GST (EACH 10 MG)
NEW GST (EACH 10 MG)
EXIST GST (EACH 20 MG)
MAIN PIPE
PRODUCTION STATION


WATER TRANSMISSION DIRECTORATE
WATER TRANSMISSION MAIN PIPES
N
W
E
S
Legend
Life Cycle Status
Proposed
T_Main Pipe
Pipe Diameter_mm
0 0.75 1.5 3 4.5 6 Miles
Electricity & Water Authority
Water Transmission Directorate
GIS UNIT - Manal Albanna
March 2014


WATER TRANSMISSION AREA SUPPLY
N
Samaheej Tower
Muharraq Tower
Muharraq North Tower
Sanabis Tower
Salmaniya Tower
Janusan Tower
Budaiya Tower
Hoora Tower
Hidd Tower
Musalla Tower
Mahooz Tower
Saar Tower
Tubli Tower
Isa Town West Tower
Sitra Tower
Isa Town East Tower
Refinary Tower
East Riffa Tower
Hamad Town BS Tower
West Riffa Tower
Hamad Town DS Tower
South Alba Tower
Durrat Al-Bahrain Tower
Hawar Islands

Tank Name	Block	Area name	No. of Water Connection / block	No. of Water Connection	2011			2012			2013			2014			2015		
					No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect
Al Areen	**1062**	**Al Areen Housing**	38	**38**	2	**2**	**5%**	2	**2**	**5%**	0	**0**	**0%**	1	**1**	**3%**	2	**2**	**5%**
BFH	**319**	**Hoora**	31	**801**	10	**19**	**2%**	18	**51**	**6%**	22	**115**	**14%**	30	**158**	**20%**	**41**	**233**	**29%**
	320	**Hoora**	263		8			24			67			69			**67**		
	322	**Mareena beach**	14		1			7			8			2			3		
	346	**Financial Harbor, Bahrain Bay**	493		0			2			18			57			122		
Bokowa	**431**	**Jablat Hibshi**	41	**2641**	2	**292**	**11%**	16	**270**	**10%**	15	**428**	**16%**	15	**344**	**13%**	12	**486**	**18%**
	433	**Jablat Hibshi**	363		23			48			106			85			86		
	435	**Jablat Hibshi**	322		50			29			43			37			45		
	439	**North Sehla**	322		32			55			69			43			63		
	441	**North Sehla**	358		45			33			68			48			77		
	447	**Jablat Hibshi**	284		8			17			32			18			53		
	455	**Bokowa**	239		21			31			34			43			48		
	457	**Bokowa**	712		111			41			61			55			102		
Budaiya	**518**	**Barbar**	234	**6641**	16	**434**	**7%**	38	**1152**	**17%**	84	**1959**	**29%**	42	**1501**	**23%**	**52**	**1540**	**23%**
	520	**Barbar**	174		10			35			61			43			**32**		
	522	**Barbar**	220		30			24			42			62			**38**		
	524	**Barbar**	211		23			51			73			47			**45**		
	526	**Barbar**	459		25			33			81			93			**69**		
	528	**Barbar**	81		10			13			19			21			**16**		
	529	**Al Markh**	233		10			61			60			63			**70**		
	530	**Barbar**	5		1			1			1			0			**1**		
	531	**Al Markh**	319		11			23			52			37			**54**		
	536	**Diraz**	460		32			116			147			116			**127**		
	537	**Banijamra**	348		27			36			69			52			**77**		
	538	**Diraz**	327		18			85			133			95			**79**		
	539	**Banijamra**	203		7			28			58			45			**42**		
	540	**Diraz**	493		23			97			195			104			**98**		
	541	**Banijamra**	341		17			49			106			72			**70**		
	542	**Diraz**	245		10			45			78			67			**48**		
	543	**Banijamra**	172		8			19			28			24			**33**		
	544	**Diraz**	28		11			4			1			7			**9**		
	545	**Quraiya**	188		26			26			69			39			**57**		
	547	**Quraiya**	88		8			16			22			10			**9**		
	549	**Quraiya**	36		10			4			22			6			**14**		
	550	**Budaiya**	172		8			31			53			40			**52**		
	551	**Quraiya**	319		16			43			84			68			**90**		
	552	**Budaiya**	397		19			43			76			70			**80**		
	553	**Budaiya**	209		19			35			67			56			**59**		
	555	**Budaiya**	490		27			146			229			173			**174**		
	557	**Budaiya**	98		2			23			16			25			**18**		

Tank Name	Block	Area name	No. of Water Connection / block	No. of Water Connection	2011			2012			2013			2014			2015		
					No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect
	559	**Budaiya**	2		0			1			3			0			**1**		
	561	**South Janubiya**	60		8			17			20			18			**16**		
	565	**South Janubiya**	29		1			7			10			6			**9**		
	569	**South Janubiya**	0		1			2			0			0			**1**		
Durathul Bahrain	**999**	**Durathul Bahrain**	909	**909**	4	**4**	**0%**	33	**33**	**4%**	284	**284**	**31%**	405	**405**	**45%**	324	**324**	**36%**
East Riffa	**901**	**Riffa**	43	**8676**	22	**598**	**7%**	72	**958**	**11%**	73	**1249**	**14%**	78	**1865**	**21%**	154	**2260**	**26%**
	903	**Booster area near Riffa Fort**	697		44			60			93			124			173		
	905	**North/East of Suq(Booster 917)**	758		36			96			99			148			208		
	913	**North/East of Riffa depot**	757		55			58			101			148			**175**		
	914	**North/West of Riffa depot**	166		20			28			44			53			**69**		
	915	**Near Riffa Municipality**	189		15			20			23			50			**52**		
	916	**H.H. the Prime Minister palace area**	119		10			18			26			39			**28**		
	917	**Near Batelco tower**	478		37			55			59			124			**140**		
	918	**Sh. Salman highway & Muharraq Av.**	20		1			1			9			12			**9**		
	919	**South of H.h. Crown Prince**	296		23			26			41			60			**67**		
	921	**South/West of M.O.H. site**	277		17			30			34			43			61		
	923	**Near old WDD stores**	261		15			22			28			59			58		
	925	**Near East Riffa club**	663		29			79			109			136			123		
	927	**Near pipe line road**	665		35			69			64			139			133		
	929	**Near Umm Al Nassn Road**	926		71			88			109			168			208		
	931	**Old M.O.H area**	193		17			19			29			50			58		
	933	**New M.O.H area**	774		48			74			158			133			181		
	934	**Riffa**	93		11			15			13			18			19		
	935	**M.O.H. Gift plot**	428		30			38			41			101			94		
	937	**Hajeeyat area**	518		36			55			58			106			113		
	939	**North East Rifaa**	231		20			26			24			49			85		
	941	**Muasker H/way & BDF camp**	124		6			9			14			27			52		

Tank Name	Block	Area name	No. of Water Connection / block	No. of Water Connection	2011			2012			2013			2014			2015		
					No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect
Hidd	**101**	**Hidd**	2	**7874**	0	**1021**	**13%**	0	**930**	**12%**	0	**948**	**12%**	0	**1672**	**21%**	**1**	**1764**	**22%**
	102	**Hidd MOH**	188		17			35			31			63			**50**		
	103	**Hidd Town**	165		28			23			40			50			**31**		
	104	**Hidd Town**	392		69			62			72			109			**97**		
	105	**Hidd Town**	347		105			56			72			115			**77**		
	106	**Hidd Town**	131		13			21			19			66			**24**		
	107	**Hidd Town**	331		31			49			54			95			**78**		
	108	**Hidd Town**	271		63			51			64			76			**91**		
	109	**Hidd Town**	828		76			55			69			123			**139**		
	110	**Hidd**	279		20			17			28			44			**71**		
	111	**Hidd**	683		66			44			48			60			**102**		
	112	**Hidd**	296		28			29			20			54			**81**		
	113	**Hidd**	1		0			0			1			0			0		
	240	**Arad MOH**	739		115			129			76			152			138		
	241	**Old Arad**	161		23			24			18			31			29		
	242	**Old Arad**	474		58			39			57			77			140		
	243	**New Arad**	496		42			59			82			158			137		
	244	**New Arad**	1248		174			169			130			249			296		
	245	**New Arad**	507		70			38			50			86			81		
	246	**New Arad**	142		5			9			5			11			49		
	247	**Halat Al-Sletah**	74		12			13			8			16			12		
	248	**Halat Al-Neaim**	119		6			8			4			37			40		
Hoora	**305**	**Fadhil**	597	**5149**	38	**309**	**6%**	141	**1325**	**26%**	151	**1648**	**32%**	181	**1792**	**35%**	**275**	**2109**	**41%**
	306	**Ras Ruman**	1045		71			223			274			295			**435**		
	307	**Dawadhah**	418		31			113			104			120			**179**		
	308	**Awal Cinema**	550		26			140			178			184			**192**		
	316	**Govt. House**	1		0			3			8			1			**10**		
	317	**Diplomatic area**	57		4			12			38			7			**23**		
	318	**Hoora**	978		58			305			401			389			383		
	321	**Gudaibiya**	1470		79			384			486			608			602		
	325	**Gudaibiya**	33		2			4			8			7			10		
HTBG	**579**	**Janubiya south**	271	**9185**	39	**706**	**8%**	19	**1295**	**14%**	68	**1194**	**13%**	72	**1785**	**19%**	120	**1760**	**19%**
	752	**West Sh. Khalifa H/W**	250		20			43			24			52			**60**		
	754	**Buri**	275		16			47			56			68			**59**		
	756	**Buri**	167		10			35			21			46			**61**		
	758	**Buri**	129		6			21			30			49			**36**		
	760	**Buri**	28		1			0			5			3			**5**		
	762	**South of Causeway**	7		0			0			0			1			0		
	947	**Safra**	0		1			0			0			0			0		
	1001	**Jasra part**	83		8			7			5			8			**5**		

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	1002	**Jasra -51**	191		4			35			19			36			**30**		
	1003	**Jasra part**	37		3			3			9			6			**10**		
	1004	**Jasra part**	152		10			23			17			23			**19**		
	1006	**Hamala**	138		7			14			17			8			**17**		
	1009	**Hamala**	9		2			2			0			3			**3**		
	1010	**Hamala**	502		51			75			49			99			**128**		
	1012	**Hamala**	149		21			31			33			30			**48**		
	1014	**Hamala**	406		36			70			45			83			100		
	1017	**Dumistan (west)**	46		3			7			8			10			**7**		
	1018	**Karzakan**	320		5			2			14			59			**57**		
	1019	**Dumistan (west)**	464		28			78			65			85			**83**		
	1020	**Dumistan**	284		4			6			29			6			**16**		
	1022	**Dumistan (east)**	557		32			59			64			82			**73**		
	1025	**Karzakan(west)**	281		26			36			31			48			**51**		
	1026	**Karzakan(east)**	441		54			75			57			112			**86**		
	1027	**Karzakan(west)**	22		1			3			14			0			**7**		
	1028	**Karzakan(east)**	89		9			20			9			16			**12**		
	1032	**Malkiya (east)**	270		38			21			24			33			**40**		
	1033	**Malkiya (west)**	816		41			58			56			87			**108**		
	1034	**Malkiya**	763		77			80			85			113			**143**		
	1037	**Sadad**	158		16			23			17			30			**23**		
	1038	**Sadad(east)**	69		8			30			6			9			13		
	1205	**Hamad Town**	1404		110			239			258			401			275		
	1207	**Hamad Town**	407		19			133			59			107			65		
HTBT	**906**	**Rowdah Palace area**	9	**5045**	1	**319**	**6%**	13	**1119**	**22%**	3	**914**	**18%**	4	**1479**	**29%**	3	**915**	**18%**
	924	**Jarai Al Sheikh**	110		7			18			23			54			37		
	928	**Wadi Salih**	398		17			113			42			79			83		
	930	**Rowdah Palace**	1		0			0			0			0			0		
	1204	**NH-1 District -1**	927		67			226			224			309			187		
	1206	**NH-2 District -1**	783		32			201			146			252			119		
	1208	**Distric-2**	847		63			184			141			271			**150**		
	1209	**Distric-3**	836		66			147			134			211			**167**		
	1210	**Distric-2**	1134		66			217			201			299			169		
HTDG	**976**	**Sakher**	1	**8470**	0	**678**	**8%**	0	**1220**	**14%**	0	**1433**	**17%**	0	**1869**	**22%**	0	**2469**	**29%**
	985	**Al Shakir**	0		1			0			0			0			0		
	1038	**Sadad(West)**	279		32			30			18			37			53		
	1041	**Sharakan (west)**	3		0			0			1			0			**1**		
	1042	**Sharakan M.O.H**	164		14			23			29			38			**28**		
	1044	**Sharakan Villages**	142		12			15			10			16			**40**		
	1046	**Dar-Kulayb,V.I.P**	363		24			62			39			71			**62**		

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		area																	
	1048	**Dar-Kulayb,V.I.P area**	335		23			22			40			42			**35**		
	1051	**Near Baheira Garden**	2		0			0			1			0			0		
	1052	**North of Bapco beach**	6		0			2			2			1			**2**		
	1054	**University area+Al Areen+Wadi Ali**	2		0			1			0			2			**0**		
	1055	**University, Al-Areen, Sakher**	67		2			3			6			4			**4**		
	1056	**Zallaq**	353		11			11			15			24			**83**		
	1057	**Zallaq**	340		24			35			41			44			42		
	1058	**Wasmiya Palace**	0		0			0			1			0			0		
	1061	**Wasmiya**	4		0			1			1			4			4		
	1063	**Al Jazayir Beach**	293		19			17			29			34			61		
	1064	**Al Jazayir Beach**	0		0			0			0			0			0		
	1067	**Al Jazayir Beach**	7		1			0			0			0			3		
	1203	**Hamad Town**	914		109			106			183			189			253		
	1211	**Hamad Town**	1061		62			209			320			408			**239**		
	1212	**Hamad Town**	181		2			9			10			21			**32**		
	1213	**Hamad Town**	266		16			49			152			84			**83**		
	1214	**Hamad Town**	917		50			167			173			261			**602**		
	1215	**Hamad Town**	236		19			24			26			47			**67**		
	1216	**Hamad Town**	1014		54			216			187			293			**458**		
	721	**Jidali**	779		104			67			70			111			166		
	813	**Isa Town**	161		12			66			23			28			21		
	814	**Isa Town**	428		80			72			39			78			74		
	934	**Rifaa**	27		2			5			4			5			4		
	941	**Near GDN**	125		5			8			13			27			52		
Isa Town-East	**721**	Jidali	779	**5091**	104	**667**	**13%**	67	**583**	**11%**	70	**738**	**14%**	112	**750**	**15%**	166	**1136**	**22%**
	729	Jurdab	855		80			110			127			149			190		
	733	H.E.Sh. Mubarak residence	272		42			24			63			24			45		
	743	Sanad	829		119			100			77			107			183		
	745	Sanad	1002		123			105			121			153			304		
	815	Isa Town M.O.H	693		113			91			164			113			**132**		
	816	North of Gosi market	661		86			86			116			92			**116**		
Isa Town-R\R	**635**	**Mameer Industrial area (West)**	58	**3894**	3	**292**	**7%**	12	**437**	**11%**	14	**497**	**13%**	26	**784**	**20%**	**25**	**1244**	**32%**
	636	**Mameer Industrial area**	4		1			0			1			0			**3**		

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Isa Town-West	**643**	**Nuwaydirat**	415	**7705**	39	**762**	**10%**	50	**1049**	**14%**	65	**1050**	**14%**	102	**1649**	**21%**	**151**	**1946**	**25%**
	645	**Sanad**	209		10			10			11			20			**41**		
	646	**Nuwaydirat**	371		26			41			53			90			**259**		
	907	**East of Suq area(Partly booster area)**	879		53			119			141			156			166		
	909	**High area(Partly booster area)**	594		50			59			55			112			114		
	911	**A.M.Al Ali block factory**	321		24			26			45			47			81		
	939	**North East Rifaa**	924		79			106			97			194			340		
	949	**Rifaa Power station**	22		6			6			6			11			15		
	951	**Alba Industrial**	50		1			1			1			1			46		
	952	**Addur area**	94		0			7			8			25			3		
	623	**East Aker**	161		31			17			58			85			**109**		
	624	**West Aker**	343		36			60			50			87			**88**		
	625	**West Aker**	415		1			35			9			3			**6**		
	626	**West Aker**	5		35			1			26			88			**73**		
	633	**Mameer Village**	353		35			44			70			105			**120**		
	634	**Mameer Industrial area(East)**	520		46			75			68			96			**132**		
	644	**Nuwaydirat**	303		42			55			42			133			161		
	701	**Tubli East of Toyota garage**	417		48			58			30			64			41		
	702	**Salmabad**	25		2			4			10			0			3		
	704	**Salmabad**	798		73			118			184			166			209		
	706	**Salmabad**	278		11			56			54			53			90		
	712	**Salmabad**	22		2			0			6			5			10		
	718	**Salmabad**	224		0			0			6			26			31		
	720	**Zayed Town**	268		8			19			15			8			10		
	801	**Isa Town strip Riyadh Avenue**	105		6			11			25			28			**65**		
	802	**Youth Centre**	122		11			14			14			18			**41**		
	803	**Marhaba market south**	59		5			13			8			10			**19**		
	804	**North of stadium**	225		16			21			32			35			**37**		
	805	**Opp. Isa Town strip**	275		25			34			33			53			**48**		
	806	**Near Matam**	322		29			77			29			48			**71**		
	807	**East of Isa Town market**	261		23			32			18			55			**60**		
	808	**North of stadium**	358		36			51			33			76			**76**		
	809	**Isa Town Fire**	172		16			0			24			63			**34**		

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		station																	
	810	**Near stadium**	155		29			22			36			45			**55**		
	812	**Isa Town**	809		102			83			83			172			230		
	813	**M.O.H booster area**	242		19			66			35			42			32		
	814	**Isa Town M.O.H**	428		70			72			39			78			73		
	840	**Ministry of Education & Schools**	7		0			4			6			4			**10**		
	841	**Ministry of Education & Schools**	6		4			2			6			1			**11**		
	934	**Rifaa**	27		1			5			1			2			1		
Jannusan	**426**	**BI Hospital**	34	**4242**	3	**326**	**8%**	7	**631**	**15%**	10	**1005**	**24%**	15	**890**	**21%**	10	**824**	**19%**
	438	**Qalah**	105		4			7			12			6			20		
	444	**Halat Abdul saleh**	112		6			19			20			28			10		
	449	**Al Qadam**	94		7			19			27			13			26		
	450	**Maqsha**	567		42			107			121			103			102		
	453	**Al Qadam**	42		1			6			11			7			10		
	454	**karana**	186		10			33			54			67			51		
	456	**karana**	210		25			36			43			47			52		
	458	**karana**	99		3			12			25			20			**18**		
	460	**karana**	240		32			21			54			61			**51**		
	463	**Al Hajar**	79		5			13			24			19			**21**		
	465	**Al Hajar**	83		7			9			22			7			**9**		
	469	**Abu Saiba**	105		3			23			50			23			**13**		
	471	**Abu Saiba**	139		10			16			40			22			**17**		
	473	**Abu Saiba**	122		10			15			30			30			**15**		
	475	**Abu Saiba**	190		14			30			38			49			**32**		
	477	**Shakura**	135		4			24			46			34			**26**		
	479	**Shakura**	74		8			19			27			29			**19**		
	481	**Shakura**	478		43			23			28			43			**62**		
	502	**Janusan**	281		21			61			114			93			**72**		
	504	**Janusan**	41		10			6			10			14			**9**		
	505	**Magaba**	194		16			38			57			47			**47**		
	506	**Janusan**	213		10			21			67			43			**59**		
	507	**Magaba**	249		22			36			43			27			41		
	508	**Janusan**	20		1			7			4			2			8		
	514	**Jid Al Haj**	150		9			23			28			41			24		
Mahooz	**324**	**Al Fatheh mosque**	1022	**4806**	124	**515**	**11%**	122	**744**	**15%**	143	**885**	**18%**	119	**900**	**19%**	387	**1520**	**32%**
	325	**Gudaibiya**	100		6			12			24			22			30		
	326	**Ramatha hotel**	99		15			26			36			27			50		

Tank Name	Block	Area name	No. of Water Connection / block	No. of Water Connection	2011			2012			2013			2014			2015		
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	333	**Umm Al Hassam**	405		30			83			109			94			169		
	334	**Mahooz**	422		44			62			73			99			**125**		
	335	**Umm Al Hassam**	210		17			40			33			60			**78**		
	336	**Adliya south**	159		24			30			26			43			**29**		
	337	**Umm Al Hassam**	510		59			78			94			119			**121**		
	338	**Gulf hotel**	191		15			31			41			38			**59**		
	339	**Umm Al Hassam**	223		13			27			42			35			**126**		
	340	**Juffair north**	251		23			40			62			36			**61**		
	341	**Juffair**	502		45			82			97			82			**120**		
	342	**Guraifa**	210		24			44			38			65			**85**		
	343	**Mina Salman**	59		5			24			15			10			**14**		
	380	**Nabi Saleh**	105		12			15			23			15			**19**		
	381	**Nabi Saleh**	146		14			19			15			18			**27**		
	382	**Nabi Saleh**	192		45			9			14			18			**20**		
Mmuharraq 'C'	**203**	**Al Amara**	1261	**9108**	119	**825**	**9%**	270	**1942**	**21%**	327	**2160**	**24%**	290	**2192**	**24%**	297	**2453**	**27%**
	205	**Al Amara**	644		63			111			165			140			183		
	206	**Al Hayayek**	505		73			140			159			138			206		
	207	**MOH**	231		21			45			59			63			75		
	208	**Ali Bin Ali**	900		66			146			149			179			231		
	209	**Sh. Abdulla**	485		24			129			109			123			136		
	210	**Al Bukhames**	476		53			88			107			91			124		
	211	**Al Binkhter**	466		45			108			125			137			140		
	212	**Al Bukhames**	418		29			68			89			88			65		
	213	**Kasaseeb**	691		53			173			192			176			182		
	214	**Sh. Abdulla**	440		40			120			110			109			92		
	215	**Al Zayani**	391		33			105			81			101			106		
	216	**Bhomaher**	1025		110			211			188			249			283		
	217	**MOH**	7		3			0			0			1			3		
	221	**Busatin MOH**	236		22			45			69			70			77		
	222	**Busatin MOH**	87		2			15			22			28			38		
	225	**Busatin**	223		25			59			73			75			70		
	227	**Busatin**	622		44			109			136			134			145		
Mussalla	**354**	**Burhama**	48	**4968**	5	**532**	**11%**	3	**686**	**14%**	9	**769**	**15%**	8	**841**	**17%**	**12**	**1073**	**22%**
	356	**Salhiya**	424		48			53			61			88			**82**		
	357	**Burhama**	30		3			5			14			7			**17**		
	358	**Bilad Al Qadim**	58		9			6			10			9			**19**		
	359	**Bilad Al Qadim**	232		21			39			25			45			**51**		
	360	**Bilad Al Qadim**	159		24			12			17			21			**17**		
	361	**Bilad Al Qadim**	246		26			44			31			25			**38**		
	362	**Bilad Al Qadim**	283		38			44			51			63			**62**		
	363	**Bilad Al Qadim**	441		52			64			84			87			**109**		

Tank Name	Block	Area name	No. of Water Connection / block	No. of Water Connection	2011			2012			2013			2014			2015		
					No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect
	364	**Bilad Al Qadim**	173		25			35			37			31			**50**		
	365	**Khamis**	210		23			36			33			42			**65**		
	366	**Khamis**	6		24			2			0			3			**2**		
	367	**Abu Baham**	86		17			12			5			13			**17**		
	368	**South Sehla**	164		15			26			19			35			**52**		
	369	**South Sehla**	7		0			0			1			3			**4**		
	405	**Tashan**	195		24			20			56			42			39		
	407	**Tashan**	158		11			32			52			14			48		
	411	**Al Musalla**	277		34			37			41			44			60		
	413	**Al Musalla**	120		4			4			12			11			21		
	419	**Tashan- MOH**	380		26			55			39			75			65		
	421	**Jidhafs**	235		19			28			35			37			56		
	423	**Jidhafs**	369		44			53			74			57			70		
	425	**Jidhafs**	667		40			76			63			81			117		
North Muharraq	**202**	**Muharraq**	458	**5002**	43	**497**	**10%**	51	**549**	**11%**	74	**579**	**12%**	93	**792**	**16%**	95	**1008**	**20%**
	204	**Muharraq**	316		37			54			68			67			71		
	223	**Busatin**	24		0			6			6			8			8		
	224	**Busatin**	43		3			10			20			19			16		
	226	**Busatin**	1169		117			198			143			226			271		
	228	**Busatin**	1647		92			75			75			125			259		
	231	**Dair Village**	635		110			80			91			104			138		
	232	**Dair Village**	365		48			44			56			100			88		
	233	**Dair Village**	345		47			31			46			50			62		
Saar	**507**	**Magaba**	250	**4591**	22	**261**	**6%**	36	**652**	**14%**	42	**1091**	**24%**	28	**1019**	**22%**	40	**1162**	**25%**
	509	**Magaba**	216		11			36			66			38			67		
	513	**Saar**	284		24			14			58			57			54		
	515	**Saar**	145		6			27			52			17			39		
	517	**Saar**	351		16			77			93			101			67		
	521	**Saar**	177		6			44			61			49			45		
	523	**Saar**	570		22			114			183			175			127		
	525	**Saar**	444		29			53			91			92			106		
	527	**Saar**	210		11			14			21			52			24		
	533	**Markh**	356		8			69			133			98			79		
	571	**Janabiya**	318		24			47			83			85			79		
	575	**Janabiya**	1098		62			104			172			197			279		
	577	**Janabiya**	141		16			15			28			22			23		
	579	**Janabiya**	31		4			2			8			8			133		
Salmaniya	**301**	**Hamam**	639	**7261**	287	**713**	**10%**	222	**2055**	**28%**	207	**1931**	**27%**	311	**2535**	**35%**	**868**	**3764**	**52%**
	302	**Makarga**	1090		35			481			477			525			**908**		
	303	**Naim**	502		16			143			130			154			**315**		
	304	**Kanoo**	950		65			239			143			579			**370**		

Tank Name	Block	Area name	No. of Water Connection / block	No. of Water Connection	2011			2012			2013			2014			2015		
					No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect	No. of Defect/ block	No. of Defect / Tank	% Defect
	307	**Dawadah-**	46		4			113			12			13			20		
	309	**Salmaniya**	234		14			57			70			75			**53**		
	310	**Salmaniya**	72		2			14			13			35			**15**		
	311	**Salmaniya**	363		24			112			110			94			**104**		
	312	**Gafool**	370		31			84			102			110			**136**		
	313	**Fire station**	8		32			2			4			4			**11**		
	314	**Naim**	411		49			84			122			102			**121**		
	315	**Delmon hotel**	10		2			9			11			2			**13**		
	327	**Adliya**	648		53			87			108			118			**188**		
	328	**Sugaiya**	449		25			153			149			109			**133**		
	329	**Salmaniya**	254		23			96			106			76			**87**		
	330	**Zinj**	478		17			70			79			95			**237**		
	331	**Zinj**	84		7			29			17			28			**19**		
	332	**Zinj**	492		22			39			55			72			119		
	333	**Bugazal (excluding MOH)**	44		3			9			3			10			19		
	373	**South of US Embassy**	117		2			12			13			23			28		
Samahij	**234**	**Samahij**	242	**6115**	25	**716**	**12%**	24	**429**	**7%**	31	**374**	**6%**	45	**701**	**11%**	44	**1095**	**18%**
	235	**Samahij**	265		27			49			36			73			68		
	236	**Samahij**	808		63			90			71			112			143		
	237	**Samahij**	6		1			0			4			0			3		
	251	**Galali**	329		103			31			14			30			38		
	252	**Galali**	324		41			49			40			64			55		
	253	**Galali**	312		31			36			19			61			72		
	254	**Galali**	1186		78			56			39			89			155		
	255	**Galali**	647		47			44			46			90			97		
	256	**Galali**	0		0			0			0			0			0		
	257	**Amwaj Island**	1993		300			50			73			136			420		
	258	**Al Dayar Island**	3		0			0			1			1			0		
	346	**Reef ilands**	265		2			2			6			30			**187**		
	351	**Burhama**	1098		6			3			16			24			**65**		
	353	**Burhama**	92		9			24			16			19			12		
	402	**Sanabis**	318		11			30			80			56			82		
	404	**Sanabis**	458		36			87			164			87			130		
Sanabis	**406**	**Sanabis**	410	**4964**	28	**290**	**6%**	101	**621**	**13%**	124	**992**	**20%**	92	**777**	**16%**	88	**1220**	**25%**
	408	**Sanabis**	259		6			64			167			72			58		
	410	**Sanabis**	2		20			1			11			3			1		
	412	**Daih**	297		59			49			50			63			63		
	414	**Daih**	576		28			77			113			105			131		
	422	**Jidhafs**	247		16			44			50			56			86		

Tank Name	Block	Area name	No. of Water Connection / block	No. of Water Connection	2011			2012			2013			2014			2015		
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	424	**Jidhafs**	89		16			16			12			17			20		
	426	**Jidhafs**	35		4			7			10			15			9		
	428	**Seef District**	54		8			23			43			16			140		
	430	**Karbabad**	211		15			23			25			41			41		
	432	**Karbabad**	267		16			25			50			34			56		
	434	**Karbabad**	200		8			30			33			34			31		
	436	**Seef District**	86		2			15			22			13			20		
Sitra	**601**	**Sitra Industrial area**	114	**4468**	15	**333**	**7%**	32	**481**	**11%**	53	**727**	**16%**	33	**947**	**21%**	**34**	**867**	**19%**
	602	**Sitra Mahazza**	520		27			59			65			107			**85**		
	603	**Hala**	324		34			37			44			76			**73**		
	604	**Al Qaraya**	834		61			70			157			175			**173**		
	605	**Markoban**	365		33			46			57			85			**84**		
	606	**Kharjiya**	801		55			85			119			161			**153**		
	607	**Abu Al Aysh**	385		29			39			65			81			**77**		
	608	**Wadiyan**	837		56			85			120			173			**137**		
	609	**Saffala**	252		19			17			22			33			**26**		
	611	**Hamriya**	12		1			2			6			7			**7**		
	614	**Umm Al - Aysh**	1		0			0			0			0			**2**		
	615	**Umm Al Bayd**	20		3			5			11			9			**13**		
	616	**Umm Al Bayd**	3		0			4			8			7			**3**		
SKBS	**115**	**HIDD Power Station,Port,Industrial area**	95	**168**	2	**7**	**4%**	14	**32**	**19%**	14	**59**	**35%**	37	**75**	**45%**	**32**	**66**	**39%**
	116	**Steel plant**	15		4			7			9			4			**11**		
	117	**Hidd**	58		1			11			33			34			**21**		
	128	**Asray**	0		0			0			3			0			**2**		
South Alba	**943**	**Rifaa view**	876	**1451**	5	**89**	**6%**	15	**99**	**7%**	16	**122**	**8%**	40	**158**	**11%**	462	**706**	**49%**
	945	**Rifaa View**	1		0			0			1			0			0		
	948	**Rifaa View**	3		0			0			1			3			0		
	950	**Asker**	299		29			45			55			69			132		
	951	**Alba Industrial**	57		4			20			22			17			64		
	954	**Ras Abu Jarjur**	0		0			0			0			0			0		
	957	**Addur area**	0		0			0			0			0			0		
	958	**Addur area**	2		0			0			2			0			1		
	960	**Addur area**	188		41			15			17			27			38		
	961	**Addur area**	2		0			0			1			2			0		
	965	**Addur area**	27		8			3			5			0			6		
	967	**Sh. Isa Air base**	3		2			1			2			0			3		
	981	**Al Rumai**	0		0			0			0			0			0		
Toubli	**701**	**Tubli**	483	**3497**	31	**340**	**10%**	51	**441**	**13%**	88	**475**	**14%**	21	**494**	**14%**	124	**812**	**23%**

Tank Name	Block	Area name	No. of Water Connection / block	No. of Water Connection	2011			2012			2013			2014			2015		
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	705	**Tubli**	512		46			74			103			89			159		
	707	**Tubli**	168		11			26			26			19			40		
	709	**Tubli**	414		50			51			66			87			101		
	711	**Tubli**	1035		94			84			102			150			187		
	713	**Tubli**	107		4			21			20			16			35		
	721	**Jid Ali**	778		104			134			70			112			166		
	902	**Near W/Riffa Health center**	252		14			24			30			61			37		
	903	**Hananiya area**	77		21			60			10			14			19		
	904	**Amiri Court**	273		5			40			52			113			71		
	906	**Near H.H Sh.Mohd. Majlis**	54		8			13			17			26			18		
	908	**Near Amiri garage**	250		16			37			55			55			51		
	910	**W-Riffa M.O.H./Sh. Khalid's Res. Booster area**	401		27			62			80			98			114		
	912	**South of Riffa Depot**	393		29			62			92			120			133		
West Rifaa	**920**	**North/West of Blending station**	60	**3107**	5	**176**	**6%**	13	**517**	**17%**	20	**537**	**17%**	15	**866**	**28%**	38	**815**	**26%**
	922	**Riffa**	75		1			12			10			21			18		
	926	**North of Blending station**	175		5			31			38			98			74		
	928	**BDF Hospital & M.O.H. area**	597		25			113			64			118			124		
	940	**Hunainiya play ground**	0		0			0			0			0			0		
	942	**Hunainiya play ground**	3		0			0			0			0			3		
	944	**Safra**	424		20			49			53			116			99		
	945	**Awali**	1		0			0			1			0			0		
	946	**Awali**	74		0			1			15			11			16		
	708	**Salmabad**	440		10			39			33			55			50		
	714	**Salmabad**	235		7			9			32			27			80		
	730	**Training school**	97		11			22			38			40			47		
	732	**Municipality**	285		22			73			126			89			**149**		
	734	**Municipality**	541		42			114			201			194			**135**		
WRBG	**736**	**A'Ali M.O.H**	723	**4114**	57	**291**	**7%**	117	**626**	**15%**	255	**1068**	**26%**	223	**1012**	**25%**	**149**	**1051**	**26%**
	738	**North of Mansoor Al A'li Villa**	501		35			69			120			143			**147**		
	740	**A'Ali Village**	320		33			44			81			45			**74**		
	742	**North of Health Centre**	612		51			83			112			95			**123**		

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	744	A'Ali Village-Farm area	49		3			6			18			9			29		
	746	South of A'Ali M O H	223		16			43			44			69			48		
	748	South of A'Ali M O H	88		4			7			8			23			20		
Total			140,037	139,981	12,014	12,014	9%	20,929	20,929	15%	25,231	25,231	18%	30,253	30,253	22%	36,624	36,624	26%

Specification of Domestic Water Meter

(S-4419-F)

Water Distribution Directorate
Maintenance & Engineering Services

Metering Unit
Water Meter Flow Test Form

Report No: TBR_201693_0260

EWA
هيئة الكهرباء والماء
Electricity & Water Authority
Kingdom of Bahrain

Meter Type : SENSUS **Meter Size :** 15 mm **Date :** 03/ 09/ 16

Maximum Flow rate : 2931.3 Lit/Hr Water Measured Quantity : 105.0 Lit Process Time: 02:08 (± 2%)

WaterMeter Serial Number	Initial Reading	Final Reading	Measured Qauntity Lit	Error %	Result
08k048040	08181287.5	08181388.0	100.5	-4.3	FAIL
09k018837	02878360.5	02878463.5	103.0	-1.9	PASS
08k015376	06560718.5	06560818.5	100.0	-4.8	FAIL
33735330	03114678.0	03114788.0	110.0	4.8	FAIL

Nominal Flow rate : 1431.7 Lit/Hr Water Measured Quantity : 102.0 Lit Process Time: 04:15 (± 2%)

08k048040	08181388.0	08181488.0	100.0	-2.0	PASS
09k018837	02878463.5	02878564.5	101.0	-1.0	PASS
08k015376	06560818.5	06560917.5	99.0	-2.9	FAIL
33735330	03114788.0	03114896.0	108.0	5.9	FAIL

Minimum Flow rate : 926.08 Lit/Hr Water Measured Quantity : 11.0 Lit Process Time: 00:40 (± 5%)

08k048040	08181488.0	08181498.5	10.5	-4.5	PASS
09k018837	02878564.5	02878575.0	10.5	-4.5	PASS
08k015376	06560917.5	06560928.5	11.0	0.0	PASS
33735330	03114896.0	03114912.0	16.0	45.5	FAIL

Tested By : (Mech.Fitter) razak

Checked By : (~~Mech. Technician~~)
HESG.

ELECTRICITY AND WATER AUTHORITY
WATER DISTRIBUTION DIRECTORATE

Water Distribution Directorate
Maintenance & Engineering Services

Metering Unit
Water Meter Flow Test Form

Report No: TBR_201693_0262

EWA
هيئة الكهرباء والماء
Electricity & Water Authority
Kingdom of Bahrain

Meter Type : SENSUS **Meter Size :** 15 mm **Date :** 03/ 09/ 16

Maximum Flow rate : 2645.3 Lit/Hr Water Measured Quantity : 104.0 Lit Process Time: 02:15 (± 2%)

WaterMeter Serial Number	Initial Reading	Final Reading	Measured Qauntity Lit	Error %	Result
10p011968	03544044.5	03544144.8	100.3	-3.6	FAIL
12s013752	02920994.3	02920995.5	1.3	-98.8	FAIL
09k011013	09111288.0	09111288.0	0.0	-100.	FAIL
08k024830	01883228.8	01883330.8	102.0	-1.9	PASS

Nominal Flow rate : 1267.0 Lit/Hr Water Measured Quantity : 102.0 Lit Process Time: 04:44 (± 2%)

10p011968	03544144.8	03544245.3	100.5	-1.5	PASS
12s013752	02920995.5	02920995.3	-0.3	-100.	FAIL
09k011013	09111288.0	09111288.0	0.0	-100.	FAIL
08k024830	01883330.8	01883431.8	101.0	-1.0	PASS

Minimum Flow rate : 801.83 Lit/Hr Water Measured Quantity : 21.0 Lit Process Time: 01:31 (± 5%)

10p011968	03544245.3	03544265.5	20.3	-3.6	PASS
12s013752	02920995.3	02920995.3	0.0	-100.	FAIL
09k011013	09111288.0	09111288.0	0.0	-100.	FAIL
08k024830	01883431.8	01883451.6	19.9	-5.4	FAIL

Tested By : (Mech.Fitter) Habib yosif (Abu Nas

Checked By : (~~Mech. Technician~~) HESG

ELECTRICITY AND WATER AUTHORITY
WATER DISTRIBUTION DIRECTORATE

Water Distribution Directorate
Maintenance & Engineering Services

Metering Unit
Water Meter Flow Test Form

Report No: TBR_201693_0261

EWA
هيئة الكهرباء والماء
Electricity & Water Authority
Kingdom of Bahrain

Meter Type : SENSUS **Meter Size :** 15 mm **Date :** 03/ 09/ 16

Maximum Flow rate : 2989.1 Lit/Hr Water Measured Quantity : 105.0 Lit Process Time: 02:05 (± 2%)

WaterMeter Serial Number	Initial Reading	Final Reading	Measured Qauntity Lit	Error %	Result
10p011968	02698691.8	02698710.8	19.0	-81.9	FAIL
10p021270	01314355.8	01314454.5	98.8	-6.0	FAIL
11p011896	01133487.3	01133591.3	104.0	-1.0	PASS
11p004437	03867884.5	03867928.5	44.0	-58.1	FAIL

Nominal Flow rate : 1492.4 Lit/Hr Water Measured Quantity : 102.0 Lit Process Time: 04:02 (± 2%)

10p011968	02698710.8	02698710.8	0.0	-100.	FAIL
10p021270	01314454.5	01314553.8	99.3	-2.7	FAIL
11p011896	01133591.3	01133692.6	101.4	-0.6	PASS
11p004437	03867928.5	03867942.5	14.0	-86.3	FAIL

Minimum Flow rate : 992.54 Lit/Hr Water Measured Quantity : 11.0 Lit Process Time: 00:37 (± 5%)

10p011968	02698710.8	02698710.8	0.0	-100.	FAIL
10p021270	01314553.8	01314562.8	9.0	-18.2	FAIL
11p011896	01133692.6	01133703.0	10.4	-5.7	FAIL
11p004437	03867942.5	03867942.5	0.0	-100.	FAIL

Tested By : (Mech.Fitter) razak

Checked By : (Mech. Technician)

ELECTRICITY AND WATER AUTHORITY
WATER DISTRIBUTION DIRECTORATE

Water Distribution Directorate
Maintenance & Engineering Services

Metering Unit
Water Meter Flow Test Form

Report No: TBR_201693_0264

EWA
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Electricity & Water Authority
Kingdom of Bahrain

Meter Type : SENSUS **Meter Size :** 15 mm **Date :** 03/ 09/ 16

Maximum Flow rate : 3411.0 Lit/Hr Water Measured Quantity : 206.0 Lit Process Time: 03:36 (± 2%)

WaterMeter Serial Number	Initial Reading	Final Reading	Measured Qauntity Lit	Error %	Result
12s009937	02189537.5	02189737.0	199.5	-3.2	FAIL
12S000526	01480978.8	01481080.3	101.5	-50.7	FAIL
07K009116	02648177.3	02648177.0	-0.3	-100.	FAIL
09K002287	07494346.0	07494543.0	197.0	-4.4	FAIL

Nominal Flow rate : 1697.5 Lit/Hr Water Measured Quantity : 102.0 Lit Process Time: 03:34 (± 2%)

12s009937	02189737.0	02189838.0	101.0	-1.0	PASS
12S000526	01481080.3	01481128.3	48.0	-52.9	FAIL
07K009116	02648177.0	02648177.0	0.0	-100.	FAIL
09K002287	07494543.0	07494642.5	99.5	-2.5	FAIL

Minimum Flow rate : 1125.4 Lit/Hr Water Measured Quantity : 51.0 Lit Process Time: 02:41 (± 5%)

12s009937	02189838.0	02189887.5	49.5	-2.9	PASS
12S000526	01481128.3	01481150.5	22.3	-56.4	FAIL
07K009116	02648177.0	02648177.0	0.0	-100.	FAIL
09K002287	07494642.5	07494691.5	49.0	-3.9	PASS

Tested By : (Mech.Fitter) Habib yosif (Abu Nas

Checked By : (~~Mech. Technician~~) HESA

ELECTRICITY AND WATER AUTHORITY
WATER DISTRIBUTION DIRECTORATE

Water Distribution Directorate
Maintenance & Engineering Services

Metering Unit
Water Meter Flow Test Form

Report No: TBR_201693_0263

EWA
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Electricity & Water Authority
Kingdom of Bahrain

Meter Type : SENSUS **Meter Size :** 15 mm **Date :** 03/ 09/ 16

Maximum Flow rate : 3072.9 Lit/Hr Water Measured Quantity : 105.0 Lit Process Time: 02:01 (± 2%)

WaterMeter Serial Number	Initial Reading	Final Reading	Measured Qauntity Lit	Error %	Result
07p006944	02739066.5	02739167.5	101.0	-3.8	FAIL
07p013464	20324944.0	20324944.0	0.0	-100.	FAIL
08k035850	00484713.5	00484816.2	102.7	-2.2	FAIL
09k010517	02995947.3	02996049.8	102.5	-2.4	FAIL

Nominal Flow rate : 1521.3 Lit/Hr Water Measured Quantity : 102.0 Lit Process Time: 03:58 (± 2%)

07p006944	02739167.5	02739267.3	99.8	-2.2	FAIL
07p013464	20324944.0	20324944.0	0.0	-100.	FAIL
08k035850	00484816.2	00484917.5	101.3	-0.7	PASS
09k010517	02996049.8	02996150.5	100.8	-1.2	PASS

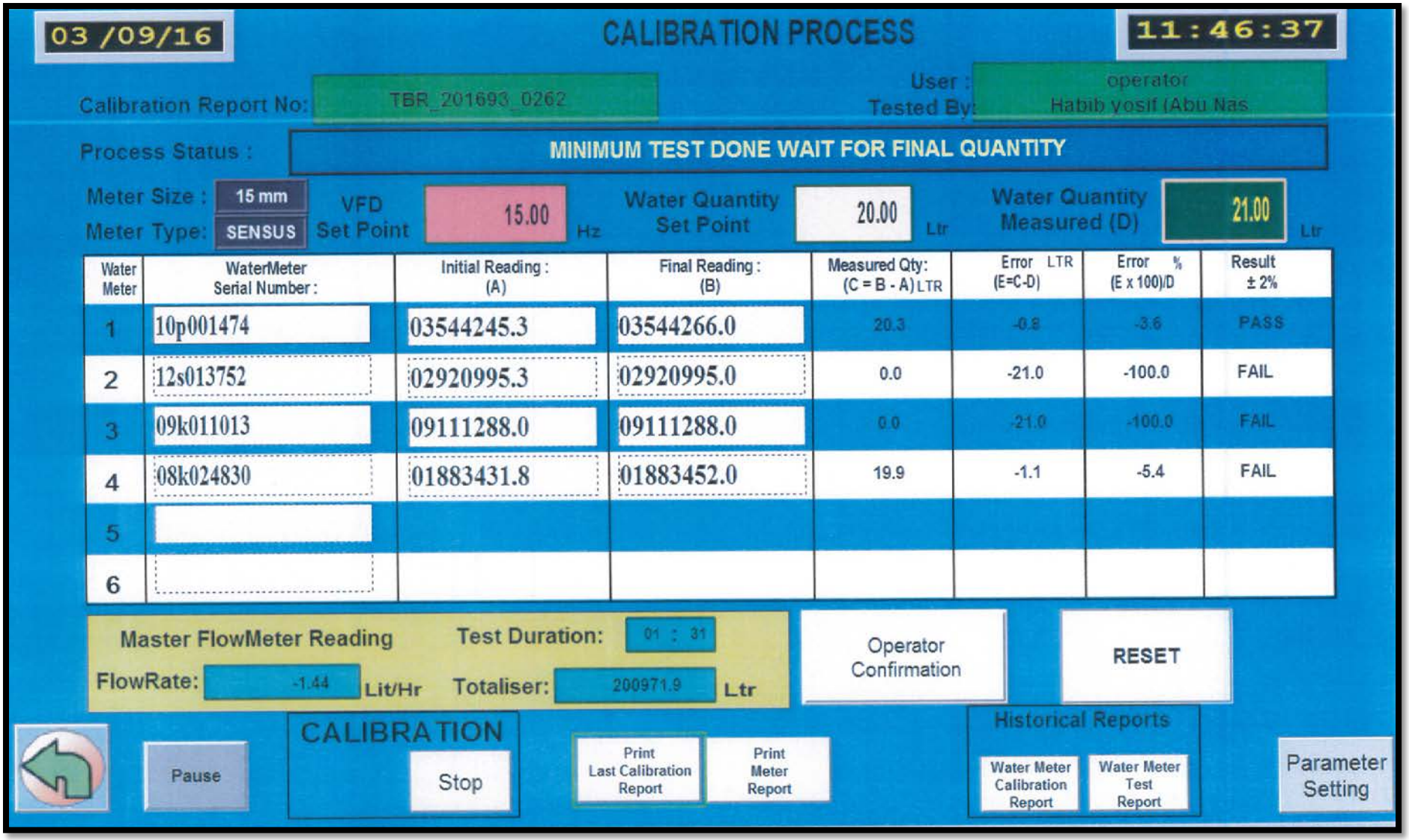
Minimum Flow rate : 1012.7 Lit/Hr Water Measured Quantity : 21.0 Lit Process Time: 01:13 (± 5%)

07p006944	02739267.3	02739288.5	21.3	1.2	PASS
07p013464	20324944.0	20324944.0	0.0	-100.	FAIL
08k035850	00484917.5	00484938.5	21.0	0.0	PASS
09k010517	02996150.5	02996170.3	19.8	-6.0	FAIL

Tested By : (Mech.Fitter) Habib yosif (Abu Nas

Checked By : (Mech. Technician) HESG

ELECTRICITY AND WATER AUTHORITY
WATER DISTRIBUTION DIRECTORATE


03 /09/16
CALIBRATION PROCESS
11:46:37
Calibration Report No: TBR_201693_0262
User : operator
Tested By: Habib yosif (Abu Nas
Process Status : MINIMUM TEST DONE WAIT FOR FINAL QUANTITY
Meter Size : 15 mm
Meter Type: SENSUS
VFD Set Point 15.00 Hz
Water Quantity Set Point 20.00 Ltr
Water Quantity Measured (D) 21.00 Ltr
Water Meter | WaterMeter Serial Number : | Initial Reading : (A) | Final Reading : (B) | Measured Qty: (C = B - A) LTR | Error LTR (E=C-D) | Error % (E x 100)/D | Result ± 2%
1 | 10p001474 | 03544245.3 | 03544266.0 | 20.3 | -0.8 | -3.6 | PASS
2 | 12s013752 | 02920995.3 | 02920995.0 | 0.0 | -21.0 | -100.0 | FAIL
3 | 09k011013 | 09111288.0 | 09111288.0 | 0.0 | -21.0 | -100.0 | FAIL
4 | 08k024830 | 01883431.8 | 01883452.0 | 19.9 | -1.1 | -5.4 | FAIL
5
6
Master FlowMeter Reading
Test Duration: 01 : 31
FlowRate: -1.44 Lit/Hr
Totaliser: 200971.9 Ltr
Operator Confirmation
RESET
Pause
CALIBRATION
Stop
Print Last Calibration Report
Print Meter Report
Historical Reports
Water Meter Calibration Report
Water Meter Test Report
Parameter Setting

KIingdom of Bahrain
Electricity Water Autority
Water Distribution Directorate
Engineering Services Group

Defective Water Meter Site Collection Form

Work Order Details									
Work Order No.		Work Order No.	W/O Classification						
Account Details									
Account No.		Address	Bld.	Villa	Flat	Shop	Road	Block	Area
Account Type									
Consumption		Meter Reading			Installation Details				
Supply Details									
Supply Tank		Type of water				Pressure (bar)			
Measurement Device Details									
Meter Serial. No.		Manufacturere				Flow Rate (cu.m/h)			
Manufacture Date		Type				Manuf. Operation Life			
Installation Date		Model				Actual Service Life			
General Details									
Inspector Name			Inspector ID				Contact No.		
Inspection Date			E-mail Adress						
Remarks									

Signature _____

نبذة مختصرة

رؤية هيئة الكهرباء و الماء "بحلول عام ٢٠١٧ ستصبح الهيئة نموذجاً متميزاً في مجال توفير خدمات الكهرباء والماء بأقل قدر من الانقطاعات وتحصيل الإيرادات في مواعيد استحقاقها" و تتمثل رسالة هيئة الكهرباء و الماء بتوفير خدمات الكهرباء والماء بأعلى درجة من الموثوقية والجودة من أجل تنمية مستدامة في مملكة البحرين وذلك من خلال أهداف و مسئوليات الهيئة المتمثلة في الحفاظ، تطوير وتحسين أدى شبكة نقل والتوزيع المياه لضمان أعلى معايير الكفاءة التشغيلية والحد من فقدان الطاقة.

و تعتبر عدادات المياه الأداة الوحيدة المستخدمة لقياس كميات تدفق المياه ، حيث أن عدد عدادات المياه منزلي في شبكة توزيع المياه بمملكة البحرين في عام بلغ ١٤٠،٠٠٠عداد ميكانيكي تعمل بتقنية إزاحة التدفق و يتراوح حجمها بين ١٥-٢٥ ملم.

ووفقا لمصنعي عدادات المياه، فإن العمر التشغيلي الافتراضي للعدادات الميكانيكية سبع سنوات وذلك بحسب الظروف التشغيل و البيئية لمملكة البحرين . ومع ذلك، وضعت هيئة الكهرباء و الماء برنامج سنويا لاستبدال عدادات المياه المنزلية بعد خمس سنوات من الخدمة من أجل تقليل الخسائر الإدارية الناتجة عن تدني دقة العدادات. وعلى الرغم من ذلك، فشلت هذه العدادات بشكل متكرر في أقل من خمس سنوات.

تهدف هذه الدراسة إلى دراسة الأسباب التشغيلية والعوامل البيئية لفشل عدادات المياه في شبكة توزيع المياه بمناطق خزانات توزيع المياه وبحسب تكرار فشل العدادات.

واستنادا إلى تحليل البيانات الإحصائية ونتائج اختبارات العدادات المعطوبة تبين أن ظاهرة الفشل العدادات تتمثل في ثلاثة عيوب رئيسية، حيث انه تبين ان ٦٠٪ من العينة المختارة توقفت عن تسجيل التدفق، و ٣٤٪ فشلت في اجتياز اختبار الدقة كما ان ٦٪ من العينات تعاني من أعطاب مرئية في جسم العدادات .

وبناء على ذلك، توصي الدراسة بالنظر في تقنيات القياس البديلة التي تناسب مع المعايير التشغيل والبيئية لشبكة المياه في البحرين مثل تقنية العدادات التوربينيه ، الموجات فوق الصوتية و الكهرومغناطيسية.

جامعة البحرين

كلية الهندسة **قسم الهندسة الميكانيكية**



تحليل ظاهرة أعطاب عدادات المياه في مملكة البحرين

أطروحة مقدمة لتلبية متطلبات درجة الماجستير في الإدارة الهندسية

تقديم

جابر ناصر أحمد علي الغنامي

١٩٩٨١٥٢٤

إشراف

الأستاذ الدكتور أحمد يوسف عبدالله

قسم الهندسة الميكانيكية

مملكة البحرين

مارس ٢٠١٨