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NON-REVENUE WATER MANAGEMENT IN KENYA

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MINISTRY OF WATER, SANITATION AND IRRIGATION

Non-Revenue Water Management in Kenya

VOLUME 1

Guidelines

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FOREWORD

Water is an important natural resource to all forms of life and for mankind. It is the backbone of economic growth and a nation's prosperity. Kenya as the rest of the world is becoming more and more water scarce due to deterioration of water sources resulting mainly from global warming and population explosion. Construction of new water schemes to meet the growing demand for water services is expensive, requires more time to develop and comes with new challenges. Alternative sources of water are water re-use, desalination and rain water harvesting. However, reduction of Non-Revenue water is the cheapest way to alleviate the water stress.

The Government of Kenya is committed to ensuring the sustainability of Water Service delivery universally and the right to water and sanitation as envisaged under the bill of rights in the constitution. However, among the challenges to achieving the Kenyan dream includes a high level of Non-Revenue Water (NRW) which is estimated at an average of 47% NRW impact 13 (201/2020) of the total water production in the country. The water services provision has been developed in the County Government and therefore, it is timely to ensure an elaborate mechanism is put in place for the proper management of Non- Revenue Water in the country.

Kenya Vision 2030 recognizes that Kenya is a water scarce country and therefore emphasizes water conservation and prudent use for the limited available portable water. In this regard, the Government of Kenya has instituted specific strategies to raise the standards of the country's overall water supply and resource management among others. The National Water Resources Management Strategy and the National Water Services Strategy aim at ensuring the water resources are conserved and maintained and Non-Revenue Water at all developed water supply and sanitation systems is reduced to acceptable levels. Accordingly the Ministry of Water , Sanitation and Irrigation in conjunction with Japanese International Cooperation Agency (JICA) has developed standards for Non-Revenue Water Management in order to cut down on Operation and Maintenance (O&M) costs and avail more water that could otherwise be lost to consumers.

The Non- Revenue Water reduction management standards consisting of the Guidelines and Handbook are meant to provide a practical approach to reduction of NRW in Kenya. The effective utilization of the standards will result in significant education of NRW and all the Water Service Providers are encouraged to use them.

Cabinet Secretary
Ministry of Water, Sanitation and Irrigation

PREFACE

Previously, a lot of myth surrounded the full understanding of what the non-revenue water really is. In some instances, management of NRW was not viewed with importance and hence there were no foreseeable benefits and need for investing in it. In other cases, NRW management was viewed as a very expensive undertaking whose management required sophisticated equipment and large capital overlays. This position is still held by many water utilities. However,the truth of the matter is that NRW is manageable as has already been demonstrated in some local and international water utilities.

The difference between the amount of water put into the distribution system and the amount of water billed to consumers is what is known as Non Revenue Water(NRW).

NRW is a key indicator of a utility's operational and financial performance. A high level of NRW normally indicates a water utility that lacks good governance,autonomy,accountability, and the technical and managerial skills necessary to provide a reliable service.

In 2010, the International Water Association (IWA) published 'The Manager's Non-Revenue Water Handbook for Africa: A Guide to Understanding Water Losses'. Later on in 2014, the Ministry of Water, Sanitation and Irrigation also published the 'Standards for Non- Revenue Water Management in Kenya'. These two publications have been used nationally by most water companies as a guide towards the management of non-revenue water.

Since their inception in 2014, the Ministry has been monitoring the use of its standards especially with regard to their application and impact to the management of NRW. To date one important finding was that the NRW ratio only reduced marginally with no prospects for substantial positive improvement. Furthermore, there was poor use of the standards guideline by water utilities with some not being aware of their existent at all. These findings tally very well with the prevailing conditions whereby the knowledge of non-revenue water is still very limited in most water service providers country wide. The same scenario-subsists in majority of the county governments who are the main stakeholders in these companies. With the prevalence of this scenario good performance in NRW management continues to be a mirage for most water utilities.

The purpose of this book therefore is to provide guidance in the management of non–revenue water in Kenya. This is reviewed version of the initial ministry's NRW management standards launched in 2014 and incorporates experiences gained from its use during the last seven years since its inception It also draws many experiences gained from the 'GoK/JICA project for strengthening capacity in non-revenue water reduction' where nine(9) WSPs were involved during the piloting phase (Meru, Embu, Ruiru Juja, Mavoko, Kilifi Mariakani, Kisumu, Nyahururu and Nakuru).

The book is designed for all categories of WSPs irrespective of their level of competency in the subject. Most importantly, the book will not only be very vital for beginners who have no prior knowledge about non-revenue water but also to those who have already started the journey to manage it. It is designed for use by all county governments and water utilities charged with responsibility for water provision at any level. The book is applicable to both the urban and rural water service providers.

Incoming up with this book the authors were inspired by the need to reduce escalating water losses in the country. With the prevailing levels of NRW remaining unsustainably high against a large solution gap about it management within water utilities, the need for proper guidance on the matter was inevitable.

The review of these standards was successfully accomplished by an experienced team comprising of WASREB, JICA Expert Team, KEWI, WASPA and the Ministry's NRW Unit.

Every effort was made to eliminate errors in the book, but should the reader discover some, the author would appreciate having these brought to his attention. Suggestions from the readers for improvement in the book will be most gratefully acknowledged.

PRINCIPAL SECRETARY
Ministry of Water, Sanitation and Irrigation

ACKNOWLEDGMENT

The completion of these guidelines could not have been possible without the support of several individuals and organizations whose invaluable support and input the development of this guidelines would not have been possible.

I therefore would like to extend my sincere gratitude to the following organizations in particular: Water Services Regulatory Board(WASREB),Kenya Water Institute (KEWI),Water Service Providers Association (WASPA),Japanese International Cooperation (JICA) and the JICA expert team,Netherlands Development Organization (SNV), Vitens Evides International (VEI) for their co-operation and contribution of information related to Non Revenue Water activities.

Nyeri Water&Sewerage Company (NYEWASCO) for their readiness to share best practices of the Non Revenue Water Reduction activities which has provided a learning platform to other water services providers

I wish to thank the nine pilot WSPs namely; Meru, Embu, Kisumu, Eldoret, Nyahururu, Mavoko, Kilifi-Mariakani, Mombasa, and Ruiru-Juja for their commitments in reducing Non-Revenue Water.

Finally,I would like to thank my colleagues in the Ministry particularly Non-Revenue Water Unit who have tirelessly devoted their time,energies and knowledge in ensuring successful publication of these guidelines and handbook.

The war on Non-Revenue Water cannot be won by a single person,it requires concerted efforts by all stakeholders and calls for commitments by everyone in the organization. I therefore, urge all the Water Service Providers in the country to make maximum use o both the guidelines and handbook to sustain the war on Non-Revenue Water reduction to attain acceptable levels of below twenty per cent.

God bless you all.

Eng. SAO Alima, EBS
Water Secretary

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AP	-	Annual Plan
Aspect	-	A primary activity in the Non-Revenue Reduction Planning Template
Baraza	-	local community meeting
CIS	-	Customer Identification Survey
CM/FM	-	Commercial Manager/Finance Manager
Co-	-	Commercial Loss Reduction Activity
Co-1	-	1st Commercial Loss Reduction Activity
Co-2	-	2nd Commercial Loss Reduction Activity
Co-3	-	3rd Commercial Loss Reduction Activity
Co-4	-	4th Commercial Loss Reduction Activity
DMA	-	District Metered Area
DZ	-	Distribution Zone
EU	-	European Union
GIS	-	Geographical Information System
GOM Player	-	Gretech Online Movie Player
HDPE	-	High-density polyethylene
HRM	-	Human Resources Manager
ICT	-	Information and Communication Technology
I&AC	-	Inspection and Acceptance Committee
JICA	-	Japan International Cooperation Agency
KEBS	-	Kenya Bureau of Standards
KEWI	-	Kenya Water Institute
KShs	-	Kenya Shilling
LMB	-	Leakage Monitoring Block
M3	-	Cubic meter
Ma-	-	Mapping/GIS Activity
Ma-1	-	1st Mapping/GIS Activity
Ma-2	-	2nd Mapping/GIS Activity
Ma-3	-	3rd Mapping/GIS Activity
Ma-4	-	4th Mapping/GIS Activity
MajiVoice	-	an innovative accountability mechanism software in the Kenyan water and sanitation sector
MD	-	Managing Director
Mo-	-	Monitoring Activity
Mo-1	-	1st Monitoring Activity
Mo-2	-	2nd Monitoring Activity
Mo-3	-	3rd Monitoring Activity
MP	-	Medium-term Plan
NRW	-	Non-Revenue Water
NRW Unit	-	May also be NRW Department or Section

OJT	-	on-the-job training
O&M	-	Operation and Maintenance
PEWAK	-	Performance Enhancement of Water and Sanitation Utilities in Kenya through Benchmarking & Collective Learning – a programme funded by the Netherlands Enterprise Agency
PDCA	-	Plan-Do-Check-Adjust
Ph-	-	Physical Loss Reduction Activity
Ph-1	-	1st Physical Loss Reduction Activity
Ph-2	-	2nd Physical Loss Reduction Activity
Ph-3	-	3rd Physical Loss Reduction Activity
SA	-	Service Area
Sht	-	Sheet
SMS	-	short message service
SNV	-	Netherlands Development Organization
SOPs	-	Standard Operating Procedures
TM	-	Technical Manager
TV	-	Television
uPVC	-	unplasticized polyvinyl chloride
uPVC-D/E	-	unplasticized polyvinyl chloride class D or E
VEI	-	Vitens Evides International, a Dutch company
WARIS	-	Water Regulation Information System
WASPA	-	Water Services Providers Association
WASREB	-	Water Services Regulatory Board
WB	-	World Bank
WSP	-	Water Services Provider
WSPs	-	Water Services Providers
yr	-	year

EXECUTIVE SUMMARY

One of the major challenges facing water utilities is the high level of water loss in distribution networks. If a large proportion of water that is supplied is lost, meeting consumer demands is much more difficult. Since this water yields no revenue, heavy losses also make it harder to keep water tariffs at a reasonable and affordable level. This situation is defined as Non-Revenue Water. NRW is a good indicator for water utility performance; high levels of NRW typically indicate a poorly managed water utility.

The main objective of this manual is to provide the basis for a substantive dialogue on NRW reduction and management of water utilities. It aims to raise awareness on key issues surrounding NRW, including the magnitude of the NRW problem, NRW management practices in the country, international terminologies and methodologies for improving NRW management and the importance of using appropriate performance indicators. The following is a brief outline of the guideline.

Chapter 1 examines the basic concept of NRW management and the overall picture of NRW reduction is explained.

Chapter 2 explains on how to coordinate the activities for mapping, commercial and physical loss reduction and NRW monitoring in a strategic way.

Chapter 3 It explains the organization structure of an NRW unit and explains the importance of capacity development and sensitization of staff, annual NRW reduction plans and self-assessment of water utilities.

Chapter 4 This Chapter talks on GIS and how to use it in NRW reduction

Chapter 5 The Chapter explains how to monitor NRW monthly and also how zoning of distribution networks into Distribution Zones and DMAs is to be done so as to closely manage NRW

Chapter 6 It explains the significance of Commercial Losses in NRW and the causes and methods for reducing this type of loss.

Chapter 7 It explains the mechanism of meters and the importance of maintaining customer meters in order to maintain accuracy and efficiency of meters.

Chapter 8 The Chapter explains the causes of Physical Water Losses and the reduction measures for this type of loss.

Chapter 9 It explains methods of underground leak detection and replacement of pipes gradually in service water connections.

Chapter 10 This Chapter provides an explanation on how to manage water pressure as it is one of the most effective methods of NRW management.

Chapter 11 It talks on the importance of water utilities conducting Cost-Benefit Analysis when trying to determine the scope of NRW reduction measures that should be implemented. Cost-Benefit Analysis will show the effects of the invested cost by comparing the benefit obtained with the cost invested.

Chapter 12 This Chapter explains what needs to be done to effectively manage NRW reduction. NRW reduction activities implemented in a Pilot area are explained and the most suitable measures for the entire service area are provided.

Chapter 13 It provides a summary of the experiences of the project for strengthening capacity in NRW reduction in Kenya from Output 4. It tries to answer the question ‘How is it possible with our limited resources to achieve the nation-wide reduction of NRW under the difficult conditions in developing countries?’

Chapter 1

Basic Concept of Non-Revenue Water Management

1.1 Definition of Non-Revenue Water

Non-Revenue Water (NRW) is defined as the amount of water which is not billed and does not earn revenue. This is the difference between the system input volume and billed authorized consumption volume in m^3.

NRW = System Input Volume – Billed Authorised Consumption Volume

Where:

System input volume = the amount of water produced for distribution,

Billed authorized consumption = amount of water billed to consumers.

NRW ratio is the percentage of the amount of water not billed against the total amount of water produced for distribution.

$$\text{NRW ratio (\%)} = \frac{\text{System Input Volume} - \text{Billed Authorized Consumption Volume}}{\text{System Input Volume}} \times 100$$

1.2 Components of Non- Revenue Water

The volume of treated water that does not earn revenue is NRW.

Components of NRW are described below:

- **REAL LOSSES:** these are Physical Losses of water through leakages and bursts in distribution pipes and service pipes; and overflows/leakages from water reservoirs;
- **APPARENT LOSSES:** these are called “non-physical losses” or “Commercial Losses” of water due to illegal connections (or water theft), meter errors, meter reading inaccuracies and unmetered connections.

UNBILLED AUTHORIZED CONSUMPTION: This is water taken by registered customers for public and institutional uses and is not paid for. This includes water for firefighting, backwash and public fountains. Figure 1.1 shows the component of NRW.

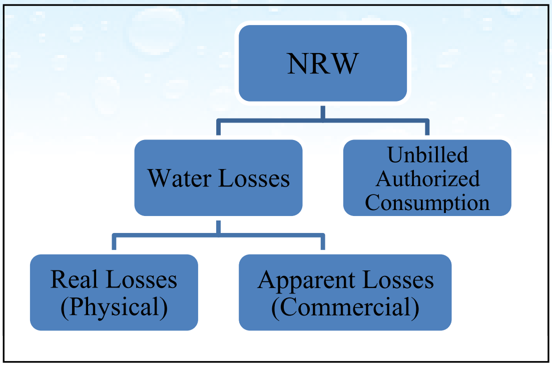


Figure 1.1: Components of NRW

1.3 Benefits of Non-Revenue Water Reduction

NRW Management consists of knowing what is happening to water supplied and taking corrective measures to reduce the loss of water or revenue.

NRW management offers the following benefits:

- Increased connectivity and revenue: By reducing causes of NRW such as water theft, meter inaccuracies and leakages, water that was previously unbilled will be earning revenue.
- Improved level of service (water pressure and hours of service) hence reduced customer complaints
- Sustains water supply and increases protection of potable water supply.
- Reduces unauthorized usage.
- Reduces potential claim due to water damage.
- Defers capital expenditure with respect to new water sources, treatment plants and distribution facilities.
- Reduces cost of energy associated with water treatment and pumping; and thus, contributes to reducing global warming.
- The precious water resources are preserved
- Improves public awareness of water value.
- Improves the company's image

1.4 Current Status of Non-Revenue Water in Kenya

Water supply systems in Kenya differ depending on social, financial and geographical conditions, but the following issues are common:

1. Dilapidated facilities
2. Weak and substandard distribution pipe materials (e.g., asbestos cement, and cast-iron, low-class uPVC) are still in use in some water supplies leading to leakages.
3. Inadequate water distribution due to lack of water resources and/or limited water facilities.
4. In general, water pressure is low with the exception of Water Services Providers (WSPs) around the foot of Mt. Kenya. However, there are significant pressure variations depending on the WSP's service area.
5. Inadequate staff with capacity to implement NRW Management programs.
6. Lack of adequate equipment to address NRW issues.
7. Lack of flow Meters in appropriate locations.
8. Low quality meters.
9. Lack of uniformity in pipe standard.
10. Poor workmanship and construction methods.
11. Inadequate (and often outdated) mapping of pipe network in most WSPs.
12. Customer meters are sometimes not read accurately.
13. Illegal connections and failure to pay for water consumed are common.
14. Lack of policies and enough budget for NRW reduction and control.
15. Lack of management's goodwill and support to fight NRW.
16. Absence of institutionalized NRW Unit and ad hoc staff appointments when required.
17. Often ignored as an essential service on the road reserve and is readily damaged by other actor like road contractors.

1.5 Non-Revenue Water Reduction Measures

In developed countries, a large part of NRW is due to real losses (physical losses). However, in developing countries including Kenya, a high percentage of water is lost through apparent losses (commercial losses) such as water theft, meter error, meter reading error and unbilled authorized consumption. Therefore, NRW reduction measures should take into consideration all these additional factors besides leakage.

Details of reduction measures are explained in Chapters 3 and 4.

1.6 Stages and Overall Procedure for Non-Revenue Water Reduction

(This section is further explained in Chapter 3)

1.6.1 Stages of NRW Reduction

Effective NRW reduction measures vary depending on the current technical and non-technical capacities of each WSP. NRW reduction measures implemented in developed countries may not necessarily be suitable for WSPs in Kenya. Hence, each WSP must assess and understand well its current NRW status so as to plan and successfully implement appropriate NRW reduction measures.

Table 1.1 broadly recommends NRW reduction measures necessary to reduce NRW from one stage to the next. The table is intended to generally orient and motivate WSP staff to discuss their conditions and prepare detailed NRW reduction plans even before carrying out a full assessment of the NRW status.

Table 1.1: The Five Stages of NRW and Recommended Reduction Measures

Stage	Approx. Range of NRW %	**Recommended NRW Reduction Measures** (Note: GIS development and NRW monitoring are not listed here, but they are required as support for NRW reduction measures)
1	**Red** NRW ratio ≥ 40% (or unknown or unreliable)	● Determine the accuracy of production meters by testing and calibrating, and replacing if faulty or inaccurate (Mo-1). ● Eliminate major commercial losses by servicing and testing (and replacing faulty) customer meters and, identifying illegal uses (starting with large and then medium customers) (Co-1, Ma-1). ● Install meters for unmetered customers and identify unbilled customers through Customer Identification Survey (CIS) and issue them with bills. (Co-2, Ma-1, Ma-2). ● Reduce the time taken to repair bursts, surface leaks and overflows (Ph-1).

Stage	Approx. Range of NRW %	**Recommended NRW Reduction Measures** (Note: GIS development and NRW monitoring are not listed here, but they are required as support for NRW reduction measures)
2	**Yellow** 30% < NRW ratio < 40%	● Intensify Stage-1 measures by e.g., establishing routines, etc. ● Isolate distribution zones and district metered areas (DMAs) with accurate bulk meters and do NRW monitoring (Mo-2). ● Reduce underground leaks by step testing, acoustic survey and pressure reduction in priority areas (this leak reduction can be carried out as a pilot project) (Ph-2). ● Map bursts and leaks and monitor their recurrences (Ma-3, Ma-4). ● Introduce better pipe materials and fittings for new pipelines and service connections (e.g., HDPE or uPVC-D/E). ● Minimize commercial losses (including at small customers and data handling errors) by improving meter reading and billing systems, and their uses (Co-3, Co-4).
3	**Green** 24% < NRW ratio ≤ 30%	● Intensify Stage-2 measures listed above. ● Reduce underground leaks in other areas (Ph-3, Mo-3). ● Start replacing pipes which are prone to bursts and leaks (Ph-3).
4	**Blue** 20% < NRW ratio ≤ 24%	● Intensify Stage-3 measures listed above. ● Accelerate and complete pipe replacement (Ph-3).
5	**Purple** NRW ratio ≤ 20%	● Intensify Stage-4 measures listed above. ● Maintain the facilities and skills to sustain the achieved low NRW ratio (Ph-3).

Note-1: This table is based on experiences in Kenya.
Note-2: The approx. percentage range of NRW for each stage corresponds to that of commercial viability criteria for each level included in WASREB Guideline on Clustering of WSPs (August 2018).

1.6.2 Organizational Set-up, Assessment of Current Status and Plan-Do-Check-Adjust Cycle

Plan-Do-Check-Adjust (PDCA) Cycle is an iterative design and management method used in business for the control and continuous improvement of processes and products.

The meaning of PDCA cycle is explained below:

- **Plan:** During this phase, the objectives and processes required to deliver the desired results are established.
- **Do:** The objectives of the **Plan** are carried out or implement in this phase.
- **Check:** During this phase, the data and results gathered from the **Do** phase are evaluated. Data is compared to the expected outcomes to see any similarities and differences. The testing process is also evaluated to see if there were any changes from the original test created during the **Plan**ning phase. If the PDCA cycle is conducted multiple times, any trends can be seen easily by plotting the data in a chart. This helps to see which changes on “**Do**phase” give better results than others, and if the said changes can be improved.
- **Adjust:** This is where a process is improved. Records from the “**Do**” and “**Check**” phases help identify issues with the process. These issues may include problems, non-conformities, opportunities for improvement, inefficiencies and other issues that result in outcomes that are evidently less-than-optimal. The root causes of such issues are investigated, found and eliminated by modifying the process. The risk is also re-evaluated. At the end of the actions in this phase, the process has better instructions, standards or goals. Planning for the next cycle can now proceed with a better base-line. Work in the next Do phase should not create recurrence of the identified issues If it does, then the action was not effective.

Figure 1.2 shows the overall procedure for NRW reduction and its proposed **PDCA** cycle based on recent WSPs’ experiences in Kenya. The monthly, quarterly and yearly PDCA cycle is important to sustain improvement of NRW-related conditions and progressively achieve lower and lower NRW levels.

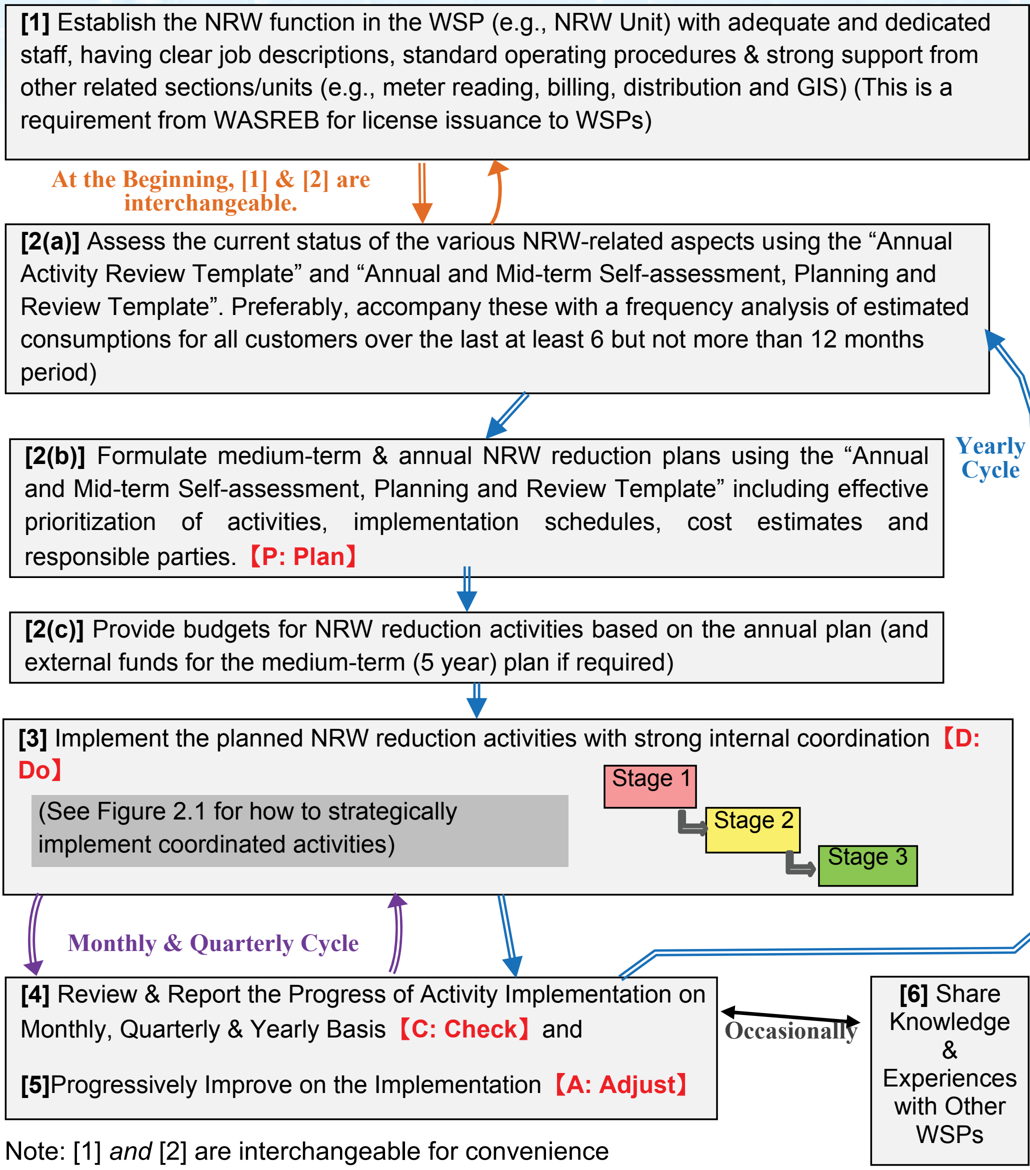


Figure 1.2: Overall Procedure for NRW Reduction & PDCA Cycle

[1] Organizational Set-up

As seen in Figure 1.2, the overall procedure for NRW reduction starts with {**[1]** *Establishing NRW function with adequate and dedicated staff…}*. This function should be permanently established and institutionalized in the organization chart of each WSP. Any temporarily appointed NRW team/unit which is not institutionalized in the organization chart is liable to fail miserably (see **Sec. 3.1** for further explanation).

To ensure an NRW Unit reduces NRW significantly, it must have the following characteristics:

- adequate and competent staff <u>dedicated</u> to NRW reduction,
- <u>strong support</u> from the management, and
- <u>strong coordination</u> with other relevant sections in both technical and commercial departments

The level of the NRW function is discretional (can be departmental level for the very large WSP; to sectional or unit level for other lower sized WSPs).

[2(a)] (P: Plan)→ Assess the Existing Conditions

Before commencing NRW reduction, it is necessary to self-assess the current conditions and capacity. These conditions and capacity are divided into four categories as follows:

[A] Organizational Structure, Sensitization, PDCA Cycles and Procurement,

[B] GIS, NRW Monitoring, Zoning and Water Balance Analysis,

[C] Reduction of Commercial (Apparent) Water Losses, and

[D] Reduction of Physical (Real) Water Losses.

A template containing 33 NRW-related aspects to assist in self-assessment of a WSP's current conditions and capacity is provided in these guidelines **[Appendix-1: Sht(2)].**

The template is also used to periodically Plan (set future targets) **[Sht(4)]** and review the status and capacity of a WSP **[Sht(1)** and **Sht(5)]** as the NRW reduction activities continue to be implemented (Figure 1.2 Item **[2(a)-(c)]).**

When data is typed into the template, the results of the self-assessment (or review) are automatically displayed as a single bar chart **[Sht(3)]** showing the current achievement levels of the 33 aspects (see **Section 3.5** for further explanation).

Most WSPs often estimate water consumption, including for large consumers, due to stalled meters, unreadable meter counters, locked gates, etc. They also often fail to send bills to existing active customers and, newly connected and reconnected customers. These failures cause a large volume of NRW.

These guidelines include a computer programme (MS Excel) **(Appendix-2)** for analysing meter readings and billing trends over a number of months to determine the status of commercial water losses in WSPs. Through this analysis at the initial stage and later as the NRW reduction activities continue to be implemented, the current conditions and periodical reviews can be assessed for planning.

[2(b)] (P: Plan)→ Formulate medium-term and annual Non-Revenue Water reduction plans

Once self-assessment is complete, it is necessary to formulate plans on how the NRW reduction will be implemented. The planning part of the "Annual and Mid-term Self-assessment, Planning and Review Template" **[Appendix-1 Sht(4)]** is useful to assist WSPs in formulating the plans including prioritization of activities from the 33 NRW-related aspects, implementation scheduling, cost estimation and allocation of responsible persons. Activity prioritization then yields the annual, quarterly and medium-term plans and budgets.

[2(c)] (P: Plan)→Provide budgets for Non-Revenue Water reduction activities

After prioritization of activities and cost estimation, it's time to allocate funds through budgeting and obtaining the necessary approvals from the WSP's senior management and the board. This process should also include approval for external funding such as grants/loans for medium term plans.

[3] (D: Do)→Implement the planned Non-Revenue Water reduction activities with strong internal coordination

Once the funding is available, NRW reduction activities should be implemented with effective coordination between the various sections/units while keeping recordsat the same time. These records will later be analysed **(C: Check)** to review the achievements and to come up with corrective measures **(A: Adjust)** going forward for more efficient and effective outcomes.

In summary, for Item [2(b)] in Figure 1.2, a template (Appendix-1) containing medium-term plans, annual plans **[Appendix-1 Sht(4)]** and capacity assessment procedure[Sht(2)] is included in these guidelines for ease of planning based on the assessment results (see Sec. 3.6 for further explanation). Item [2(c)]is explained in Sec. 3.7. Item [3]is explained in Chapter 2 with a flow chart example (Figure 2.1) of how to strategically implement coordinated activities.

Reviewing and reporting (Item [4])should be on monthly basis to facilitate internal discussions; quarterly for progress monitoring; and yearly for updating the medium-term and annual plans.

Quarterly review can be done by filling the additional columns in the planning template **[Appendix-1 Sht(5)]** while the yearly review can be done by filling the Annual Activity Review Template **[Sht(1)]** (see Sec. 3.8 for further explanation).

Every annual review should include updating (Item [5]) of each year of the medium-term NRW reduction plan based on the results of the yearly activity review, re-assessment of improved conditions including skills, availability of funds, etc.

For Item [6] (Figure 1.2), occasional internal and external sharing of knowledge and experiences (e.g., at Water Services Providers Association's (WASPA) benchmarking workshops) and participation in trainings are vital for development of country-wide capacity (see Sec. 3.2 for further explanation).

Chapter 2

Strategic Implementation of Coordinated Activities

2.1 Understanding the Necessary Skills and Interactions

Planning and implementation of NRW reduction activities require a wide range of skills such as:

- GIS maps development,
- design work to modify the existing distribution facilities,
- pressure management, etc.

These skills usually belong to different sections/units (e.g., GIS mapping development – GIS/mapping Unit; Design – Design Section; etc).

One of the most difficult aspects of NRW reduction is how to coordinate the various actors in a strategic way such that the effectiveness and efficiency of their activities is maximized for successful NRW reduction.

It is crucial that the head of NRW Unit and his/her manager/supervisor gradually develop enough capacity to properly coordinate the activities. Further, other staff/sections need to understand the interactions and skills necessary to interlink them in order to ease the coordination. These interactions should be discussed in monthly meetings for improvement.

Figure 2.1(a) explains how to coordinate the activities for commercial and physical loss reduction in a strategic way.

(Note: The activities are from Table 1.1 and are coloured correspondingly; e.g., Stage 1 activities are coloured red in both Table 1.1 and Figure 2.1(a), and so on.)

Since majority of WSPs in Kenya are still in Stage 1 (i.e., NRW ≧ 40% or unreliable), Figure 2.1 begins by elaborating priority activities for Stage 1 (red).

The figure is developed based on recent experiences in WSPs in Kenya.

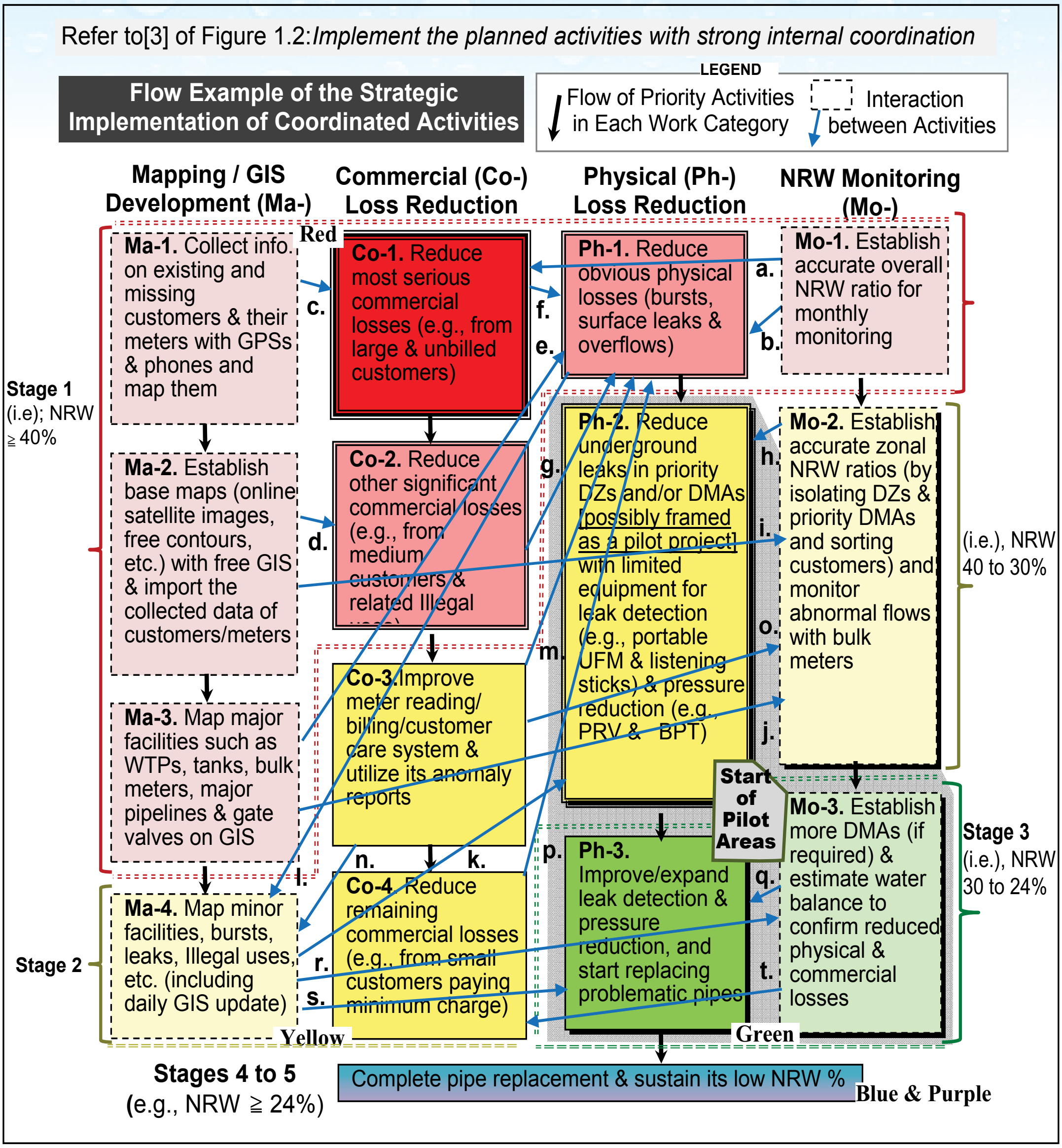


Figure 2.1 Example of Strategic Implementation of Coordinated Activities

Table 2.1: Legend to Figure 2.1

Symbol	Meaning
Ma	Mapping/GIS development activities: - Ma-1 is 1^{st} activity to be undertaken, Ma-2 is 2^{nd}, etc
Co	Commercial Loss Reduction activities: - Co-1 is 1^{st} activity to be undertaken, Co-2 is 2^{nd}, etc
Ph	Physical Loss Reduction activities: - Ph-1 is 1^{st} activity to be undertaken, Co-2 is 2^{nd}, etc
Mo	NRW Monitoring activities: - Mo-1 is 1^{st} activity to be undertaken, Mo-2 is 2^{nd}, etc
Black Arrow	The activities in the textbox behind the arrow are of higher priority than those in the textbox ahead of the arrow
Red and light-red box	Activities to be undertaken when WSP is in Stage 1
Yellow and light-yellow textbox	Activities to be undertaken when WSP is in Stage 2
Green and light-green textbox	Activities to be undertaken when WSP is in Stage 3
Blue-toped and purple-bottomed rectangle textbox	Activities to be undertaken when WSP is in Stages 4 and 5
Bright coloured textbox	Activities in the box are of higher priority than light coloured box
Light coloured textbox	Activities in the box are of lower priority than bright coloured box
Coloured double dash borderline	Borderline between Stages (e.g., Stage 1 and Stage 2)
Grey coloured textbox Pilot Areas	Symbol indicates the 4 activities (i.e., Ph-2, Ph-3, Mo-3 and partly Mo-2) to be undertaken in pilot areasbefore expanding them to other areas.
Interaction arrow(blue)	• Implementing the activity behind the arrow will assist while implementing the activity ahead of the arrow; OR, • The activity behind the arrow can be implemented together with the activity ahead of the arrow

Table 2.2: How to Read Figure 2.1

Arrow	Explanation
Blue arrow: a.	• Implementing Mo-1 will assist to implement Co-1; or, • Mo-1 can be implemented together with Co-1
Blue arrow: b.	• Implementing Mo-1 will assist to implement Ph-1; or, • Mo-1 can be implemented together with Ph-1
Blue arrow: c.	• Implementing Ma-1 will assist to implement Co-1; or, • Ma-1 can be implemented together with Co-1
Blue arrow: d.	• Implementing Ma-2 will assist to implement Co-2; or, • Ma-2 can be implemented together with Co-2

Arrow	Explanation
Blue arrow: e.	• Implementing Ma-3 will assist to implement Ph-1; or, • Ma-3 can be implemented together with Ph-1
Blue arrow: f.	• Implementing Co-1 will assist to implement Ph-1; or, • Co-2 can be implemented together with Ph-1
Blue arrow: g.	• Implementing Co-2 will assist to implement Ph-1; or, • Co-2 can be implemented together with Ph-1
Blue arrow: h.	• Implementing Mo-2 will assist to implement Ph-2; or, • Mo-2 can be implemented together with Ph-2
Blue arrow: i.	• Implementing Ma-2 will assist to implement Mo-2; or, • Ma-2 can be implemented together with Mo-2
Blue arrow: j.	• Implementing Ma-3 will assist to implement Mo-2; or, • Ma-3 can be implemented together with Mo-2
Blue arrow: k.	• Implementing Ma-4 will assist to implement Ph-2; or, • Ma-4 can be implemented together with Ph-2
Blue arrow: l.	• Implementing Ph-1 will assist to implement Ma-4; or, • Ph-1 can be implemented together with Ma-4
Blue arrow: m.	• Implementing Co-3 will assist to implement Ph-1; or, • Co-3 can be implemented together with Ph-1
Blue arrow: n.	• Implementing Co-3 will assist to implement Ma-4; or, • Co-3 can be implemented together with Ma-4
Blue arrow: o.	• Implementing Co-3 will assist to implement Mo-2; or, • Co-3 can be implemented together with Mo-2
Blue arrow: p.	• Implementing Co-4 will assist to implement Ph-1; or, • Co-4 can be implemented together with Ph-1
Blue arrow: q.	• Implementing Mo-3 will assist to implement Ph-3; or, • Mo-3 can be implemented together with Ph-3
Blue arrow: r.	• Implementing Ma-4 will assist to implement Mo-3; or, • Ma-4 can be implemented together with Mo-3
Blue arrow: s.	• Implementing Ma-4 will assist to implement Ph-3; or, • Ma-4 can be implemented together with Ph-3
Blue arrow: t.	• Implementing Mo-3 will assist to implement Co-4; or, • Mo-3 can be implemented together with Co-4

2.2 Coordination of Stage 1 Activities

Stage 1 activities involve production and large customer meters, CIS and visible leaks.

As illustrated by the coloured textboxes (Figure 2.1(a) and (b)), the most important activity among the activities highlighted in red (Stage 1) are Co-1(Reduce most serious commercial losses, starting with the large and unbilled customers. It is relatively easy and cost effective to focus on those customers consuming large volumes of water (e.g.,> 100m3/month) because they are few and their locations are well-known. Eliminate their under-registering meters and under-estimated consumption (caused by stalled or unreadable meters, gate locks, etc.) through meter accuracy testing, meter replacement, meter relocation and resizing; and investigation of illegal connections and leaks around their meters.

Through conducting the targeted activities of consumers with large meters described above, a huge volume of NRW can be reduced and the revenue increased drastically since the higher water tariff (Ksh/m3)is applied to the same large consumers. The revenue increase from addressing large customers should support and encourage other NRW reduction activities to follow.

Therefore, the management should adequately support procurement of prioritized large customer meters to replace faulty ones. This activity on large customers, as well as other activities for commercial loss reduction, should be carried out over the entireservice area of the WSP to maximize its impact (see Sec. 5.2, 5.6 and Chapter 6 for further explanation).

In order to monitor NRW reduction from the activity on larger customers and other basic activities (e.g., Ph-1), accurate calculation of monthly overall NRW ratio should be established and institutionalized as soon as possible (as illustrated by interaction arrows ↙a. and ↙b.), based on reliably accurate production meters and total billed consumption (see Sec. 5.2 for further explanation).

Some customers may have been connected by WSP staff but, for some reason, not captured in the billing system. These are unauthorized unbilled consumers and sources of most serious commercial losses (Co-1). Customers previously disconnected due to non-payment, vacated premises, etc but reconnected later (by staff or self illegally) without being billed for the consumed water also cause significant NRW. These hidden unbilled customers should be identified immediately by conducting CIS and mapping (Ma-1); and billed to reduce NRW. It is recommended that mapping (Ma-1) of the water supply should be done using, e.g., handheld GPSs and smartphone-based data-collection software with cloud mapping functions. Kobo Toolbox is free (or open source) and a good example of such a software and can be easily be downloaded and used with the help of mapping/GIS staff (arrow ↘c.) (see Sec. 4.3 and 6.7 for further explanation).

The next priority in Stage 1 is Co-2 and Ph-1.

This should target the large number of medium customers such as multi-dweller buildings (e.g.,>20m3/month) and their potential illegal connections in the entire service area (e.g., irrigated agricultural areas that have limited irrigation systems of their own, informal/slum areas, houses with large gardens, car wash services). The WSP should introduce own GIS mapping database with a customer meter layer. Use of free (open source) GIS software (e.g., QGIS) as indicated in Ma-2 and (↘d.) is recommended and is quite helpful.

Arrow (↘e.) recommends digitization of the major facilities in the entire service area on GIS maps (Ma-3) and sharing the maps,accessible from smartphones, with field staff through PDF format, mobile GIS or web-publishing. This would significantly help to reduce time spent to locate and repair obvious physical losses (bursts, surface leaks and overflows – Ph-1). This digitization can be done mainly on-screen in a relatively short period using online or offline high-resolution satellite images as the GIS base map (see Sec. 4.2 for further explanation). As illustrated by Arrow (↘f.) and (↗g.), surface leaks found while reducing most serious and other significant commercial losses at large and medium customers (Co-1 and Co-2) should be repaired together with obvious physical losses {Phy-1.}. This should include the noises detected with listening sticks from customer meters/meter stands hinting at potential underground leaks.

2.3 Coordination of Stage 2 Activities

Stage 2 activities involvezoning, invisible leaks, pipe materials and commercial loss minimization.

Even for WSPs considered to be in Stage 2 or Stage 3, Stage 1 activities should be completed while proceeding to Stage 2 and 3 activities.

Among commercial and physical loss reduction activities of Stage 2 (yellow textboxes), WSPs may start with Ph-2. As illustrated by arrow (↘h.), reduction of underground leaks should start from the priority areas (priority DZ(s) and/or priority DMA(s)). The priority areas should be identified through planning and gradual implementation of zoning over the entire service area for better NRW monitoring, (Mo-2). This can be achieved by understanding the existing structures, network pipe materials, terrains, areas having water shortage, etc; (see Sec. 5.3 and 5.4 for further explanation).

Referring to arrow (↗i.) and (↗j.), development of GIS layers for customer meters and major facilities (Ma-2 and Ma-3) is essential for planning the separation of DZs (and DMAs in large DZs – Mo-2). These advanced physical loss reduction activities within a few priority DZs and/or priority DMAs may be recognized as pilot activities. They may then be framed as a pilot project after combining with the necessary basic activities in the same areas. This is a good tool for further motivation, engagement and training of staff (see Chapter 12).

Arrow (↗k.) introduces mapping of tertiary distribution pipes, past bursts and leaks, pressure measurements, etc (Ma-4) which is useful for Ph-2 through leak detection and pressure reduction. Arrow (↙l.) recommends mapping (Ma-4) of bursts and leaks detected through Ph-1. In addition to underground leak detection and pressure reduction, better pipe materials and fittings can be introduced for new pipelines and service connections in this stage in order to reduce bursts and leaks.

Alternatively, in Stage 2, the WSP may start with Co-3 if a software for meter reading, billing, customer care, etc. is available. Full utilization of monthly abnormalities reports (on bursts, surface leaks, unreadable dials, stalled meters, tampered meters, gate locks, significant consumption reduction, illegal connection hints, underground leaks from service connections, etc.) from the system is recommended in order to effectively and efficiently address recurrence of serious commercial losses at large and medium customers (Co-1 and Co-2), and the un-investigated commercial losses at the many small customers (Co-4).Customers billed on fixed minimum charge (e.g. ≦ 6m3/month – residential and ≦10m^3/month – other customers) may not have a high impact on NRW reduction, hence Co-4 is given lower priority than Co-3 in this example.

Arrows (↗m.), (↙n.) and (↗o.) imply the need for system improvement to better handle notification of bursts and leaks from the public to assist Ph-1 and Ma-4 while accurate zonal/DMA total billed consumption is essential for Mo-2. Arrow (↗p.) recommends that surface leaks and underground leak noise hints found during Co-4 be communicated to staff repairing Phy-1.

2.4 Coordination for Stage 3 Activities

This involves expansion of leak detection and beginning of large-scale pipe replacement.

The priority activities in Stage 3 are shown in green text-boxes (Figure 2.1). Enhancement of leak detection and pressure reduction (possibly with more equipment) are part of Ph-3. Ph-3 also includes area-by-area expansion of underground leak detection and pressure reduction over other areas outside the pilot area.

Arrow (↙q.) and (↗r.) means implementing Mo-3 for better NRW monitoring may be required to expand the target areas of leak detection and pressure reduction while Ma-4 may assist in selection of priority areas to create additional DMAs (Mo-3).The start of replacement of problematic pipes (having frequent and recurrent bursts, leaks and illegal connections) in the priority areas previously targeted for underground leak detection is also part of Ph-3.

Arrow (↙s.), means implementing Ma-4 on GIS can assist in selection of pipelines or service connections to be replaced with better pipes.

Underground leak detection is labour-intensive and pipe replacement is expensive. However, commercial losses are relatively easy to reduce. Therefore, as indicated with arrow (↗t.), estimation of overall water balance as part of Mo-3 is recommended. The purpose is to check whether commercial loss components have been adequately reduced in the entire service area before starting leak detection in DMAs pipe replacement (Ph-3) (see Sec. 5.6 for further explanation).

As shown in Table 1.1 and Figure 2.1, Stage 4 involves further improvement of physical loss reduction including acceleration and completion of pipe replacement, while Stage 5 is for maintaining the achieved low NRW ratio.

Chapter 3

Organization Structure and Plan-Do-Check-Adjust Cycle

3.1 Establishment of NRW Unit and Coordination with other Units

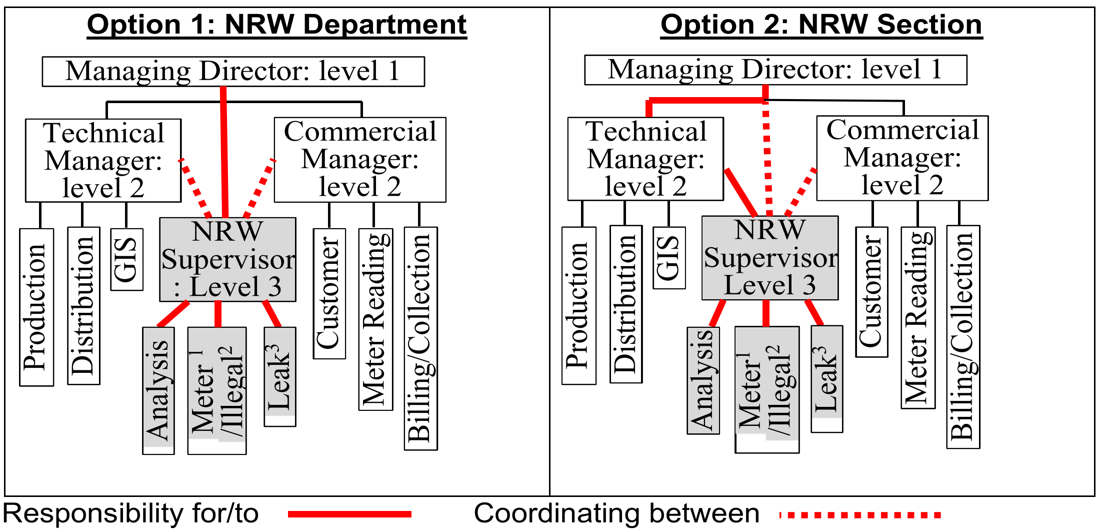
1) NRW Unit should be established and permanently embedded in the organization chart.
2) NRW Unit should be fully operational with adequate dedicated staff (e.g., technical officers, leak surveyors, etc).
3) NRW Unit should have adequate support from:
   i) the top managers (e.g., MD, TM, CM/FM and HRM)
   ii) other relevant commercial and technical staff (e.g., billing, meter reading, meters servicing, GIS mapping, distribution, connections installation, procurement, customer care, etc).
4) NRW Unit should have suitable:
   i) job descriptions,
   ii) standard operating procedures (SOPs), and
5) The other staff should:
   i) Be sensitized on their jobs' contribution to NRW reduction,
   ii) Have SOPs in order to ensure effective workflows for NRW reduction including interaction among them and with NRW Unit.
6) Incentives for NRW reduction (e.g., allowance for night-time activities, performance-based incentives for individuals and/or groups in charge of different areas, etc.) should be established to motivate NRW Unit and other staff.
7) An inter-departmental committee on NRW management should be established comprising representatives (preferably the heads) of all departments/sections/units that have a stake in NRW management. The committee should hold monthly meetings to review the previous month's NRW reduction activities and give guidance on the way forward. The MD strive to chair this committee to understand the challenges and give support where needed.
8) Each WSP should come up with a NRW policy to guide in management.

3.2 Organization Structure for NRW Reduction

The organizational structure of a WSP should be optimized for NRW reduction based on the most prevalent types of NRW (e.g., metering errors), etc. The Managing Director and board of directors should clearly understand that organizational optimization is a basic requirement for successful NRW reduction. The two basic organizational options shown in Figure 3.1 can be considered for different conditions. The supervisor of NRW-related tasks should be at least Level 3.

NRW can be reduced by all the staff understanding that NRW activities have to be shared among all the staff.

Since NRW reduction activities need various quick coordination between departments and sections, the NRW Supervisor needs to have direct access to and support from both the Technical and Commercial Manager and even the Managing Director if necessary (e.g., for funding).



Notes 1: Reduction of inaccurate meters, 2: Reduction of illegal water use,

3: Reduction of physical water losses

Figure 3.1: Organizational Options for Coordinating NRW Reduction Activities

Option 1 may be suitable where:

a. A WSP is very largeand the NRW Department consisting of many staff,

b. The Technical Manager is already overloaded,

c. The Managing Director wishes to get involved in NRW reduction directly, and

d. More commercial staff should be involved in NRW reduction than technical staff.

Option 2 is suitable for other WSPs but

a) The Technical Manager should ensure effective coordination between the Distribution Section and the NRW Section to effectively deal with bursts and leaks repair, pipe replacement, zoning of distribution systems, etc.

Option 1 is ideally the most recommended while Option 2 is more balanced. Regardless of the option, the NRW head should have direct access to the Managing Director, Commercial Manager as the Technical Manager.

In each case, the NRW head, should put a strong initiative in coordinating with the departments, sections and units, as well as head office and zonal offices, to reduce NRW effectively. It is crucial for the MD to give full support to the NRW head to enable him effectively execute the NRW reduction. The NRW Unit may have zonal NRW teams administratively under Zone Heads.

3.3 Main Tasks of NRW Unit

The staff of NRW Unit may be divided into three teams:
Team 1 for management, analysis and coordination,
Team 2 mainly for reducing commercial water losses on site, and
Team 3 mainly for reducing physical water losses on site.
Below are the main tasks of each team in order of priority:

Team 1

Members: NRW Supervisor

NRW Unit Head and Analysist

1) Establishing a robust yearly and quarterly PDCA cycles (annual activity review, self-capacity assessment, annual planning and update of medium-term plan, implementation, monitoring, adjustment, reporting, etc.) for NRW reduction in coordination with Team 2 and 3 and relevant departments/sections.

2) Discuss with Team 2 and 3 and relevant departments/sections (monthly) and report the progress and effects of NRW reduction activities based on the results of Universal NRW Monitoring (i.e., analysing NRW ratio fluctuations, total billed consumption, average tariff, etc.).

3) Analyse monthly meter reading and billing data of all the customers (including the ratio of estimated billed consumption) by consumption categories based on water tariff (e.g., Category 1: 300 m3/month and above, Category 2: 100 – 299 m3/month, ….) in liaison with Commercial Department and prioritize the NRW reduction activities.

4) Liaise with Commercial Department, Team 2 and GIS staff to:

   a) conduct customer identification survey (CIS) including mapping of all customer meters, and

   b) focus on large customers (e.g.,> 100m3/month) to reduce metering errors and illegal water use (Managing Director, Commercial Manager and Technical Manager should be involved).

5) Liaise with Distribution Section, Team 3 and GISstaff to conduct:

   a) daily abnormal flow monitoring of mains,

   b) bursts and leaks data collection and mapping, and

   c) planning and implementation of priority pipe replacement to reduce pipe bursts and leaks (Technical Manager should be involved).

6) Develop:

   a) relevant policies,

   b) internal standards and materials specifications (pipes, fittings, meters, etc.), and

   c) better workmanship to prevent leakage, meter errors and tampering in liaison with relevant technical and procurement sections (Technical Manager should be involved).

7) Work with Distribution Section and GIS staff to:

   a) establish hydraulic distribution zones and DMAs with bulk meters for zonal/ DMA based NRW reduction activities, and

   b) optimize water pressure using pressure regulating valves and/or break-pressure tanks (Technical Manager should be involved).

8) Liaise with Team 2 and 3 and Zonal Heads on their zonal based NRW reduction activities (zonal NRW teams may be necessary).

9) Once distribution zones and DMAs are established to some extent, discuss monthly (and report) the progress and effects of zonal NRW reduction activities with Team 2 and 3; and Zonal Heads based on monthly zonal NRW monitoring results in order to target the most problematic areas the following month, and create competition among zones.

10) If water supply is continuously, work with Team 2 and 3 and conduct minimum night flow measurement and step test to identify areas with large leaks and night water theft.

Team 2

(Staff dealing mainly with customer meters and illegal water use on site to reduce commercial water losses)

1) Contribute to the annual and quarterly review; and planning of NRW reduction activities.

2) Contribute to the monthly discussions on improving NRW reduction activities

3) Work with Commercial Department and GIS staff to:

    a) conduct CIS, and

    b) focus on large customers (plus possible large illegal water users) to reduce meter errors and water theft

4) Test and ensure bulk meters are accurate; and read them monthly (maybe with Team 3's help) synchronous with customer meter reading for universal and zonal NRW monitoring.

5) Deal with medium customers (e.g., 20 to 100m3/month) and potential medium illegal water users (e.g., farmers) with help of Zonal Heads to reduce metering errors and water theft (small customers can be dealt with later selectively with help of meter readers and Team 3 by checking service connections with listening sticks).

Team 3

(Staff mainly dealing with bursts and leaks on site to reduce physical water losses)

1) Contribute to the annual and quarterly review; and planning of NRW reduction activities.

2) Contribute to the monthly discussions on improving NRW reduction activities.

3) Work with Distribution Section and GIS staff to conduct:

    a. daily abnormal flow monitoring (e.g., reading bulk meters preferably by 9 am to determine 24 hours flows and prioritizing the day's patrol areas),

    b. bursts and leaks data collection and mapping, and

    c. planning and implementing priority pipe replacement to reduce pipe bursts and leaks.

4) Check leaks on service connections and near-by distribution pipes with listening sticks (e.g., 20% of service connections per year starting from prioritized areas) possibly in liaison with meter readers and distribution staff; and replacing spaghetti connections.

5) If water supply is continuously, work under Team 1 (maybe with help of Team 2) to:

   a. conduct minimum night flow measurement and step test in prioritized zones, and

   b. carry out follow-up leak detection survey with listening sticks and other equipment in areas having high night flow rates (Team 2 may need to conduct follow-up illegal water use survey).

6) If water supply is intermittently,

   a. track down leaks with potable ultrasonic flow meter from upstream to downstream in areas expected to have large leaks and,

   b. narrow down leak location with other equipment.

3.4 Capacity Development through Training and Benchmarking

1) Adequate relevant staff (e.g., NRW Unit staff, zone managers, plumbers, meter readers etc) should be sent to KEWI's training course on NRW management.

2) Adequate relevant plumbers and other field staff should be sent to KEWI's other training courses relevant to NRW reduction (e.g., plumbing, metering, connection installation, O&M of distribution system, etc).

3) Adequate relevant ICT and GIS staff and other technical officers should be sent for GIS-related training courses at KEWI, Kenya Institute of Mapping and Surveying and/or Kericho WSP.

4) Adequate relevant staff should be sent for WASPA's benchmarking workshops/forums for collective learning.

5) Adequate staff should have opportunities of trainings held by donor organizations (e.g., JICA, VEI, SNV, WB, EU, etc.) and other Kenyan institutions (e.g., WASREB, other prominent WSPs, etc.).

6) Adequate in-house and tailor-made training (including on-the-job training (OJT)) for various NRW activities should be conducted at the WSP.

7) Adequate training on culture change should be impacted on all staff to improve the attitude of the staff.

8) WSPs should institutionalize writing and sharing of training reports by training participants with other staff members; benchmarking tours, etc.

3.5 Sensitization of Staff and Board of Directors on NRW Management

1) Ethics and the spirit of cooperation of all WSP staff should be effectively enhanced through sensitization activities for NRW reduction (e.g. through speeches from managers, warning against being involved in water theft, collusion with customers and water wastage, requests for thorough internal information-sharing and whistle blowing on any hints of surface (visible) leakage and water theft, and request for cooperation in relevant data collection for calculation of performance indicators, etc).

2) Recent operational financial losses (KSh/yr or /month) due to NRW should be:

   a) calculated (by multiplying the total of authorized unbilled and commercial losses with the average tariff (i.e. (total revenue – grant revenue)/ (annual billed consumption, KSh/m3) and the total of physical losses with the unit production cost (i.e., total O&M cost / annual production, KSh/m3) based on their roughly-estimated or assumed balance (e.g., authorized unbilled + commercial losses: 60% and physical losses: 40%)) and converted to financial loss per staff.

   b) explained to a wide range of staff and board members of WSP

3) Other parameters such as revenue loss per staff, capital investment from saved revenue loss, etc can also be calculated to sensitize staff and board on the need to reduce NRW.

4) Potential reduction in further capital investment (KSh) for water resource development (e.g., additional intakes, water treatment plants, pipeline facilities etc) through NRW reduction should also be roughly estimated (KSh) based on the volume of expected or assumed physical losses reduction (e.g., 40% → 20%).

5) The overall scale of justifiable investment for NRW reduction should be discussed among the managers and board members (e.g., based on the rough financial estimations described above).

3.6 Enhancement of Customer Compliance and Support

1) Printed or electronic water bills, SMS, etc. carrying messages requesting customers for cooperation, such as notification of visible leaks and illegal water uses, to reduce NRW and excessive water uses should be extensively used.

2) Toll free telephone number, low-cost SMS number, etc. should be established to encourage the public to notify problems to the WSP.

3) Customer care section should be enhanced with a software system (e.g., WASREB's Maji Voice and a customized internal customer management system) for receiving and managing complaints and problem notifications (e.g., bursts, leaks and water theft).

4) Awareness campaigns for NRW reduction and saving water (e.g., overflow from customers' ground/underground/rooftop reservoirs/tanks and excessive consumption) in the following forms should be adequately conducted:

    a) Public forums/open clinics (e.g., baraza, water action group, etc) for community sensitization (especially in areas with many illegal water users)

    b) Activity-based sensitization such as inviting school to learn about the water facilities

    c) Media campaigns (e.g., TV, radio and social media)

    d) Participating in events and trade shows (e.g., World Water Day, trade fairs and exhibitions, etc)

3.7 Self-Assessment of Existing Conditions

3.7.1 NRW Self-Assessment Matrix

At the start of NRW activities, WSPs are required through their NRW functions or otherwise to conduct a self-assessment on diverse NRW issues/variables herein called aspects. The WSPs are required to carry out the Self-Assessment as teams as per the template in **Appendix-1Sht(2)**.

Currently identified NRW challenges fall into four main categories with affiliated sub-categories. Within these categories, 33No aspects of NRW are identified and outlined for action in a bid to facilitate a better understanding of the challenges and hence identification of potential NRW management aspects for positive results.

For self-assessment, each NRW aspect is assigned points on a scale of 5 (5 levels) depending on perception of status. WSPs must therefore objectively assess their own levels to establish their NRW baseline conditions.

Level 1 is the most advanced status and corresponds to a state where nearly all good practices of NRW measures have been taken and the WSP is at cutting edge of NRW management and can only sustain the status at the lowest NRW expectation. Level 5 is the lowest and most basic status which corresponds to a situation where operations in relation to that aspect are either non-existent or still very low and therefore requires much improvement.

After assessing the NRW status level using the standard Self-Assessment template, WSPs can then strategically plan for NRW reduction specifically along those distinct

NRW aspects. They should follow the steps outlined in the Template for Annual Review, Assessment, Planning and Monitoring [Appendix-1Sht(4)] where there are provisions to identify required resources and investments as appropriate in order to improve NRW management in the short, and medium terms.

The four main categories of NRW reduction and management are as follows:

a) Organizational Structure

In the past, addressing NRW challenge were dampened by inadequate commitment from the management. It is therefore proposed that WSPs shall institutionalize the NRW function in their organizational structures. This shall be followed by staffing this function with the required competent staff, resources and other necessary capacities and facilitation. Just like other functions, NRW unit shall be assigned responsibilities with expected targets.

b) GIS, NRW Monitoring, Zoning and Water Balance Analysis

Mapping of water supply facilities including customer meters and sharing GIS data and maps (using free software) are critical essentials to addressing NRW. In addition, daily NRW monitoring by zones and DMAs plus monthly water balance analysis assist in detecting abnormal flows, bursts, leakages and illegal water use; and addressing them early enough, hence mitigating the potential losses.

c) Reduction of Commercial (Apparent) Water Losses

Water service provision is supposed to be run on business principles where potential losses should be at the bare minimum if any. Each WSP management shall therefore pay special attention to large customers through analysis of their meter reading and billing data including conditions of these customer meters. In addition, the WSP shall aim to reduce unbilled, unmetered and illegal water uses by frequently undertaking CIS as well as targeting suspicious customers.

d) Reduction of Physical (Real) Water Losses

This entails reduction of physical losses through proactive patrolling for leaks, quick quality repairs, daily detection of illegal water use including illegal connections, use of better-quality pipe materials, underground leak detection and pressure management among many others.

Beyond the assessment of all the NRW aspects, sub-categories and main categories with each being allocated points as appropriate, there shall be the weighted scores which then give rise to the level of assessment as per the template(Appendix-1).

3.7.2 NRW Reduction Planning

After successfully conducting NRW self-assessment, the next step is the planning phase. The achievement level of the self-assessment is taken as the baseline. The maximum achievable point in every NRW aspect is noted. Priority for improvement in every NRW aspect, with 1 being the highest and 5 the lowest, is determined. Subsequently, the target achievement for the short term (1 year) and the medium term (5 years) are determined which then become the basis for execution of the required activities and their corresponding monitoring and evaluation over time (monthly, quarterly or annually).

Appendix-1Sht(2) shows the Capacity Self-Assessment Template on current conditions for NRW Reduction.

3.7.3 Analysis of the Self-Assessment Matrix

Based on the Self-Assessment Matrix developed by the WSP, the management must analyse the priority activities to be implemented by the NRW function directly or through coordination with other pertinent functions of the WSP.

Table 3.1 shows the “Issues and Questions” that are raised in the Self-Assessment Matrix and describes the priority of each issue in column 2. Column 3 describes the activities that need to be implemented by the management in order to accomplish the priority issue in column 2.

Table 3.1: Issues and Questions Raised in Self-Assessment Matrix and their Priorities

Issues and questions	Priority of each issue	Activities by Management
1. Organizational Structure, Sensitization, PDCA Cycle and Procurement		
1.(a) Staffing with Essential Support and Training	-Establishment of a permanent NRW unit with requisite skills and competencies plus explicit job descriptions and SOPs and its Strong Coordination with other units. -Capacity Development through Trainings and Benchmarking	Management support through facilitation with resources as appropriate

Issues and questions	Priority of each issue	Activities by Management
1.(b)Sensitization and Awareness raising for wider support	Sensitization of staff and Board on Ethical, Cooperative, Financial and Water resource aspects of NRW - Enhancement of existing and potential customers compliance and support	Reaching out to both staff and current and potential customers and other people of affiliated interest to be part and parcel of NRW reduction initiatives either directly or indirectly
1.(c) PDCA Cycle	-Yearly PDCA Cycle: Participatory Review and Planning, and Budget and Funds for NRW Reduction Activities -Monthly and Quarterly PDCA Cycles: Performance Indicators, Monthly Report, Data-based Discussions and Progress Monitoring	-Management support through self- involvement in the planning and review activities, Monthly Reports, Data-based Discussions and Progress Monitoring -Facilitation with resources as appropriate
1.(d) Suitable, Sufficient and Timely Procurement	-Internal Standardization of Pipes, Fittings, Customer Meters, etc. and Quality Control -Procurement of Sufficient Materials, Equipment, Means of Transportation, etc.	- Management support through facilitation with resources as appropriate
2. GIS, NRW Monitoring, Zoning and Water Balance and Analysis		
2.(a) Mapping/GIS Development, and Utilization of Free Mapping Soft-wares	-GIS Establishment and Mapping of Water Supply Facilities -Mapping of Customer Meters, Various Problems at Customer Points, and Bursts and Leaks -Backup, Update and Enhanced Sharing of GIS Data/Maps using Free Software	- To ensure there are updated pipe network drawings of the infrastructure

Issues and questions	Priority of each issue	Activities by Management
2.(b) Monthly NRW Monitoring and Zoning	-Monthly Monitoring of Total Billing, Universal NRW Ratio, etc. for entire Service Areas (SA) - Zoning of the Existing Distribution Networks into DZs and DMAs -Monthly Calculation of NRW Volume and Ratio for Each DZ and DMA	- Ensuring there are accurate production and customer meters as a mandatory priority for reconciliation to make sense - Management support through facilitation with resources as appropriate
2.(c) Abnormal Flow Monitoring and Water Balance	-Abnormal Flow Monitoring for Quick Detection of Bursts, Leaks and Illegal Water Uses -Universal Water Balance Table 1/2 (Confirmation of the Reduced/Remaining Commercial Losses) - Universal Water Balance Table 2/2 (Separation of Physical Losses) and Additional Zonal Analysis	-Management support through facilitation with resources as appropriate -Penalties must be imposed as stipulated by the law, and water theft must be punished in liaison with the enforcement arm of the county government. -All Illegal connections must be legalized or removed.
3. Reduction of Commercial (Apparent) Water losses (i.e., Data Handling and Meter Accuracy Errors and Illegal Uses) etc.		
3.(a) Starting from Large Customers (e.g., by NRW Section)	-Analysis of Meter Reading and Billing Data to Understand the Conditions of Existing Customer Meters, etc -Straight-forward Reduction of Various Commercial Losses starting from Large Customers -Additional Focused Management of Large and Medium Customers	-Management support through facilitation with resources as appropriate

Issues and questions	Priority of each issue	Activities by Management
3.(b) Activities for New and Problematic Customers (e.g., by the section installing Service connections and Customer meters)	-Reduction of Unbilled, Unmetered and Illegal Water Uses based on CIS and Targeting of Suspicious Customers -Preventive Measures at the Installation of Service Connections and Customer Meters	-Management support through facilitation with resources as appropriate -Information Management System such as the GIS should be introduced -Training must be conducted for GIS.
3.(c) System-Related and Procedural Internal Improvements (e.g., by the section in charge of Meter Reading and Billing)	-System-related and Procedural/ Internal Improvements for Meter Reading and Billing -Procedural/Internal Improvements against Illegal Water Uses	-Management support through facilitation with resources as appropriate -Information Management System such as the GIS should be introduced. -Training must be conducted for GIS. -Penalties must be implemented as stipulated by law, and water theft must be punished in liaison with enforcement arm of the county government. -All Illegal connections must be legalized or removed.
4. Reduction of Physical (Real) Water Losses i.e. (Bursts, leaks and Overflows)		

Issues and questions	Priority of each issue	Activities by Management
4.(a) Physical Loss Reduction Measures applicable without isolating DZs and /or DMAs	- Reduction of Visible Physical Losses by Active Patrolling and Quick Quality Repairs -Daily Usage of Low-Cost Listening sticks and Hand Pumps for Detecting Leaks (and Illegal Water Uses) -Sufficient Valves, Introduction of Better Pipe Materials and Small-scale Replacement of Most Problematic Pipes	-Management providing: - -Institutionalized and operational NRW function -Appropriate equipment -Training for use of these equipment -Budget provision for implementation of prioritized NRW reduction-based activities - Management support the implementation of efficient and effective leakage control measures - Adoption of geographical information system (GIS) for management of leak repair records to facilitate decision-making
4.(b) Underground Leak Detection in a priority DZ(s) and /or DMA(s) and its expansion over other areas	-Strategic Approaches for Underground Leak Detection varying from Place to Place -Improvements for Underground Leak Detection	-Management providing: - -Institutionalized and operational NRW function -Appropriate equipment -Training for use of these equipment -Budget provision for implementation of prioritized NRW reduction-based activities - Management support the implementation of efficient and effective leakage control measures - Adoption of GIS for management of leak repair records to facilitate decision-making

Issues and questions	Priority of each issue	Activities by Management
4.(c) If REQUIRED Pressure Measurement and Pressure Reduction / Management without large investments (e.g., PRV and BPT)	-Zone Prioritization for Pressure Reduction and Identification of Problematic Pipelines with Pressure Measurements -Pressure Reduction/ Management with Relatively Small Investments (e.g., PRV, BPT, etc.)	-Management providing: - -Institutionalized and operational NRW function -Appropriate equipment -Training for use of these equipment -Budget provision for implementation of prioritized NRW reduction-based activities - Management support the implementation of efficient and effective leakage control measures - Adoption of GIS for management of leak repair records to facilitate decision-making -Creation of Water pressure map(s) by use of water pressure gauge. -Installation of Pressure Reducing Valves as appropriate
4.(d) If REQUIRED Leak Reduction with large Investments (e.g., Pressure reduction with Reservoirs and Replacement of Many pipes).	-Pressure Reduction/ Management with Relatively Large Investments (e.g., Zoning with Reservoirs, Pump Replacement, etc.) -Large-scale Replacement of Deteriorated Pipelines and/or Service Connections	-Budget provision for implementation of prioritized NRW reduction-based activities - Management support the implementation of efficient and effective leakage control measures - Adoption of GIS for management of leak repair records to facilitate decision-making -Creation of Water pressure map(s) by use of water pressure gauge. -Installation of Reservoirs and Pipe replacement with the correct pipe material as appropriate

3.8 Preparation of Medium-term and Annual NRW Reduction Plans

3.8.1 Developing and Implementing a NRW Reduction Plan

Water is a fundamental resource for human and economic development. Many water utilities in Kenya are not able to account for large portions of water they deliver. In some cases, the NRW is above 50%. This is a major cause of concern in terms of inefficient use of the scarce water resources. It also affects a utility's ability to earn revenue to support its financial sustainability and thereby offer efficient services. A utility which has a high NRW means it has lower revenue hence it does not have funding to fix the problem that causes NRW and NRW increases.

In order to address the situation of high NRW and achieve the required efficiency, a utility needs to operate in an environment in which NRW declines, revenue increases, the utility has funding to invest in system improvement, and network expansion resulting to further decline in NRW.

Developing and implementing a successful NRW reduction plan entails the following steps:

Step 1: Seek support for a Non-Revenue Water Reduction Programme

NRW programmes require resources and time which are scarce. Therefore, the first step should be to outline a NRW programme. The programme should show the anticipated benefits in order to gain support of the utility's leadership and customers.

Step 2: Establish a Non-Revenue Water management team

The team performs the analysis and develops a strategy, recommends intervention and oversees implementation. The team must include members from all of the utility's departments; i.e., Administration, Technical (Production, Distribution) and incorporate customer service, communication, etc. this is crucial in order to promote ownership and build consensus by the utility's senior management.

Step 3: Calculate the Non-Revenue Water Ratio

The NRW ratio will show the magnitude of the losses and the areas where NRW is present. This enables decision-making in use of the limited utility resources in areas of high return in revenue and cost cutting.

Step 4: Set Non-Revenue Water reduction targets

The utility should set realistic targets for NRW reduction taking into consideration the utility's goals, policies and resources and any targets established by the National Water Policy and the regulator. The National Water Services Strategy (NWSS: 2019-2030) for NRW is 25% by 2030 while the benchmark by WASREB is 20%.

Sep 5: Identify Non-Revenue Water reduction projects

Undertaking a pilot project to demonstrate the effectiveness of NRW reduction is a useful way to start because it will generate lessons and it will show the value of NRW reduction strategy. A pilot project covers a small area that is still large enough to test the NRW reduction strategy.

The type of pilot project can vary from improved metering to better customer accounting to full-scale repair and rehabilitation of the network and customer service connections.

Step 6: Prioritize Non-Revenue Water projects

Most utilities face scarce resources in staffing, equipment or funding. The potential projects will have different levels of payback, impacts on service, timing, etc. Prioritizing is the way to select the projects that will have the greatest overall benefit and to decide on the timing of when projects are accomplished.

Some projects may reduce NRW significantly but will have a high cost. Others may have a lower cost and lower reduction but can be accomplished more readily because resources are available. Gains from doing these projects may generate additional revenues which can then be used to accomplish the more expensive projects.

Step 7: Planning and approvals

In order to obtain resources. The team needs a budget that is approved by the utility leadership. Therefore, when developing an NRW plan, remember that reducing NRW is not a short-term process. Some activities may span years rather than months. Timeframe between four and seven years are reasonable. Anything shorter is ambitious and anything longer will not be cost effective.

In preparing the budget, the team must identify costs that may include:

i) Staffing for both direct NRW works (e.g., leakage technicians) and direct support (e.g., procurement staff).

ii) Equipment installed permanently (e.g., DMA meters) and those used on a day-to-day basis e.g., leak detection equipment)

iii) Vehicle and equipment to maximize the productivity of staff.

Step 8: Implementation, monitoring and evaluation

As the project takes place, it is a good idea to monitor both the costs and benefits and compare them to budgets and NRW targets. This will demonstrate the benefits of NRW reduction and build support for the strategy. It will also allow the team to take action to improve performance as needed.

Step 9: Sustain the gains of a Non-Revenue Water reduction project

NRW management is a continuous process. Even after the initial gains are made, NRW must continue to be managed. This requires vigilance and attention to make sure that leaks are eliminated when they occur, that all customers are legally connected and billed and, all water uses are tracked.

3.8.2 Contents and Layout of Non-Revenue Water Reduction Plan

There are many activities that constitute NRW reduction measures. The purpose of an NRW Reduction Plan is to determine the most suitable measures for adoption and use the available budget effectively.

An NRW Reduction Plan must include the following components:

a) Introduction

This covers the WSP's background, rationale for the reduction of plan, assumptions in developing the plan, methodology of developing the plan, and organization of the plan.

As geographical and social conditions are unique to each WSP, any existing problems related to these conditions must be identified. Hence, the overall management, financial status and funds available are all important factors in the planning for NRW reduction.

b) Current status of Non-Revenue Water

It is important to first understand the current situation that is causing high NRW. Therefore, the analysis of the current status should be based on a self-assessment carried out by the WSP using the SELF ASSESSMENT MATRIX.

As a first step it is important to understand what happens to water when it enters the network. Therefore, NRW must be calculated by using volume of distributed water (system input volume) and billed authorized consumption volume.

In cases where the volume of distributed water and/or volume of consumption cannot be correctly established, then priority should be placed on the installation of flow/water meters.

c) Objective (target Non-Revenue Water ratio and target area)

A company-wide target for NRW reduction, taking into account the utility's other goals or policies that will either complement or conflict with NRW reduction should first be established. This target should be guided by the National Water Services Strategy and the sector benchmark as issued by the regulator. Often, many utilities choose the NRW target arbitrarily, without any real consideration of cost implications or whether it is achievable.

Identifying the economic level of NRW is essential to setting the initial NRW targets and requires a comparison of the cost of water being lost versus the cost of undertaking NRW reduction activities.

For utilities with more than 40% NRW ratio, commercial loss reduction and visible leakage reduction measures must be given priority. For those utilities with NRW ratio of between 40% and 30%, invisible leak detection and repair are necessary. Between 30% and 24% ratio, it is necessary to replace aging pipes. Significant amount of funds will be required to replace all aging pipes and therefore, it is necessary to prioritize areas and also activities.

Generally, leakage occurrence record must be plotted onto a map, which will show areas with high occurrences of leakages. Areas with high water pressures and also large pressure variations should be given priority. Furthermore, if there are any asbestos cement pipes, replacement of those must be prioritized.

d) Non-Revenue Water Reduction Implementation Plan

It presents the implementation matrix, which covers for each of the strategies, proposed actions, bill of quantities, and cost estimates, implementation schedules, expected outputs and output indicators.

e) Monitoring and Evaluation

It is essential for the success of the NRW management programme. It enables managers to track progress against plans, budgets and expected results in the form of performance indicators. It also enables managers take action when performance is lagging behind expectations or exceeding budgets. To achieve the desired results from the plan, MONITORING through regular observation and recording of activities taking place is important.

3.8.3 Prioritizing Implementation Plan of Non-Revenue Water Reduction

Once the utility's NRW target is set, utility managers should calculate the proposed volume of water saved by comparing the NRW baseline with the target level. The volume components, as detailed in the implementation plan for NRW reduction Table 3.2 are then prioritized according to how the required total reduction can be most cost-effectively achieved. That is, some components may comprise a significant volume, but would not be targeted because of the high cost to achieve reduction in that component. On the other hand, focusing on another component may cost less while reducing the same volume. Therefore, the scope of implementation will depend on the financial capability of each utility and be guided by the action plan in Table 3.3 (also refer to Appendix-1Sht(5).

In general, if a physical loss is detected and repaired then the savings will be in terms of a reduction in variable operational costs. When a commercial loss is detected and resolved, then the savings will be an immediate revenue increase, and this is based on the water sales tariff.

The water sales tariff is higher than the variable production cost for all profitable water utilities. Therefore, a smaller volume of commercial loss may have a higher financial value, so if increasing financial resources is the objective, then commercial losses should be prioritized.

Similarly, where a water utility has a shortage of treated water, and some customers receive less than a 24-hour supply or the supply coverage is less than 100%, then reduction in physical losses would effectively create additional water supply. Hence if increasing water supply is the objective, then prioritizing physical losses reduction could enable customers to receive water 24 hours a day, or new customers to be connected to the supply system.

Table 3.2: Non-Revenue Water Reduction Implementation Plan

Issues	**Activities**	**Description of Activities**	**Concept and Quantified Aim**
Fundamental Measures: Water Balance/ Flow/ Pressure Monitoring/ Mapping, Procurement & Zoning	Consumption Metering	Customer meter installation	Installation of customer meters at every household to aid in the determination of consumption and billing process and also to assist in the determination of the NRW volume in the system is therefore paramount
	Pressure Monitoring	Pressure gauge installation	To determine current water pressure at select points in the distribution system
		Water pressure map	Water pressure map must be developed using data from water pressure gauge measurements
	Maps/GIS	Pipeline map	Pipe network maps and drawings are absolutely necessary for WSPs to implement efficient and effective NRW reduction measures. In the absence of drawings, the WSP should start to build up the drawings of distribution mains and major distribution facilities. Coming up with pipeline map which contains types of pipes, size, age, length, valves, etc.
		Digitize the mapping data	Comprehensive map of the pipelines by computer aided design ensures ease in retrieval, updating, amendment, storage, etc.

Issues	Activities	Description of Activities	Concept and Quantified Aim
	Leak Repair Records	Check for any leakage. Recording the leakage promptly. Checking and recording meter tampering	It is necessary to provide repair records, such as pipe diameter, material, location, etc
	Provision of basic equipment necessary for NRW reduction		Procurement of equipment related to NRW reduction. To carry out the leakage control work at least the following equipment are necessary: Hearing bar, electronic leak detector, Pipe locator (for metallic and non-metallic pipes). Necessary number of basic equipment depends on the size of the WSP
	Separating into distribution zones and DMAs gradually while getting trained in a pilot DMA		Establishment of small DMAs requires a lot of resources. It is therefore recommended to begin by establishing a pilot DMA to conduct training of NRW reduction measures for relevant WSP's staff while gradually separating the entire service areas into large distribution zones and then into DMAs.
Reduce Commercial Losses	Customer metering	Inspection of all customer meters	- Inspection of stuck meters, non-active and/or aged customer meters
		Ensure 100% metered connections	- Improving the customer meter ration
	Customer meter replacement based on age and accuracy	Replacement of stopped/ inaccurate and/or aged customer meters	- Investigating all customer meter tampering suspects - Repairing and/or replacement of customer meters

Issues	Activities	Description of Activities	Concept and Quantified Aim
	Customer meter class	Ensuring purchase of meters that meet required standards	- Replacement of existing meters not meeting required specifications
	Customer database	Customer database and billing	- Update and maintain the database with specific times of update. - Purchase of software to make work easier to manage database
	Customer meter reading	Reading all meters monthly	Develop a schedule on the meter readers rotation
		Billing all customers on monthly basis	- Preparation and Printing of meter reading books. - Capturing of all the meter readings. - Bill adjustments. - Processing the bills
		Less errors in meter reading. Less corruption cases	- Correct reading of meters. - Rotating meter readers in the company. - Sub-contract meter reading. - Ensuring proper routing
	Illegal connection, meter tampering, bypasses	Illegal and dormant connection inspection	- Identifying illegal accounts - Disconnecting/legalizing illegal accounts - Management to take stern, stiff and legal action on corrupt staff manipulating meter readings, meters, etc.
		Forming inspection team, taking legal action on the illegal cases, random monthly inspection by top management	- Management to be swift, steady, fearless and persistent in dealing with corrupt cases like meter interference, illegal connections.

Issues	Activities	Description of Activities	Concept and Quantified Aim
Reduce Physical losses	Active leakage control	Leakage detection	Conduct continuous non-visual leakage detection activities
		Leakage repair works	In principle, detected leakages must be repaired immediately
		Replacement of service pipes	When leakage occurs in the service pipes, the fundamentals are to replace rather than repair.
		Replacement of distribution pipes	Plans for distribution pipes replacement are affected by the availability of financial resources. However, replacement is preferred option
	Reduce repair time in distribution pipes	Record time taken to repair leakages. Analyse the data to determine time taken	Reduced response time of pipe repair to 6hrs irrespective of size.
	Water pressure management	The most common and cost effective is the use of pressure reducing valve - PRV	Water pressure of around 1 MPa must be maintained as much as possible throughout the distribution system.
Capacity Building	Training on NRW management	Taking the relevant staff for training on NRW management. Field visitation. On-Job-Training (OJT)	To improve technical skills and capacity

Issues	Activities	Description of Activities	Concept and Quantified Aim
Public Aware-ness	Aware-ness of stake-holders on NRW management	NRW public campaigns	Create stakeholder awareness for proper water use and disseminate benefit of NRW management.

The action plan would be summarized as shown in Table 3.3.

Table 3.3: Non-Revenue Water Reduction Action Plan

Issues/Questions		Desired Status / Target	Short Term Measure
1	**Water Balance, Flow and Pressure Monitoring, Mapping**		
1.1	Water Balance		
1.2	System Input Metering		
1.3	Pressure Monitoring		
1.4	Mapping/GIS		
2	**Leak Repair Records**		
2.1	Leak Repair Records		
3	Performance Indicators		
3.1	Performance Indicators		
4	**Active Leakage Control**		
4.1	Active Leakage Control		
4.2	District Metered Areas (DMAs)		
4.3	Leak Repair - Distribution Pipes (Repair Time)		
4.4	Leak Repair - House Connections (Repair Time)		
5	**Customer Metering**		
5.1	Customer Metering		
5.2	Customer Meter Replacement and Age		
5.3	Customer Meter Class		
5.4	Customer Database		
5.5	Customer Meter Reading		

Issues/Questions		Desired Status / Target	Short Term Measure
5.6	Illegal Connections, Meter Tampering, Bypasses		
6	**Other Interventions**		
6.1	Capacity Building on NRW Management		
6.2	Stakeholder awareness on NRW Management		

3.9 Budgeting, External Funds and Public Private Partnership

3.9.1 General

a) Sound strategies and/or main activities to reduce NRW should be well stated in the WSP's latest 5-year strategic plan.

b) The following documents should be developed in a fully participatory way among relevant staff:

i) yearly self-assessment of current conditions (i.e., Self-Assessment Template and its visualized results) – Appendix-1 Sht(2).

ii) yearly update of medium-term NRW reduction plan (MP) with activity prioritization (i.e., MP - Appendix-1 Sht(4)Template <2-1>)

iii) annual NRW reduction plan (AP) with cost estimation (i.e., AP - Appendix-1 Sht(4)Template <2-2>)

iv) yearly review sheet (i.e.,Appendix-1 Sht(1) and/or report of NRW reduction activities

c) Submission of the four documents listed above (e.g., to managers, board of WSP and/or WASREB)

d) The budget required for implementing the annual NRW reduction plan should be approved (e.g., by the managers and/or the board of WSP)

e) Possibility of receiving external funds required for capital investment included in the medium-term plan (e.g., for replacing degraded pipes) should be discussed well.

3.9.2 Caution

Private sector participation can take many forms, and the best approach in the short term is probably a low-key gradualism whilst preparing the ground for larger scale private sector participation.

a) If a loan/grant is involved, ensure relevant constitutional requirements are followed in formulation of the loan/grant agreement

b) Develop adequate legal, institutional and regulatory setting to promotePublic Private Partnership (PPP)

c) Ensure financial proposal is adopted and approved by the legislative arm of the government and has gained enough social and political support

d) Create internal and external accountability, prioritizing investments within financial availability

e) Overcome institutional rigidities, particularly regarding manpower and investment planning and implementation

3.9.3 Performance Based Contracts

a) Under Performance Based Contracts (PBC), a private firm is contracted to implement an NRW-reduction programme, and contract payments are linked to achievements.

b) Contract models and the level of performance-based payments can vary widely from one utility to another.

c) It is important that contract period should be Realistic and in proportion to the project network area. Not too short and not long period.

Note: The principal advantages of NRW PBCs over conventional projects that are directly implemented by a utility is that the utility can benefit more rapidly from NRW reduction and faces a lower risk of the project not achieving its targets.

3.9.4 Drivers for implementing Non-Revenue Water Performance Based Contracts

a) Major constraints on water resource availability, currently or expected in future

b) Utility is not recommended to increase staff to reduce NRW and then scale back staff to maintain low NRW

c) Limited or low utility expertise in NRW planning and reduction

d) High water production costs, such as through the use of desalination or high energy cost.

3.9.5 *Characteristics of Performance Based Contracts*

It is output-based: design, build, operate contract with strong performance element.

a) Both the client and contractor must understand the contract before signing.
b) Payment - Small fixed fee - 'Priced Activity Schedule'
c) DMA establishment - lump sum price per DMA established
d) Performance indicator fee per m3/day leakage reduction
e) BoQ (supply and installation) for unforeseen works
f) Works to connect new customers
g) Leak Repair
h) Network Pipes Replacement and Extension
i) Pressure Control Implementation and Optimisation
j) Improving water customer services (customer satisfaction)

3.10 Periodic Discussions, Progress Monitoring and Review Reports

1) Prioritization of data collection (daily, monthly, quarterly and annually) for calculating performance indicators (should be carefully done. The indicators can also be used for WASPA's benchmarking activities and WASREB's Impact Report.

2) Systematic and simplified data collection and analysis methods should be formulated and operationalized.

3) The NRW Unit should:

   i) prepare quantitative monthly progress report using selected PI's

   ii) submit the report to the supervisor/manager

4) The NRW Unit and other relevant staff including managers should have monthly NRW reduction coordination meetings and discuss concrete improvement of the PI's

5) Progress in implementing the planned NRW activities should be monitored

3.11 Internal Standardization and Procurement

1) The types of problematic existing pipes, fittings, valves, etc (causing bursts and leaks frequently) and bulk and customer meters (with defects and being tampered with) should be discussed adequately (and analysed based on collected data) to identify the need for changing their procurement.

2) Suitable types of pipes, fittings, valves, etc of different sizes and suitable pressure rating (e.g., HDPE pipes to reduce leaks from joints) should be selected for procurement with adequate internal standardization (based on performance, availability and price)

3) Suitable specifications of bulk and customer meters such as ISO Class and/or OIML R, type (e.g., copolymer piston), availability of spare parts, etc should be decided for each size

4) The procurement of pipes, fittings, valves, bulk and customer meters, etc should be done in accordance with suitable types and specifications (including those provided by WSB, County, etc)

5) The WSP should appoint adhoc but competent staff for different inspection and acceptance committees based on the various procurement categories (e.g., pipes and fittings, motors and pumps, meters, etc). The committees should be strengthened well to reject faulty and unmatched materials and services

6) Some portion (e.g., 5%) of each batch of new customer meters should be sent to a credited meter testing institution (i.e., KEBS and Nyeri WSP) and sub-standard ones rejected (WSP with own meter test bench may test all or some of the new meters)

7) Trace survey should be conducted to evaluate durability and actual lifespan of newly procured meters (results showing a significantly limited durability may be used to reject the products from the same manufacture)

8) Enough pipes, fittings, valves and other common appurtenances should be procured and stored for quick repair of bursts and leaks.

9) Enough bulk and customer meters of different sizes (including spare parts if available) should be procured and stored for quick replacement and repair of faulty and degraded meters

10) Enough number of NRW survey equipment (e.g., listening sticks, calibrated buckets, portable ultrasonic flow meter, electric leak detector, noise correlator, pipe locator, pressure gauges with maximum pressure pointer/ pressure loggers, hand pumps, etc) should be acquired

11) Enough office appliances and specialized hardware required for establishing or improving GIS database, e.g. A3- inkjet printer with scanner (or plotter), spare inks, desktop PC or laptop, hand-held GPSs, large PC monitor, etc should be procured and well maintained (Note: Free GIS software programmes and free base maps such as QGIS and online satellite images are available for PCs)

12) Enough official-use smartphones/tablets should be procured for improving NRW activities at site (Free mobile GIS and interactive data collection software programs, etc can be installed in the procured smart-phones/tablets)

13) Reliable internet connections with reasonable speed in WSP offices (i.e., WIFI) and in official-use smartphones/tablets (i.e., data connection) should be provided to the staff involved in NRW-related activities

14) Enough transportation means should be secured for NRW reduction activities

Chapter 4

Mapping and Use of Free Software

4.1 Necessity for Geographical Information System

4.1.1 What is Geographical Information System?

Geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show many different kinds of data on one map, such as streets, buildings, vegetation etc. It is therefore ideal for viewing and managing water facilities (e.g., pipelines, storage tanks, etc.) compared to paper maps that have been in use in the past.

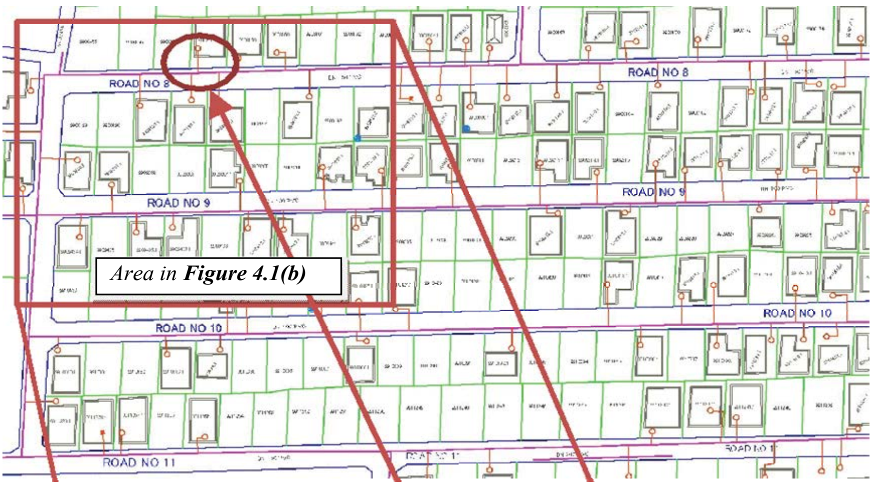


Figure 4.1(a): Advanced GIS map showing water supply network

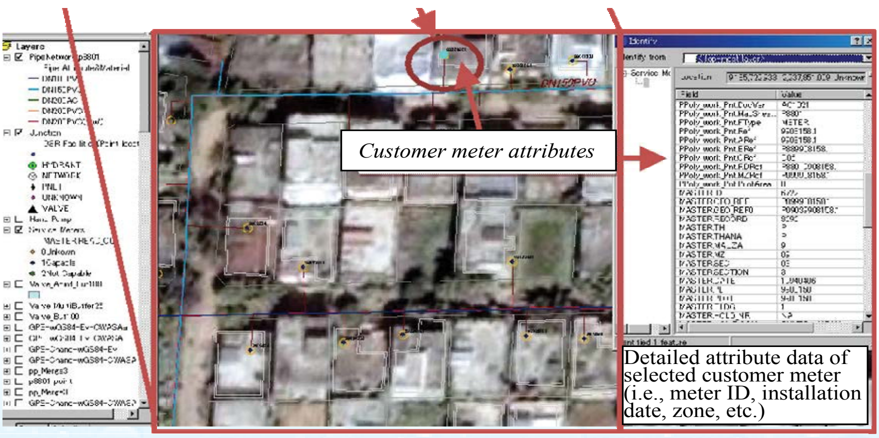


Figure 4.1(b): Satellite imagery used as base map of GIS

GIS can be used for storing and updating the geographical locations of water supply facilities such as customer meters, area boundaries, etc. and their attributes (including records of problems - bursts, leaks, water thefts etc.). Figure 4.1(a) is an example of advanced GIS database of water supply (customer meters, service and distribution pipes) showing supplementary layers (plots and buildings). Figure 4.1(b) is the satellite image showing part of the area covered by Figure 4.1(a).

4.1.2 Free GIS Software

In order to effectively reduce NRW, it is essential to utilize data from multiple information systems such as:

- Customer management systems for data on meter readings, billing, revenue collection, complaints handling, etc.
- Statistical data calculation sheet/processing system relating to NRW management (e.g., spreadsheets to calculate NRW ratio in each area)
- GIS and other mapping systems for collecting, identifying and analysing information on water supply facilities and their problems including locations of bursts, leaks, water thefts, etc.

Most of these systems are already installed as stand-alone systems by WSPs in Kenya. However, some of the large and/or advanced WSPs try integrating the systems using local software developers.

For mapping, highly-functional software programs (e.g., Kobo Toolbox/Collect, QGIS, QField) are now widely available online free of cost. WSPs just need to acquire the basic skills on handling these information systems. They can then use the systems in combination for more effective NRW reduction by exporting and importing data from one system to another.

4.1.3 Advantages of GIS over Other Mapping Software

Use of GIS by WSPs has been low in Kenya due to the high cost of software. However, there is no more excuse for not using GIS for NRW reduction since highly-functional GIS software and online base maps are available for everybody at no cost.

Other mapping software are Computer-Aided Design (CAD) and Google Earth.

1) GIS has significant advantages in operation and maintenance of water supply facilities (e.g.,searching facilities having certain conditions, analysing problems, etc.) over CAD systems such as AutoCAD, online-mapping software such as Google Earth, etc., GIS can also be integrated with smartphone based free software applications and the billing software thereby further easing management of the water facilities.

2) CAD system is quite useful for detailed design but has also been widely used for mapping by WSPs (and WSPs should safely keep all the as-built CAD and paper-based drawings of existing water supply facilities for occasional reference). These CAD files can be used to develop GIS layers to some extent but it is very difficult to convert CAD data (e.g.,dxf files) to GIS data (e.g., shapefiles) because their data structures are quite different. Therefore, if a WSP wishes to have a useful geographical database of water supply facilities in future, it should start the preparations by using a GIS software from the beginning without temporarily resorting to the familiar CAD system.

3) Google Earth is another free software program which is often used at WSPs to create geographical data sets of their existing water supply facilities. Google Earth allows mapping of water supply facilities and also updating high-resolution satellite images. However, when converting the digitized data on Google Earth (i.e.,kml or kmz files) into GIS data (e.g., shapefiles) later to develop a fully-fledged GIS database, there may be difficulties in transferring the attribute data of each mapped facility due to the differences in their data structure. Therefore, a GIS software such as QGIS should be used from the beginning without detouring to Google Earth.

4.2 Establishment of GIS

4.2.1 Characteristics of GIS Establishment and Utilization

Since GIS field is a very wide and relatively complicated technology, competent IT specialists are needed to apply the technology in the actual work. WSPs are therefore advised to deploy IT specialists toset up GIS database and coordinate its full utilization among the WSP staff. Where necessary, the specialists can undergo further training in KEWI or other institutions.

The tasks for establishing and using GIS fall under three categories:

a) Initial establishment of GIS and mapping of water supply facilities (see 4.3)

b) Mapping of customer meters, problems at customer points, and bursts and leaks (see 4.2.2 and 4.4)

c) Updating and wider use of GIS data/maps (see 4.5)

4.2.2 Activities Prior to Establishment of GIS Skills

Development of a GIS layer for customer meters is time consuming but very important for effective NRW reduction. If there are no staff with basic GIS skills, the WSP may need to recruit or wait until its designated staff to acquire the skills or send them for a training course such as QGIS in KEWI.

While waiting for the GIS skills acquisition, the WSP may commence collection of data which will later be required to build the GIS layer of customer meters. This data collection can be done using smartphones installed with an easy data collection software with map view functions (e.g., Kobo Toolbox/Collect – refer to YouTube on how to create kobocllect forms) to record the locations and conditions of all the existing customer meters at site. It is advisable to include handheld GPSs to confirm the accuracy of the smartphones during the data collection. The collected customer meter data can then be exported (refer to YouTube on how to export data)from Kobo Toolbox into a text-based data table (i.e., CSV legacy file) which can be imported later into GIS database.

4.2.3 GIS Layers Necessary for NRW Reduction

Table 4.1 gives the typical GIS layers to be considered for inclusion in a WSP's GIS database for NRW reduction activities.

The recommended combination of geographic coordinate systems to use for easy GIS operation is the World Geodetic System 1984, WGS84 (i.e., longitude and latitude) and Universal Transverse Mercator, UTM (Zone 36N, 36S, 37N, 37S depending on location in Kenya) for metric/x,y coordinates.

After creating the base map (e.g., satellite image) and general layers for the WSP's GIS database with these coordinate systems, the digitization of the major facilities such as distribution tanks, pipelines, etc. can be done initially by plumbers confirming on the screen and then through field surveys using GPSs.

Table 4.1: Typical GIS Layers for O&M, Planning and NRW Reduction Activities

Category	**Example of GIS Layers**
1. Base Map and General Layers (from external sources)	**[First Priority]** ● **Base Map:** Recent high-resolution satellite imagery with a geographical coordinate system called WGS84 (which is used for GPS and Google Earth) is recommended. [Note: This could be an online satellite image layer of free GIS software (e.g.,Open Layers Plugin - an experimental plugin of QGIS), satellite imagery downloaded by using low-cost software (e.g.,geotiff images created by using Google Satellite Maps Downloader) or satellite imagery purchased/shared by the country]. Otherwise, online street maps, which is much lighter than satellite imagery, can be used (e.g.,OpenLayers Plugin or Quick Map Services of QGIS)

Category	Example of GIS Layers
	[Second Priority] ● **Elevation Contours:** For example, standard GIS files (i.e., shapefiles) of the contours with 25m interval are available at http://www.opendem.info/opendem_client.html [Note: the contours probably need clipping with a boundary such as country boundary to reduce the heaviness of the GIS layer]. ● Other General Layers such as Administration Boundaries (e.g., county, sub-county, etc.), Roads, Water Bodies including Rivers, Landmarks, etc.: These general layers can usually be found on the Internet (e.g., https://www.wri.org/resources/data-sets/kenya-gis-data) or extracted from Open Street Map (OSM).
	[Third Priority] ● Cadastral Maps with Land Plots: Paper cadastral maps, which carry an old geographical coordinate system (i.e., Arc 1960 but not WGS84), are usually purchasable by sections at a national government institution [Note: This means that scanning the paper maps, combining the images, georeferencing and digitization are required at the initial stage and occasional updates to use them as a GIS layer] ● **Current and Future Land Use Maps:** This may be required for the planning of water supply systems over a large area.
2. Layers for Water Supply Facilities and Area Boundaries (through conversion of existing data, on-screen confirmation and site surveys)	**[First Priority]** ● **Main Structures/Sites [Polygon or Point] (possibly multiple layers separated by type):** The required data fields are probably type (office site, intake site, well field, water treatment plan, distribution reservoir/tank, elevated tank, pump station, etc.), name, identification number, construction year, status (e.g., not in use), condition (e.g. leaking), remarks, label and other type-specific information such as capacity, dimensions, low and high water levels, target area, number of pumps, etc. ● **Main Pipes [Line]:** Type (raw water transmission, clear water transmission, primary distribution, secondary distribution, tertiary distribution, etc.), line name, diameter, material, pressure rating, installation year, status, condition, remarks, label, etc. [Note: When drawing pipe lines on GIS, it is better to reflect which side of road each pipe is laid, how pipes are connected at intersections and within main sites such as WTP to make the GIS more useful for various activities including leak line survey]

Category	Example of GIS Layers
	• **Customer Meters [Point]:** Connection/customer account number, meter serial number, type, product name, material, diameter, pressure rating, installation year, existence of meter box, orientation (horizontal or vertical), condition, etc. The digitization of customer meters can be done through CIS by using data collection software such as Kobo Toolbox/Collect. [Note: Connection/customer number or meter serial number can be used as a common data field to join other customer information such as each customer's name, account number, address, cadastral map number, type, connection status, etc. extracted from the customer database used for meter reading and billing] • **Service Areas [Polygon]:** Type (individual supply area, bulk supply area, etc.), name, etc.
	[Second Priority] • **Bulk Meters [Point]:** Type (raw water transmission/intake meter, back wash meter, clear water transmission meter, DZ meter, DMA meter, etc.), product name, meter ID, diameter, material, pressure rating, installation year, status, condition, remarks, label, etc. • **DZs and DMAs [Point] (possibly separated by type):** Type (DZ, DMA, pressure zone, etc.), name of bulk meters for inflow and outflow, number of customers, etc. • **Other Equipment and Appurtenances [Point] (possibly separated by type):** Type (well pump, intake pump, transmission pump, distribution pump, booster pump, pressure reducing valve, break-pressure tank, isolation valve, air valves, washouts, hydrants, pressure gauge, strainer, etc.), product name, ID, installation year, status, condition and other type-specific information such as size/diameter, capacity, pressure head, settings, etc.
	[Third Priority] • **Service Connections or Take-off Points [Line or Point]:** diameter, material, pressure rating, installation year, length, condition, type of take-off point (e.g., tee, saddle, etc.), etc. • **Meter Reading Sections and Routes [Polygon or Line]:** Section and/or route ID, etc. • **Other Pipe Fittings [Point]:** Type, diameter, installed year, etc. [Note: The digitization of minor fittings is probably not necessary in developing countries like Kenya]

Category	Example of GIS Layers
3. Layers showing NRW-related Problems	• **Perceptional Maps of Problematic Areas [Polygon]:** For example, problematic areas (e.g., old pipe networks, high pressure areas, and water-theft prone areas) can be encircled on a satellite image base map through participatory discussions based on participants' perception and/or limited available data) • **Records of Bursts/Leaks, Water Theft, etc. [Point] (possibly separated by type):** Type (burst, leak, underground illegal connection, above-ground illegal connection, meter tampering, etc.), location (distribution pipe, distribution pipe fitting, service pipe, service pipe fitting, etc.), magnitude of water loss, repair method, remarks, etc. • **Problematic Customer Meters [Point]:** After analysing the meter reading and billing data in spreadsheets or conducting CIS, identified problematic customer meters can be presented on GIS.

4.3 Initial GIS Establishment and Facilities Mapping

4.3.1 GIS Procedure 1

This subsection covers the points to be checked regarding the initial establishment of GIS in a WSP and the digitization of major water supply facilities (such as water treatment plant, distribution tanks, transmission pipes and distribution pipes) into GIS layers. The beginning of GIS establishment typically includes the set-up of a base map (e.g., georeferenced satellite image) and the development of general layers (e.g., contours, administration boundaries, rivers, etc.) (see Table 4.1), The following broad procedure is recommended:

1) Ensure that the need for developing and fully-utilizing a GIS database is well discussed between different departments/sections/units (including branch offices covering different areas) and prioritized.

2) Ensure enough number of GIS staff to support NRW reduction activities are employed.

3) Ensure free GIS-related software programs are used for mapping of existing water supply facilities with:

    i) PCs (e.g., QGIS with various plugins such as OpenLayers)

    ii) Android smartphones/tablets (e.g.,QField, Kobo Collect, etc.) and,

    iii) Cloud space/web site (e.g., Kobo Toolbox).

Note: Initiative by GIS staff may be required to shift from expensive commercial GIS software programs with familiar interface (e.g., ArcGIS) to free software programs so that more staff can use GIS without spending additional funds such as annual software license fees.

4) Ensure the following base maps and other general layers are added to the GIS map/project file being developed to establish the GIS database (Note: offline base maps/layers usable without internet connections are more reliable) as follows:

   i) online base maps such as satellite image, street and terrain maps (e.g., from OpenLayers plugin of QGIS) if the internet connection is reliable and fast.

   ii) offline high-resolution satellite image (e.g., offline satellite imagery) downloaded and automatically-georeferenced with low-cost commercial software such as Google Map Downloader.

   iii) offline street map (e.g., open street map - OSM) layers downloaded with OSM Downloader plugin of QGIS.

   iv) offline elevation contours (e.g., downloaded from http://www.opendem.info/opendem_client.html).

5) Ensure reliable GIS layers of major water supply facilities (e.g. intakes, WTPs, pumping stations, distribution reservoirs/tanks, transmission pipelines, major (primary and secondary) distribution pipelines with sluice valves, BPTs, PRVs, bulk meters, etc.) are developed well (e.g. through on-screen digitization with those staff who know the locations of these facilities, on-site digitization with mobile GIS such as QField, mapping with data collection software such as Kobo Toolbox/Collect, digitization from existing drawings, import/conversion of existing CAD data, etc.) (see 4.3.2).

6) Ensure reliable GIS layers of existing zone/area boundaries (e.g., boundaries of water supply service areas, schemes, customer meter reading zones, DZs, DMAs, etc.) are developed well (see Figure 4.2).

7) Ensure reliable GIS layers of minor water supply facilities other than customer meters (e.g., minor (tertiary) distribution pipelines with gate valves, service connections, air valves, hydrants, washouts, etc.) are developed well.

8) Ensure GIS layers of public sanitation facilities (e.g., wastewater treatment plants, public toilets, sewers, manholes, etc.) are developed well.

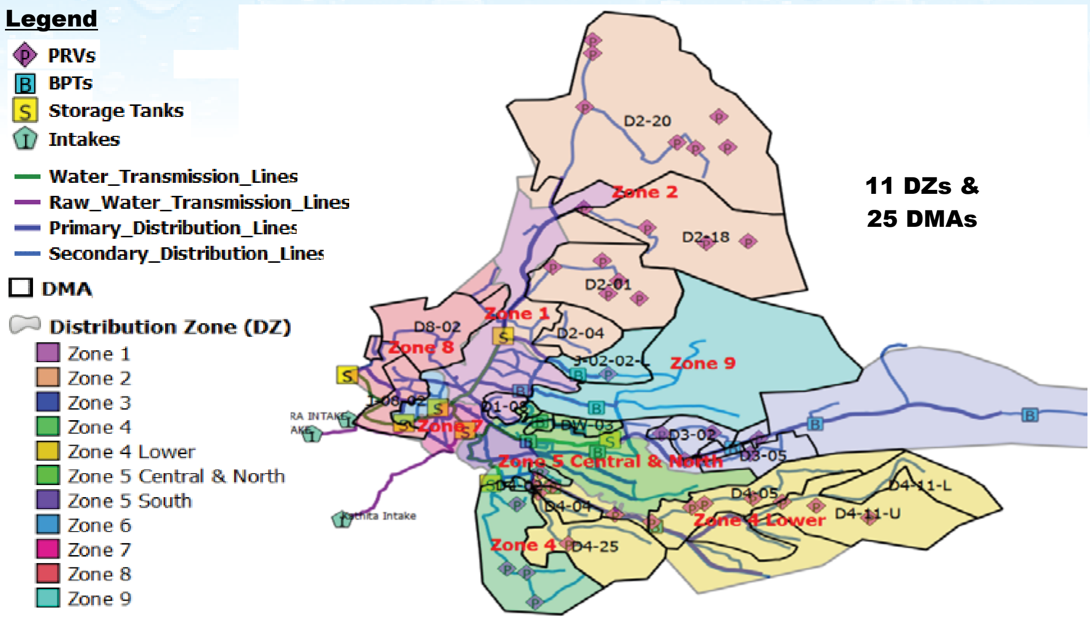


Figure 4.2: DZs and DMAs planned on GIS at Meru WSP

4.3.2 Use of Handheld GPS and Mobile GIS Software for Digitization

Digitization of water supply facilities into GIS layers can be done through a combination of following methods:

1) Scanning, geo-referencing and on-screen digitization of paper maps.

2) Data conversion from CAD files, KML/Z files, etc. into GIS files (Note: Manual re-entry of attribute data would probably be required [see 4.1.3(2)].

3) Direct on-screen digitization with technical staff who know the location of facilities such as plumbers (Note: at least 27-inch external screen or a projector is better for effectively communication between GIS operators and field staff in front of the screen).

4) Use of low-cost handheld GPSs (e.g., Garmin eTrex 10) and paper data collection forms/tables on site. (Note: the horizontal accuracy of a handheld GPS under clear sky is usually ±2→3m but its vertical accuracy error can often be more than ±10m).

5) On-site use of free mobile GIS software installed on smartphones (e.g.,QField which can open QGIS files) [Note: satellite images used as base map in QGIS may need to be compressed into suitable formats (e.g.,geotiff-RGB to geotiff–PCT or Mbtiles) to operate smoothly with smartphones].

6) Use of free cloud-based data collection software installed on smartphones and PCs on site and in the office (e.g., Kobo Collect/Kobo Toolbox), preferably in combination with handheld GPSs to confirm the accuracy of locations (see further explanation in Sec. 4.4.2).

4.4 Mapping of Customer Meters, Problems at Customer Points and Bursts/Leaks

4.4.1 GIS Procedure 2

While on site locating existing customer meters for GIS mapping, a large number of problems related to and around customer meters (e.g., stalled meters, water thefts, leaks, etc.) can be found. This is especially so if CIS is implemented effectively to locate existing and missing customer meters and identifying various problems.

Therefore, this section covers not only how to digitize customer meters but also how to identify and map the problems including those related to and around customer meters [see 4.4.2 for example of CIS and Table 4.1(3) for types of GIS layers and NRW-related problems]. It also covers the CIS issues that should be checked and,mapping of NRW-related problems for analysis and geographical representation.

1) In the beginning, ensure that the areas and pipelines with many problems related to NRW are mapped based on the knowledge of relevant staff through participatory mapping. Examples are areas with many stalled meters, illegal connections and high pressure; pipelines with many and frequent bursts and leaks.

2) Ensure that CIS is conducted to locate all the customers (registered and unregistered water and, kiosks) and collect data on their meters including existing problems. Examples of problems are unreadable and stalled meters, illegal connections, leakage from service connection, etc.

Note 1: CIS can be done using an electronic on a form of data collection software (e.g., Kobo Collect) installed in smartphones and cloud software for mapping and analysing the collected data (e.g., Kobo Toolbox).

Note 2: Handheld GPSs can be used (by entering waypoint number) in combination with smartphone-based data collection software to enhance the accuracy of the captured coordinates.

3) Ensure GIS layers of customer meters and kiosks are developed well. Example of GIS layer include collected attribute data of customers and their meters such as connection number, meter serial number, meter size, type, class, status, reading at during CIS, etc. Development is by importing the location and attribute data of customer and kiosk meters collected during CIS.They should then be represented with symbols for the different types of identified problems such as unregistered, tampered, stalled, unreadable meters; meters inside locked gates, leaking service connection, etc.

4) Ensure the results from meter reading and billing data analysis (e.g., for 12 months) are linked to the customer "account number" layer and presented with categorized symbols. The results include customer categorization by consumption level, frequency and continuity of estimating consumption due to stalled meters, locked gates, meter reading/billing status of customers registered as disconnected, etc.

5) Ensure the various problems at customer points listed in the monthly abnormalities/complaints reports (e.g., for 12 months) from the billing/customer care system are linked to the customer account number layer and represented with categorized symbols. Examples of the problems are unreadable or stalled meters, locked gates, etc.

6) (i) Ensure bursts, leaks, illegal water uses, etc. are recorded with GPS coordinates by all staff (O&M, leaks detection, illegal connections, etc.) using data collection software on smartphones (e.g., Kobo Toolbox/Collect) or handheld GPSs with paper forms, and

   (ii) Ensure the collected data is mapped on GIS including enough attribute data (e.g., pipe material, size, probable leak cause, leakage scale, etc.).

4.4.2 Use of Data Collection Software for CIS

a) CIS can be done with handheld GPSs and printed survey forms. However, data collection software such as Kobo Toolbox/Collect can be used to collect the same data faster and more accurately.

Figure 4.3 is an example of Kobo Toolbox/Collect installed in smartphones of field staff and used for CIS at Nyahururu WSP. From the figure, the data is sent to the server (cloud space/website created with Kobo Toolbox) where it is consolidated and analysed (mapped, tabulated, sorted and graphed) to determine the best NRW reduction actions (e.g., leaks repair) and for export to other databases including GIS.

b) Additional Notes on Use of Handheld GPS and GIS for CIS:

Normally, the accuracy of a smartphone GPS depends on the quality of installed GPS sensor, weather (i.e., access to GPS satellites) and settings (e.g.,internet connection on or off). This accuracy can significantly deteriorate in rural areas. Therefore, at the beginning of CIS, it is recommended to compare the smartphones GPS accuracy and that of handheld GPSs (Figure 4.3). This can be done by entering the way point/location number from the handheld GPS onto the printed form of Kobo Collect so that the two sets of GPS coordinates can be compared later.

The data after consolidation on the (Kobo Toolbox) website can then be exported into a CSV (legacy) file and further imported into the GIS to create a GIS layer of customer meters. This is achieved by adding the CSV file as a delimited text layer into the QGIS and saving the delimited text layer as a shape file for converting the data into an editable GIS layer.

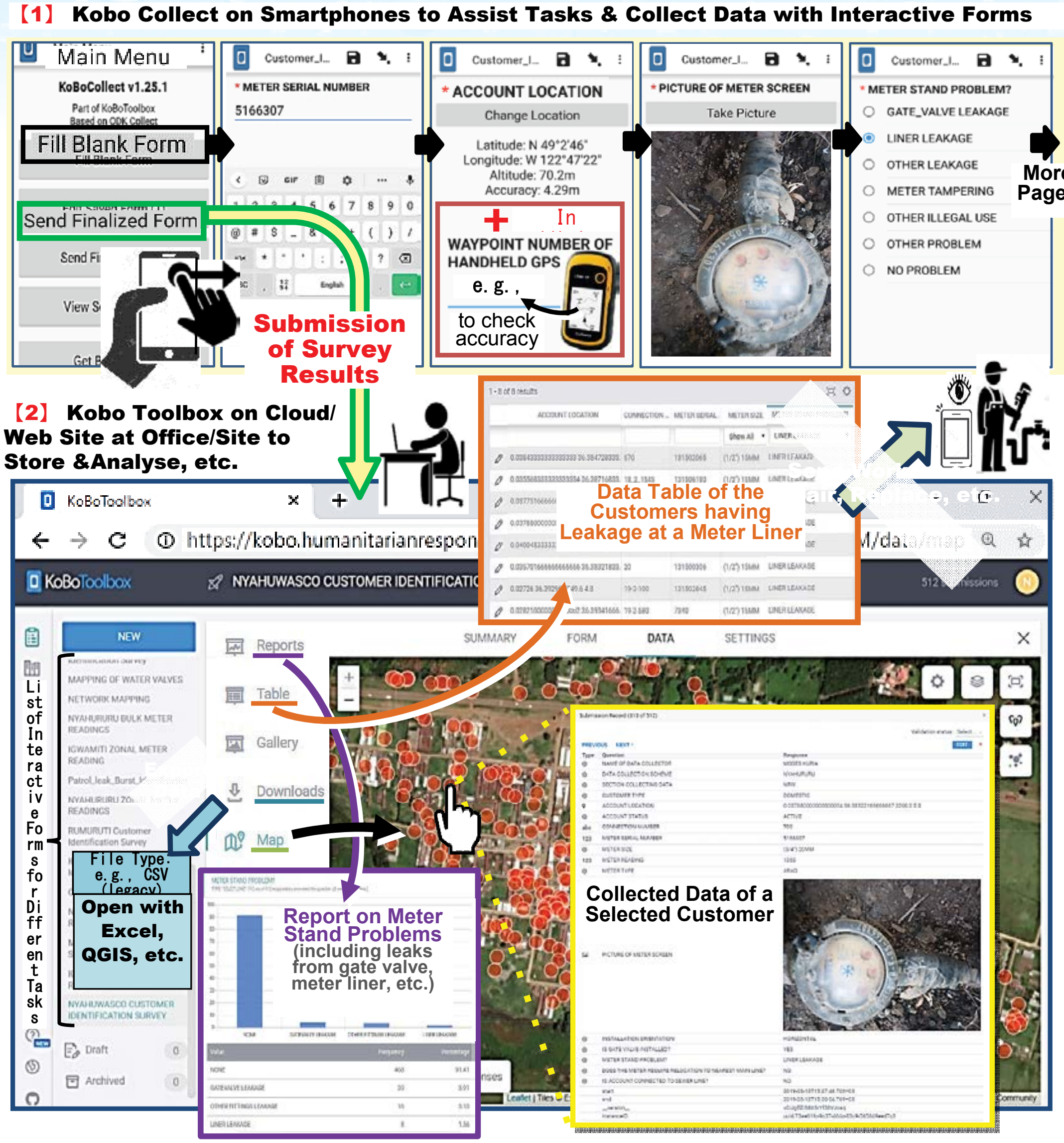


Figure 4.3: Use of Kobo Toolbox/Collect for CIS to Locate Existing & Missing Customer Meters and Collect Relevant Data Including Problems at Nyahururu WSP

c) Additional Notes on Using Kobo Toolbox/Collect for CIS

i) To download a sample CIS form developed at Nyahururu WSP:

1) open https://kf.kobotoolbox.org/accounts/login/?next=/#/

2) enter the username “nrwprojectinkenya” for both the username and its password and login

3) select "Customer_Identification_Survey_ver1"

4) select the tag "FORM" and click the icons of eye and three dots to view the sample form and download its XLS file.

ii) Then, create your WSP's own account on the cloud space/website and import the downloaded sample XLS form into Kobo Toolbox and Kobo Collect as follows:

1) Open the same login page shown above,

2) Create a new account for your WSP and long in,

3) Select the blue bottom "NEW" and upload the downloaded XLS form into the web page of Kobo Toolbox with a project name,

4) Click on the pen icon to edit the sample form to meet your WSP's needs and deploy it,

5) Download and install Kobo Collect into your smartphones and set the server info under its general settings as "https://kc.kobotoolbox.org/" along with the same username and password created for your WSP, and

6) Get the edited form from your web page of Kobo toolbox wirelessly by clicking "Get Blank Form" under the main menu of Kobo Collect. To use your own satellite imagery as the offline base map of Kobo Collect, create the specific holders "Android/odk/layers/offline/" to save the imagery under the internal storage of your smartphone.

4.5 Updating and WiderUseof GIS Data/Maps

4.5.1 GIS Procedure 3

This subsection details the points to be checked during and after development of the GIS layers to sustain and enhance the impacts of using GIS by continuous update and extensive sharing of the GIS data among WSP staff for a wider GIS utilization:

1) Ensure that all the latest GIS data is frequently backed up into a secure data storage of the WSP.

2) Ensure GPS coordinates of customer meters (including service pipes take-off points from distribution pipes and their alignment) are captured on site and mapped with QGIS (e.g., Kobo Toolbox/Collect plus Smartphones or Handheld GPSs plus paper forms and GPS Tools of QGIS plugin) when:

   i) installing new service connections/customer meters, or

   ii) improving/replacing existing service connections/customer meters.

3) Ensure the newly installed and replaced facilities such as distribution pipelines, bulk meters, valves, etc. are continuously mapped on the GIS layers without delays.

4) Ensure that QGIS (free GIS software) is installed on every PC of relevant staff and is used to enhance sharing and use of GIS data (the latest GIS data may be shared through the WSP's internal network).

5) Ensure creation of high-resolution PDF maps (showing existing facilities with or without a raster base map such as a high-resolution satellite imagery) from the GIS data with QGIS's print composer and, viewing of the maps with Acrobat Reader (free PDF reader) installed on each PC and/or Smartphone of relevant staff.

6) Ensure printing of the high-resolution PDF maps on A3 or A4-size papers using Acrobat Reader to create large wall maps (without using an expensive plotter) for easy daily discussions among staff (a low cost A3-size inkjet printer with functions of flat head scanner is recommended as a low-cost alternative to a plotter).

7) Ensure publishing of GIS layers on QGIS Cloud (free online GIS platform) by using QGIS Cloud plugin (free plugin of QGIS) and viewing of the online map from web browsers on PCs and smartphones of staff.

8) Ensure use of QField (free mobile GIS software) installed on each smartphone of relevant staff.

Note:

- The GIS data needs to be copied into the location: -</Android/data/ch.opengis.qfield/files/share/> within the internal storage of smartphone for editing.
- A base map of satellite imagery may need to be compressed into PCT, MBTiles, etc. for quick display.

9) Conversion of GIS layers such as customer meters into kmz files (e.g., with Layer2kmz plugin that is free plugin of QGIS) for viewing with Google Earth (on PCs and smartphones) and/or MAPinr capable of searching and navigating (on smartphones).

Note:

- kmz files of multiple layers can be combined into a single kmz file with Google Earth on PC and saved into a shared holder of Google Drive for quick and easy downloading of the data into multiple smartphones) (see 4.5.2 for further explanation).

4.5.2 *Locating and Visiting Customers Easily*

Many WSPs have difficulties in locating customers on site although most of their customers are registered in the customer database used for meter reading and billing. Locating customers can be especially difficult if meter readers with knowledge of the system are not available or have left a WSP. This leads to failure in customer meter reading, delay in sending staff on site to solve problems, etc.

Therefore, full utilization of GIS' customer meter layer (developed from CIS results) is very important for making the visits to customers easier and faster in the day-to-day tasks without depending on meter readers.

Figure 4.4 shows a technic for locating and visiting a particular customer quickly using a mobile mapping software called MAPinr and Google Map which is capable of route search and real-time route navigation.

Step 0: Create a kmz file having labels showing customer numbers and names from the GIS layer of customer meters (e.g., by using Layer2kmz plugin of QGIS), and then load the kmz file into MAPinr installed on smartphones

Figure 4.4: Locating a customer using MAPinr's search function on smartphone & visiting the customer using Google Map's navigation function

4.5.3 Updating Customer Connections on GIS

When an installation (e.g., of a new service connections) or a repair is done (e.g., of bursts and leaks) are done, the results must be recorded on site and updated in the GIS. When new materials such as pipes, valves, etc. are used in installation or repair works, it is important to record their type, diameter, location, etc. and submit the records to the office for updating GIS layers. Recording can be by handheld GPS or printed data-collection forms and sketches or; by smartphones and electronic interactive forms for easy data collection including taking of pictures.

Regarding service connections, the paper forms for new connection application,new connection installation record, relocation of existing meters, etc. should include connection numbers and GPS coordinates of customer meters among other data for updating the GIS layer of customer meters.

Recording GPS coordinates at the take-off locations of service pipes from the distribution pipes as well as sketching the service pipes routes from take-off points to customer meters on paper forms is also recommended for the purpose of NRW reduction. The coordinates and/or routes recorded on the paper forms can be used later to create additional GIS layers of take-off points and service pipes when the GIS development reaches an advance stage.

4.6 Integration of Free Desktop GIS, Mobile GIS, Data Collection and Billing Software

4.6.1 Integration of Desktop GIS & Field GIS

Integrated use of different software programs (e.g., meter reading software, billing software and GIS software) is essential for a successful implementation of NRW reduction activities which requires involvement ofboth office and field staff of several departments/sections. Free mobile GIS software and cloud-based data collection software have been evolving fast since the proliferation of smartphones all over the world. For example:

a) QGIS is the most popular free desktop GIS software. It has integrable free mobile GIS solutions called QField and Input; which can be installed into a smartphone:

   i) The GIS data updated on QField can then be easily synchronized into QGIS on PC using QGIS plugin called QField Sync although a data package file has to be copied from the smartphone into PC manually before synchronization. Currently, QField is being upgraded to adopt a cloud-based synchronization technology (i.e.,QField Cloud).

   ii) Input is a powerful free GIS-based data collection software, which can be installed in a smartphone and used on site. Input uses a QGIS plugin called Mergin to easily synchronize/transfer the field data into QGIS on a PC through a cloud space.

b) MAPinr may be used to view and search customer locations. Google Map can then be easily launched from MAPinr to have real-time route navigation to the target customer.

c) Web-based GIS publishing software (e.g., QGIS's plugins such as QGIS Cloud, qgis2web or GIS Cloud) is another solution for various staff to utilize GIS data efficiently for NRW reduction and other purposes.

4.6.2 Combined use of Software for Active Leak Reduction

A smooth coordination between NRW staff investigating leaks and O&M staff repairing leaks is the most important characteristic of a sustainable implementation of proactive leak detection.

Some commercial software developed for water utilities (e.g., ERP)are capable of collecting data (e.g., registering problems based on reports from staff and customers), assigning tasks to field staff and registering feedback reports, all remotely. This kind of advanced software can be used to improve the coordination between NRW staff and O&M staff foractive leak reduction. However,if a WSP does not have this kind of commercial software, creative combinational use of free software programs may be a solution to enhance the coordination.

For NRW staff, Kobo Toolbox/Collection can be quite helpful in investigating leaks, meter-related problems and illegal connections. However, it is often too complicated for O&M staff to use for reporting repairs remotely.

It is therefore recommended that O&M supervisors should use simple and common communication software such as WhatsApp to assign tasks to each plumber and receive feedback reports once the tasks are attended to. Example of the tasks are repair of leaks investigated and registered in Kobo Toolbox cloud server by NRW staff using Kobo Collect installed on their smartphones.

When assigning tasks using WhatsApp, the coordinates (e.g., -0.5354971, 37.4502462) of each issue recorded by the NRW staff with Kobo Collect can be used as the ID of each task and sent to a plumber with a pre-fix for creating a weblink to show its location on Google Map and a brief instruction on the issue (e.g. https://www.google.com/search?q=-0.5354971+37.4502462 Nicolas, please repair this leak this morning. Very Urgent!).

This way, plumbers can view the reported issue together with its coordinates by accessing the Kobo Toolbox cloud server while locating it on site using Google Map. This creative combined use of free software programs can contribute greatly in NRW reduction.

4.6.3 Smooth Data Transfer from Non-Spatial Database to GIS

Customer-related information from commercial meter reading and billing software (e.g.,Majics, ERP, etc.) or field data from free data collection software (e.g., Kobo Toolbox) can be transferred to free GIS software (e.g., QGIS) or web maps (e.g., by using a plugin of QGIS such as QGIS Cloud, GIS Cloud, qgis2web, Lizmap, etc.) in order to map issues related to customers or facilities if their coordinates are available. As already realized in Nanyuki and Nakuru WSPs, dynamic integration between meter reading & billing software and GIS can also be done by using free database management software (e.g., PostgreSQL and PostGIS). However, periodic update of customer and facility data to desktop GIS (e.g., by exporting the data into a CSV file and adding it as a delaminated text layer of QGIS) and upload of the layer onto a web map or potable GIS on smartphones may be enough for efficient NRW reduction.

More importantly, customer locations should be searchable with customer number or meter serial number(customer names can be excluded from GIS to protect customers' private information) to enable staff working on NRW reduction find customers having problems without the help of meter readers. The search can be achieved by using different types of free software such as MAPinr and QField on a smartphone and qgis2web (a plugin of QGIS for creating web maps) and Google Earth on a PC.

The anomalies found through monthly meter reading (e.g., stopped meters, buried meters, visible leaks from service connections, etc.) can also be mapped periodically on desktop GIS, mobile GIS and web GIS to effectively analyse the current situation and address the anomalies every month. However, WSPs may face difficulties in transferring the anomaly data to GIS because GIS software normally accepts upto only 10 characters for each data field name. For smooth data transfer to GIS(including the addition of recent data to existing GIS layers), data-field names used in data collection software, billing software, etc. should be no longer than 10 characters and should match those in the attribute tables of GIS.

Moreover, using the same drop-downlist of selections for existing facilities and problems (e.g., tampered meter, buried meter, stalled meter… as meter reading anomalies) in the different software (e.g., billing software and GIS) makes the data transfer to GIS and the combinational use of multiple softwareprograms easier.

For example, if leaking gate valves of different sizes are to be mapped in different colours, a drop-down list of valve sizes (e.g., 15mm, 20mm, 25mm…) can be used for easy data entry on QGIS (i.e., by setting Value Map as Widget Type) while using exactly the same list of selections on data collection software such as Kobo Collect (i.e., not ½ inch, ¾ inch, 1 inch…. but 15mm, 20mm, 25mm….) in order to update the GIS layer of leaking gate valves easily without having inconsistencies in data categorization. By using the same set of selections, muddling up the categorized symbology of GIS layers (e.g., symbol of valves in different coloursbased on size) can be avoided without editing data each time newly recorded data is imported into the GIS.

Chapter 5

Monthly NRW Monitoring and Zoning

5.1 Relationship Between Monthly NRW Monitoring and Zoning

When conducting trial NRW reduction activities within a limited area, it is normal to calculate NRW ratio of the area twice (before and after the activities) to determine by how much NRW has been reduced through the activities. Unfortunately, NRW ratio in Kenya often fluctuates seasonally, and the NRW ratio of a target area may rise again soon after NRW reduction activities end in the area. Therefore, measuring NRW ratio only twice is not enough to understand the effects of the implemented NRW activities and their sustainability over time. This is one of reasons monitoring of NRW-related performance indicators (Section 5.2) on monthly basis from the beginning of NRW reduction efforts is quite important. The monthly monitoring should be based on the monthly cycles of reading bulk meters and customer meters, billing and reporting of NRW-related activities. The results of the monthly NRW monitoring can also be used for the quarterly and annual NRW reduction monitoring.

Once a WSP has succeeded in establishing a reliable monthly monitoring of main performance indicators of the entire service area (e.g., total amount of supplied water/ production, total billed consumption, universal NRW ratio, etc.), the WSP can also try to monitor similar NRW-related performance indicators for each hydraulically isolated area. However, if the distribution system is not properly separated into DZs, the zone-by-zone monitoring of the entire service area for more effective and efficient NRW reduction will never happen. This is one of the reasons zoning of the distribution system (Section 5.3) is very important for effective and efficient expansion of NRW reduction activities over the entire service area. WSPs may further sub-divide large DZs with NRW high level into DMAs to enable planning, implementation and review of NRW reduction activities area-by-area in detail.

Moreover, when dealing with reoccurring bursts on transmission and distribution pipelines and/or service connections due to deteriorated old pipes, high pressure, etc., monthly monitoring may be inadequate to identify and fix potentially large water losses from bursts in a timely manner. In such cases, setting up weekly, daily or even real-time abnormal flow monitoring using bulk meters on transmission and distribution pipelines, including those used for monthly monitoring may be necessary. As soon as abnormal flow at one of the monitored bulk meters is detected, a team is sent to fix the burst, large leak or illegal water use causing the abnormal flow.

In large WSPs in developed counties, filling a detailed water balance table(Section 5.4) once a year (e.g., Water Audit) may be a focal point of their NRW monitoring. However, it is quite difficult for most WSPs in Kenya to create a reliable water balance table consisting of various water loss components for their entire service area. Filling a detailed water balance table is especially difficult in WSPs where commercial losses (e.g., underestimated billed consumption due to faulty customer meters and water thefts) have not been actively reduced substantially and where minimum night flow cannot be measured to verify the balance table (say, due to intermittent water supply condition). Therefore, filling a water balance table (to be explained at the end of this chapter) is given less priority in this chapter compared to monthly monitoring of NRW-related performance indicators, zoning, and abnormal flow monitoring.

5.2 Monthly NRW Monitoring

5.2.1 Selection of Suitable Performance Indicators

There are many performance indicators (PIs) related to NRW reduction activities. If too much data for calculating an excessive amount of NRW-related performance indicators is repeatedly collected without realising enough benefits from monitoring of those indicators, the NRW reduction activities will be negatively affected. Excessive collection of data for PIs wastes the limited manpower available for NRW reduction activities and causes distrust among those providing the data when they realise the limited benefits of collecting the data. Therefore, it is very important for each WSP to carefully consider which data to collect and how often to realisethe expected benefit.

Of course, all WSPs in Kenya are required to submit PIs data to WASREB through WARIS. The comparative results of these PIs are published every year as the Impact Report for benchmarking among WSPs. Further, many WSPs are also involved in WASPA's comprehensive benchmarking fora for mutual learning.

Besides these benchmarking fora, each WSP should carefully monitor its own progress in NRW reduction over months and years based on its own select PIs based on its specific needs.

Table 5.1 shows examples of essential and basic PIs recommended for NRW reduction although the selected PIs depends on the conditions of each WSP.

The seven essential PIs (three raw data ([1] to [3]) to be collected, and four values ({4} to {7}) to be calculated from the raw data) are explained in details in Section 5.2.2.

The 12 basic PIs (eight raw data to be collected, and four to be calculated ([9], [12], [16] and [18]) are directly related to different types of NRW reduction activities.

The table also shows the break-down of data to be collected for some of the raw data (e.g., for [10] - Number of Bursts and Leaks Repaired, 3 break-downs for transmission pipes, distribution pipes, and service connections including tapping points). The raw data that requires broken-down data for analysis may be collected using a data collection software (e.g., Kobo Collect) installed on smartphones of field staff. One example of utilizing these basic PIs to analyse the effects of NRW reduction activities is explained in Section 5.2.4.

When calculating PIs related to estimated billed consumption due to faulty meters, etc (i.e. [14], [17] and [19]), the active connections should be categorized based on their billed consumption level (preferably in reference to their block tariff ranges such as 0-6m3/month). This is in order to obtain helpful broken-down data for analysis of the PIs. Further, more focus should be on larger customers to reduce NRW significantly within a limited time.

An example of customer categorization and analysis to evaluate the effects of replacing faculty meters at different groups of customers are explained in Section 5.2.5.

Table 5.1: Example of Essential and Basic Performance Indicators to Monitor NRW Reduction

Category	Data No. or Formula No.	PIs for the Entire (Universal) Service Area and Each Area (e.g., DZ or DMA)	Unit	Note
Essential PIs	[1]	Total Water Produced for Distribution (or Supplied as Inflow)	m^3/month and year	Related to Physical Losses
	[2]	Total Billed Consumption	m^3/month and year	Related to Commercial Losses
	[3]	Total Billing of Water Supply Services	Ksh/month and year	
	{4}=[3]/[2]	Average Tariff	Ksh/m^3 -monthly and yearly	
	{5}=[1]-[2]	Total NRW	m^3/month and year	Showing Overall Effects
	{6}=([1]-[2])x 100/[1]	NRW Ratio	% -monthly and yearly	
	{7}={1}x{2}	Potential Revenue Loss due to NRW (excluding Sewerage)	Ksh/month and year	
Basic PIs	[8]	Total Length of Transmission and Distribution Pipes*(make break-down of Transmission and Distribution pipes) ← **Thiscan becalculated on GIS.** Monthly pipeline replacements and extensions should be documented separately to avoid confusion*	km	Related to Physical Losses
	{9}=([1]-[2])x 100/[8]	NRW per km	m^3/km/month and year	
	[10]	Number of Bursts and Leaks Repaired *(e.g., Breakdown-1: Transmission, Distribution, and Service Connections including Tapping Points. Breakdown-2: Bursts, Visible Leaks and Underground Leaks)* → **To be mapped on GIS**	number/month and year	
	[11]	Total Number of Water Connections	number	Related to Commercial Losses
	{12}=([1]-[2])x 100/[11]	NRW per Connection	m^3/connection/ month and year	
	[13]	Number of Water Theft incidences identified*(e.g., Breakdown of Meter Reversed, Meter Tampering, Above-ground Illegal Connection including Meter Removal, Underground Illegal Connection including Meter Bypass, etc.)*→ **To be mapped on GIS**	number/month and year	
	[14]	Total Number of **Active** Water Connections*(e.g., Break-down based on billed consumption level categorized by WSP's block tariff ranges)*	Number	
	[15]	Total Number of **Active Metered** Water Connections	Number	
	{16}=[15]x100/ [14]	Metering Ratio	%	
	[17]	Total Number of Estimated Billed Consumption (e.g., Broken down as in [14])	Number	
	{18}=[17]x100/ [14]	Ratio of Estimated Billed Consumption (e.g., Broken down as in [14])	%	
	[19]	Number of Customer Meters improved*(e.g., Breakdown 1: As same as in [14] // Broken down 2: Serviced, Replaced, Relocated, etc.)*	number/month and year	

Once the calculation of PIs become a routine and reliable for entire service area, then the same or similar sets of PIs may also be applied for each DZ and/or DMA for more detailed analyses. Two additional PIs for the amount of NRW (i.e. {9} NRW per km and {12} NRW per connection) can be helpful to use in addition to {5} Total NRW and {6} NRW Ratio especially for comparing different DZs and/or DMAs with different concentration levels of customers and/or distribution pipes.

5.2.2 Seasonal Fluctuations and Overall Effects of NRW Reduction Activities

Monthly meetings between departments are quite important to discuss the strategies and progress of NRW reduction activities based on the results. However, the effects of NRW reduction activities can be difficult to understand especially when only a limited data that indicate variation in NRW ratio over the last few months is presented in the meetings. This is because NRW ratio often fluctuates a lot seasonally especially under intermittent water supply conditions. Therefore, in order to isolate the effects of NRW reduction activities from seasonal fluctuations, WSPs should analyse the monthly values of the seven essential PIs (Table 5.1) over at least the previous 3 years on a single graph and thereafter update the graph every month. Figure 5.1 indicates the monthly changes of the 7 essential PIs over the previous 3 years in Nyahururu WSP. The figure helps to understand the difference between seasonal fluctuation of NRW ratio and the effects of NRW reduction activities.

In this example, the NRW ratio (Red line ▲) decreased by about 10% within two years (July 2017 to July 2019) while fluctuating seasonally every few months. Regarding the seasonal fluctuations, it was revealed that there are shallow wells used by small customers (as alternative water sources) which dry up in the dry season, resulting in a corresponding increase in both total Supplied Water (Orange line ●) and total Billed Consumption (Purple line ●). Therefore, while the amount of NRW (Red line ●) (=Supplied Water - Billed Consumption) did not change much, the NRW Ratio (the amount of NRW / Supplied Water x 100) decreased for a few months in each dry season. The decrease in Average Tariff for water supply (Blue line ◆) (=Billing for Water (Green line ■) / Billed Consumption(Purple line ●)) in each dry season can be considered as resulting from the increase in piped-water consumption among small customers whose average water charge per m3 is relatively low due to the low charge block in the tariff. In WSPs, shortage of water sources and intermittent water supply conditions often significantly affect the total amount of supplied water while fluctuations in water demand significantly affect the total billed consumption. Therefore, these values fluctuate repeatedly due to the seasonal changes in temperature and rainfall. This phenomenon, that NRW ratio (Red line ▲) often goes up and down every few months was found to be common, as illustrated in this example.

The changes in the monthly amount of Supplied Water (Orange line ●) shown in Figure 5.1 is a useful indicator to understand the progress of physical water loss reduction. The total Billed Consumption (Purple line ●) and the total Revenue Billed (Green line

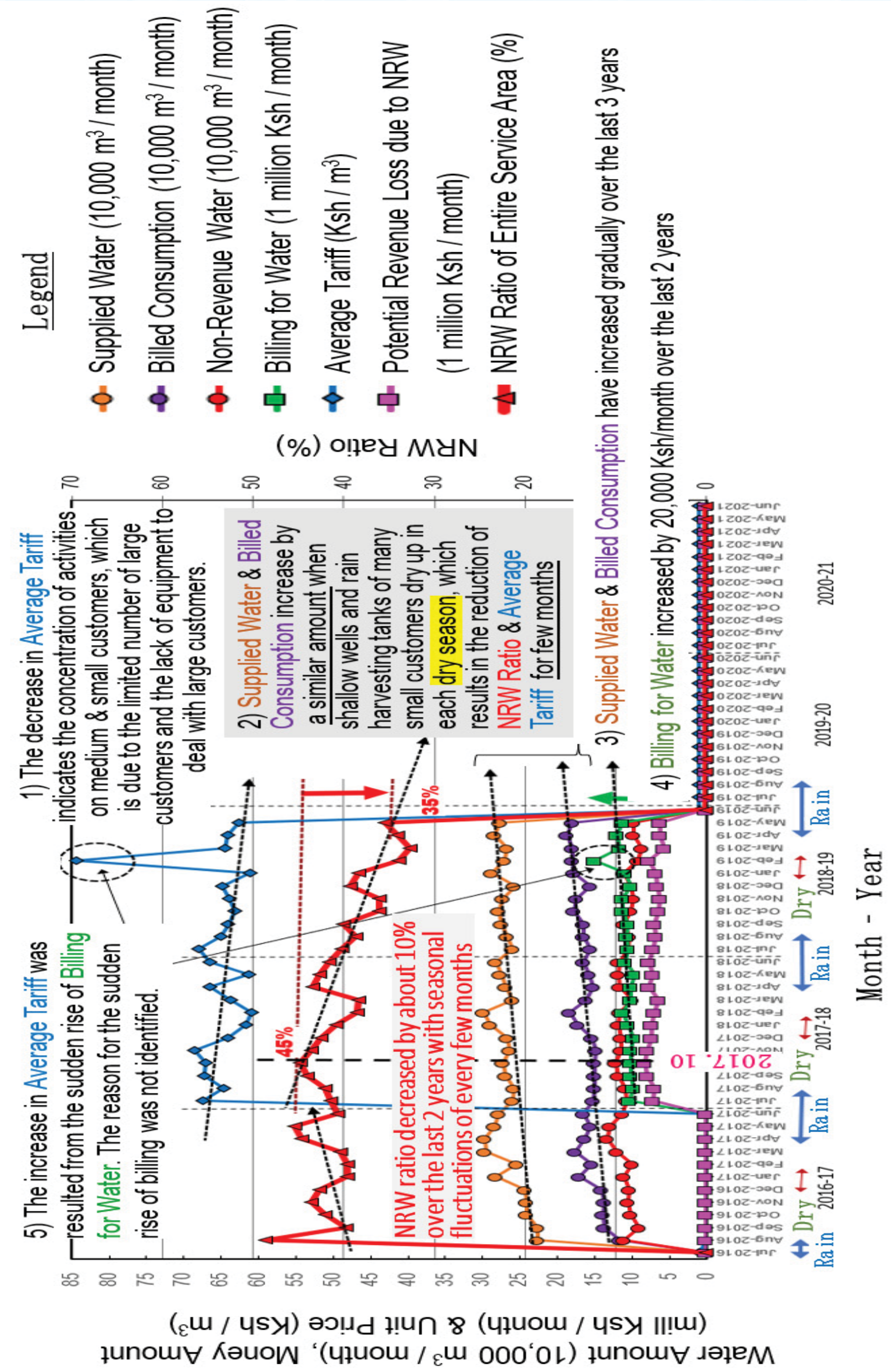


Figure 5.1: Seasonal Fluctuation of NRW Ratio & Effect of NRW Activities in Nyahururu WSP

■) are effective indicators for understanding the progress in reducing commercial losses resulting from low meter accuracy,meter reading and billing errors and water thefts. Moreover, the Average Tariff (total billing / total amount of billing consumption) (Blue line◆), which usually increases when billing of large customers improve, can be an indicator of how well large customers are targeted in the commercial loss reduction. The universal supplied amount (Red line ●), the ratio of NRW for the entire service area (Red line ▲) and the potential revenue loss due to NRW (Pink line ■) are useful indicators for evaluating the overall effects of NRW reduction activities quantitively. This analysis using a line graph is much easier and often more effective than filling annually a complicated water balance table for the entire service area.

5.2.3 Ensuring Credible Universal NRW Ratio at the Beginning

In Kenya, many WSPs use estimated monthly flow instead of measured monthly flow, due to inaccurate bulk meter readings (from faulty bulk meters) used for calculating the universal NRW ratio. In such cases, the universal NRW ratio most likely fluctuates a lot with seasons; much more than the usual seasonal fluctuations.

For example, during the dry season, the amount of supplied water usually increases as water demand increases. If during this season a WSP uses the average monthly flow of the previous year or the previous few months as the estimated flow of a bulk meter which has just become faulty, the NRW ratio during the dry season will probably,erroneously, drop drastically (Note: this is because the supplied flow of previous year or previous few months is likely to be smaller than the actual flow which the faulty meter has failed to measure). This drop in NRW ratio will not be due to NRW reduction activities but the underestimated inflow at the faulty bulk meter thereby causing a higher rate of underestimation to the total amount of NRW than to the total supplied volume (Note: NRW ratio = NRW amount / supplied volume x 100). Therefore, the abnormal fluctuations of NRW ratio caused by faulty bulk meters should be checked through analysis of the main performance indicators over the last few years. If a WSP ignores the problems of existing bulk meters that often make the universal NRW ratio deceptively low (with the purpose of conveniently reporting false figures to WASREB or BoDor out of negligence), then the WSP will remain in the dark and NRW will probably never,in reality, be effectively reduced. Therefore, any problems with production bulk meters or those used to calculate the total amount of supplied water should be resolved as soon as possible and as a matter of priority.

5.2.4 Additional Analysis to Evaluate Effects of NRW Reduction Activities

Figure 5.2 shows an example of monthly changes and the relationship between several additional monthly indicators. It shows the amount or results of certain NRW reduction activities in Kisumu WSP (i.e., 4 basic PIs – [10], [15], {16} and {18} – in addition to 3 essential PIs – [1], [2] and {6} – from Table 5.1). This graph was used to identify the factors that were significantly affecting the successful reduction of NRW.

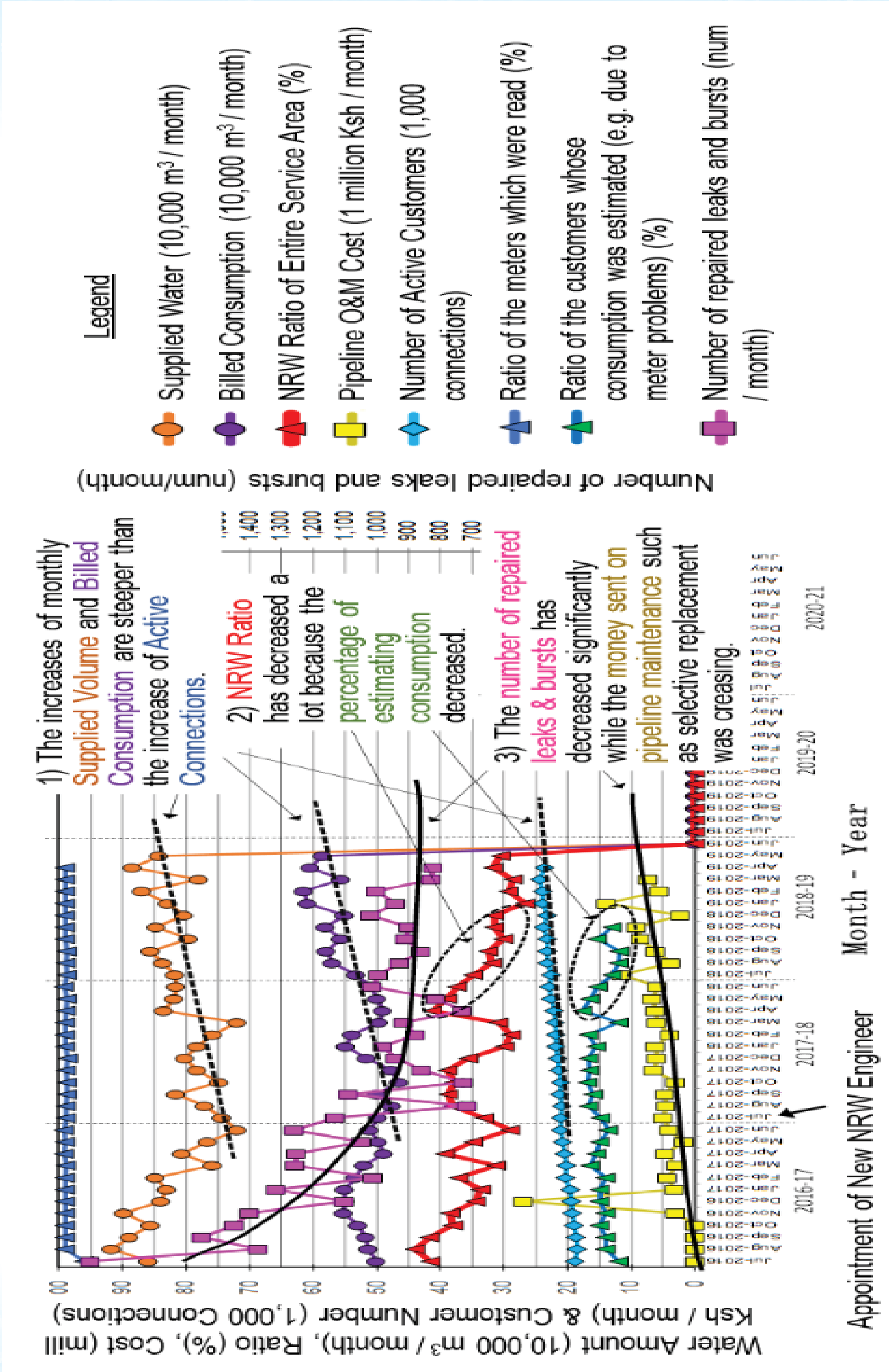


Figure 5.2: Analysis of NRW Reduction Factor based on the Changes of Additional Monthly Indicators in Kisumu WSP

The findings from this graph are that replacement of faulty customer meters to reduce estimated billed consumption (Greenline ▲) was quite effective in reducing their NRW ratio (Redline ▲) and; that the budget increase for pipeline maintenance such as selective replacement of aged pipes (Yellowline ■) could successfully reduce the number of leaks and bursts found and repaired per month (Pinkline ■).

5.2.5 Categorization of Customers and Reduction of Estimated Billed Consumption

Table 5.2 is a comparison of two months data (before reading and billing improvement and, after meter reading and billing improvement such as replacement of faulty meters). The table was drawn to evaluate the reduced use of estimated consumption for billing and its effects on the total billed revenue amount (see {18} and [3] of Table 5.1) in Nakuru WSP. In this analysis, the customers were categorized by their monthly billed consumption level based on their tariff block ranges. This example shows that active reduction of using estimated billed consumption (especially for large customers) successfully resulted in large increases of the total billed consumption and total billed revenue.

5.2.6 Performance Indicators for Monthly Monitoring

1) Prioritize data to be periodically collected (monthly, quarterly and annually) for calculating useful performance indicators (PIs).

2) Prioritize data such as NRW %; number of meters tested, replaced and/or relocated, etc (to enable targets setting in planning, progress monitoring and encouraging internal competition between zones, etc.). Prioritization should be carefully done taking into account the practical aspects of data collection. Note: the calculated indicator values can also be used for WASPA's benchmarking activities, WASREB's Impact Report and WARIS.

3) Ensure that a systematic and easy way to periodically collect and analyse the prioritized data from the different departments/sections/units and/or branch offices is fully operational to enable PIs calculation.

4) Ensure the NRW Unit (i) prepares its monthly report showing the progress in a quantitative manner using selected PIs and (ii) submits the report to its supervisor/manager.

5) Ensure that the NRW Unit and other relevant staff including managers have (i) monthly coordination meetings for NRW reduction and (ii) concrete monthly discussions for improvements based on the PI values included in their monthly reports.

6) Ensure that the progress in implementation of the planned NRW activities is continuously monitored.

Table 5.2: Analysis of the Reduced Frequency of Estimated Billed Consumption for Each Customer Category based on the Billed Consumption Amount and Water Tariff Block in Nakuru WSP

Customer Category by Average Billed Consumption	Year - Month	Number of Connection: [1] Num	Number of Connection: Distribution %	Billed Consumption: [2] Total Volume (m³/month)	Billed Consumption: Total Distribution %	Billed Consumption: [3] (=[2]/[1]) Average (m³/month/customer)	Customers whose Consumption is Estimated: [4] Num	Customers whose Consumption is Estimated: Distribution %	Customers whose Consumption is Estimated: [5] (=[4]/[1]) Frequency %	Increase from no consumption (0↑X)	Increase from other than no consumption (+X)	Change to no consumption (X↓0)	Decrease to other than no consumption (-X)
C1: > 300 m3/month	2017 - October	130	0.3%	115,732	18.1%	890.2	17	0.2%	13.1%	15	1	0	1
C2: 101-300 m3/month		465	1.2%	74,839	11.7%	160.9	64	0.8%	13.8%	36	18	0	10
C3: 51-100 m3/month		1,077	2.7%	73,597	11.5%	68.3	155	1.9%	14.4%	110	27	0	18
C4: 21-50 m3/month		4,664	11.6%	144,864	22.6%	31.1	891	10.9%	19.1%				
C5: 7-20 m3/month		15,330	38.0%	181,004	28.3%	11.8	4,800	58.6%	31.3%	4327			
C6: 0-6 m3/month		18,630	46.2%	49,882	7.8%	2.7	2,267	27.7%	12.2%	1989			
Total		40,296	100.0%	639,919	100.0%	15.9	8,194	100.0%	20.3%	7,464	437	9	284
C1: > 300 m3/month	2019 - May	114	0.3%	130,787	18.9%	1,147.3	4	0.1%	3.5%	2	0	0	2
C2: 101-300 m3/month		601	1.4%	94,577	13.7%	157.4	43	0.6%	7.2%	23	11	0	9
C3: 51-100 m3/month		1,375	3.3%	93,946	13.6%	68.3	127	[illegible]	9.2%	95	14	0	18
C4: 21-50 m3/month		5,769	13.7%	177,675	25.7%	30.8	[illegible]	11.1%	14.0%	726	44	0	35
C5: 7-20 m3/month		16,971	40.4%	199,200	28.8%	11.7	3,959	54.7%	23.3%	3702	192	0	65
C6: 0-6 m3/month		19,437	46.2%	50,480	7.3%	2.6	2,058	28.4%	10.6%	1767	163	14	114
Total		44,267	100.0%	746,666	[illegible]	16.9	6,996	100.0%	15.8%	6,315	424	14	243

Effective focus on large & medium customers (reduction of about 10% to 5%)

Increase of customers by around 4,000 (10%)

Large increase of billed consumption by more than 100,000 m³/month (17%)

Reduction of the number of customers whose consumption is estimated by around 1,200

Reduction of the estimated consumption for billing by 4.5% on average

Mainly by replacing the faulty meters which are completely stalled.

5.2.7 *Monthly Monitoring of Main Performance Indicators*

1) Ensure bulk meters required to accurately calculate the total production of the entire service area (SA) (including imported water and excluding exported water over the boundary of the SA) are:

i) installed, and

   ii) Properly installed (including improvement of meter chambers, installation of strainers before bulk meters, etc if required).

   Note: Bulk meters should be installed in such a way that air does not enter the bulk meter during interruptions of water supply or water shortage. This is to prevent over-estimation by mechanical bulk meters (happened in Embu WSP- resolved by relocating the meter to a lower location) or under-estimation by ultrasonic or electromagnetic flow meters).

   Bulk meters where air intrusion is difficult to avoid may need to be relocated to a low-lying location where the pipe is always full of water even during water supply interruptions. If such a low-lying point is not available, a small section of the pipe on which the bulk meter is installed should be lowered so that the section remains full during water supply interruptions.

2) Ensure bulk meters required for measuring all the production are read on monthly basis without failure to accurately calculate monthly total production. It is recommended that the meters be read daily to enable daily flow monitoring and data flexibility during calculations of the monthly PIs.

3) Ensure the accuracy of each production bulk meter is monitored based on its monthly flow fluctuation; and tested periodically (e.g., semi-annually/quarterly) with portable clamp-on UFM for timely meter servicing and/or calibration; or replacement. Note: calibration is adjustment of measured volume by adding or reducing a certain percentage of the volume if found to be necessary.

4) Ensure monthly calculation of the total billed consumption volume for the entire SA is continuous and accurate. This should preferably be done by a computerized meter reading / billing system. Care should be taken not to misuse the upper consumption limit of the lowest tariff block. For example, if the lowest tariff block is fixed say at Kshs 200 for all consumptions from 0 to 6m3/month, some WSPs bill 6m3/month even when the consumption is 0 to 5m3/month. This implies that the consumption is 6m3/month thereby erroneously reducing the NRW volume.

5) Ensure monthly calculation of NRW volume and ratio and other prioritized PIs related to NRW volume, if any, for the entire SA is continuous and accurate based on synchronized bulk meter and customer meter readings.

6) Ensure that the:

i) fluctuations of monthly total production, total billed consumption, NRW volume and ratio for the entire SA for the last few years are tabulated and represented on a graph. They should be plotted on the same graph by factoring the volume in million m3/month (for example) and placing the volumes (mill m3/month) on the right Y-axis and the ratio (%) on the left Y-axis for easy analysis of the relationships, and

ii) the graph(s) are updated monthly and the causes of fluctuations and effects of NRW reduction activities analysed.

7) Ensure that increase in monthly total billing (Ksh/month) and monthly average tariff (KSh/m3) (i.e., monthly total billed revenue/monthly total billed consumption) are monitored to confirm that revenue is increasing because of tackling large customers first (i.e., the average tariff is expected to increase if more large customers are properly billed due to the high incremental block of the tariff structure.

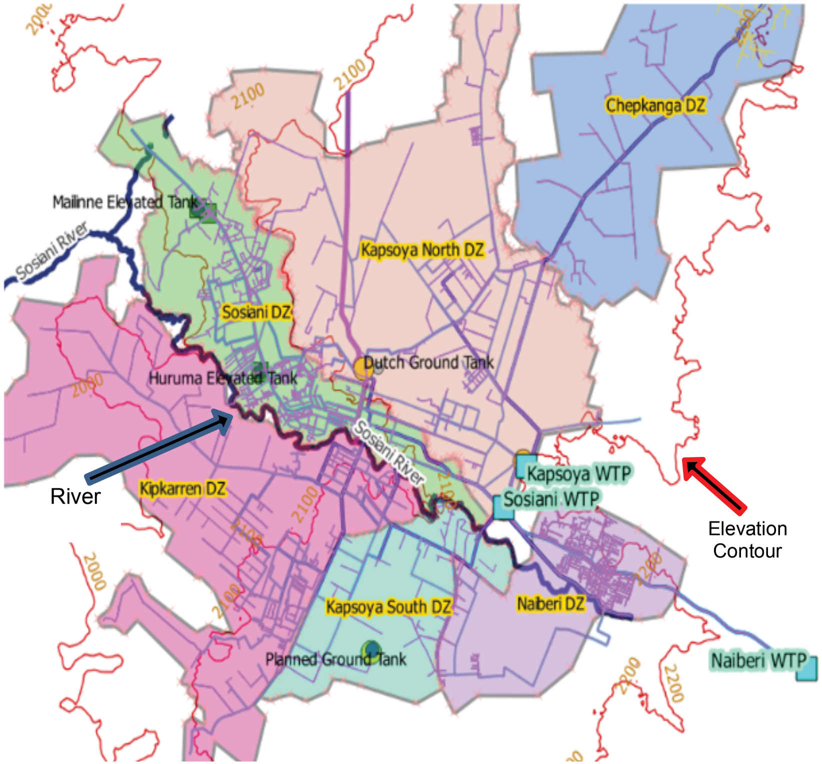
8) Ensure the tables and graphs are updated every month and used effectively in the monthly and other meetings held among relevant staff including manager(s) to improve NRW reduction activities.

5.3 Zoning of Distribution Networks

5.3.1 Zoning and NRW Monitoring at DZ Level

Figure 5.3 is an example of a plan for separating the existing distribution system into hydraulically isolated DZs in Eldoret WSP mainly to enable effective monitoring of monthly zonal NRW in addition to the universal one (refer Figure 5.1).

Figure 5.4 shows NRW monitoring at DZ level at Nyahururu WSP. In this example, two of the existing five DZs were selected as priority zones for NRW reduction as both had a relatively large share of the supplied water and one of the two had especially high NRW ratio although it had been falling over the previous three years.



Distribution Zone	Required Water in 2027 (m3/day)	Water Sources until 2027 (m3/day)	Water Sources beyond 2027 (m3/day)
Chepkanga DZ	8,016	Chebara WTP 22,000 + Kapsoya WTP 7,000 = 29,000	Chebara WTP + Kapsoya
Kapsoya North DZ	18,135		
Kapsoya South DZ	3,036		Kipkarren Dam WTP (use the elevated tank for Kapsaya South)
Kipkarren DZ	8,919	Kipkarren Dam WTP 24,000 (around 13,000 required)	
Sosiani DZ	15,659	Sosiani WTP 12,000	
Naiberi DZ	1,332	Naiberi WTP 2,000	
Zone 50	845	Kipkarren Dam WTP (2,000 allocated)	

Note: These distribution zones (DZs) were planned in 2019 based on the locations of existing WTPs & tanks, the terrain (elevatior contours) of service areas, the balance between future water demand (including NRW & increase) & production capacity, etc. The required water supply calculated for 2027 includes reduced NRW ratio (40%→30%) and the annual demand increase of 6% over 8 years (from 2019 to 2027).

Figure. 5.3: Planned Zoning of the Distribution Networks into 7 DZs in Eldoret WSP

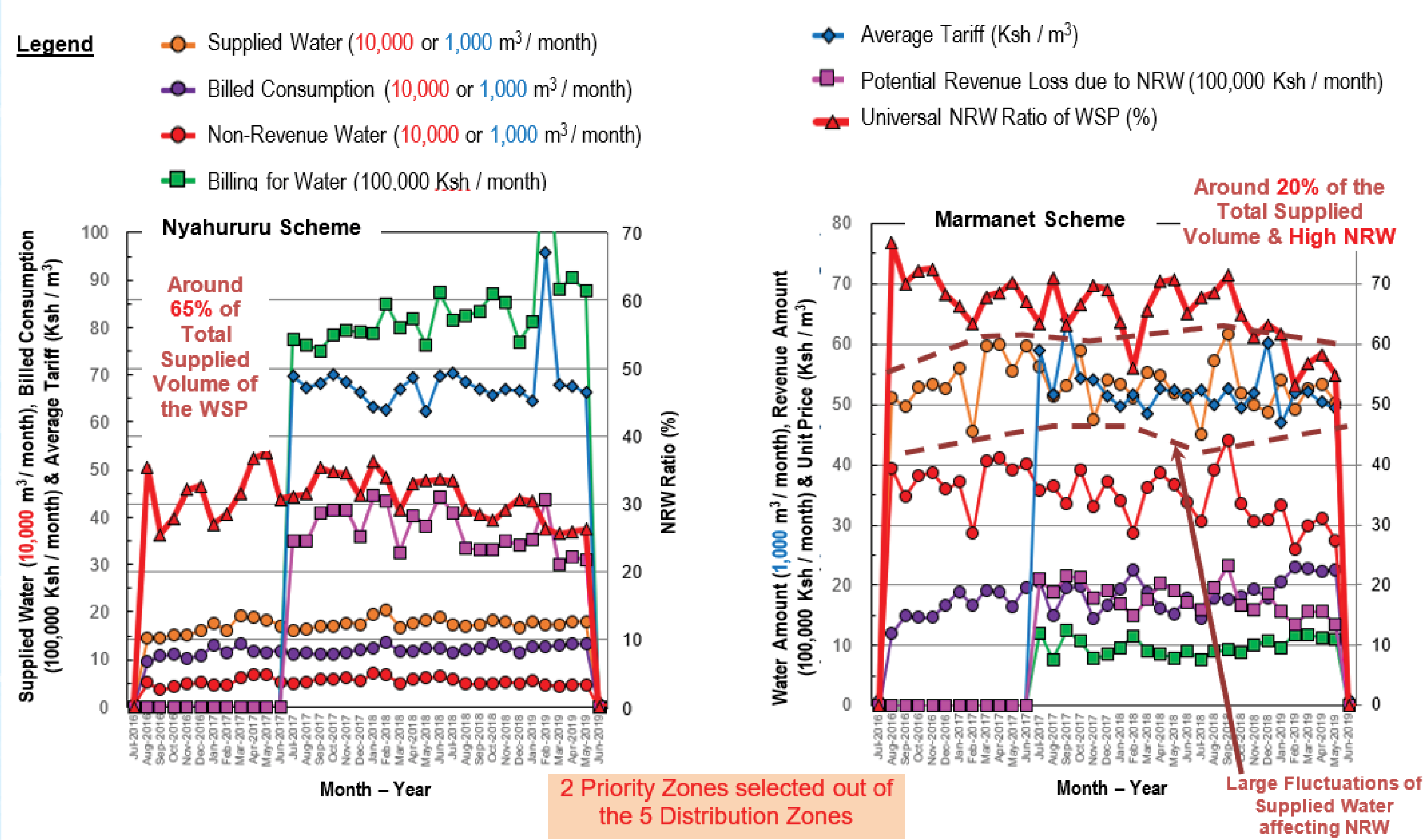


Figure. 5.4: Comparison of Zonal Monthly NRW and Selection of Priority Zones in Nyahururu WSP

5.3.2 Subdivision of Zones into DMAs in Developed Countries

Zoning of distribution networks in each WSP should be carried out primarily for controlling flow and pressure within the networks. In developed countries, distribution systems are usually well separated as hydraulically isolated DZs by default. In those countries, water is usually distributed to each DZ at a suitable pressure from a certain distribution reservoir/tank or a certain set of distribution pumps without water crossing over the boundaries of DZs unless it is required for emergency. The number of inlets for each DZ is usually limited to only one or a few, and zonal bulk meters are installed at the inlets by default. DZs can be separated into pressure zones by installing pressure reducing valves (PRVs) and/or brake pressure tanks (BPTs), which can be counted as DMAs if bulk meters (DMA meters) are installed on the inlet pipes at those pressure reduction facilities (see Chapter 10 Pressure Reduction/Management including Zoning by Reservoirs). As illustrated in Figure 5.5, large DZs can be further subdivided into DMAs without pressure reducing facilities for more detailed monthly monitoring of NRW and regular measurement of minimum night flow that indicates the amount of leakage if water supply is continuous. Once the established DMAs become operational, the DMAs can be used for monthly monitoring of NRW at DMA level, besides the monthly NRW monitoring at the universal and DZ levels, in order to manage both physical and commercial losses in each area.

Wherever possible, there should be only one permanent inlet into a DMA to ease management. Each DMA may have about 500 to 1,000 connections but, more importantly, hydraulic isolation of DMA should be easy enough for practical and sustainability purposes and, the number of inlets should be limited.

What if a WSP has heavily interconnected distribution network and does not have hydraulically separated DZs by default? This is the case for most WSPs in Kenya. Lack of well separated DZs has caused a lot of difficulties not only in controlling water flow and pressure but also in reducing NRW and leakage because DZs separation is not easy and DMAs creation without clear DZs is even more difficult.

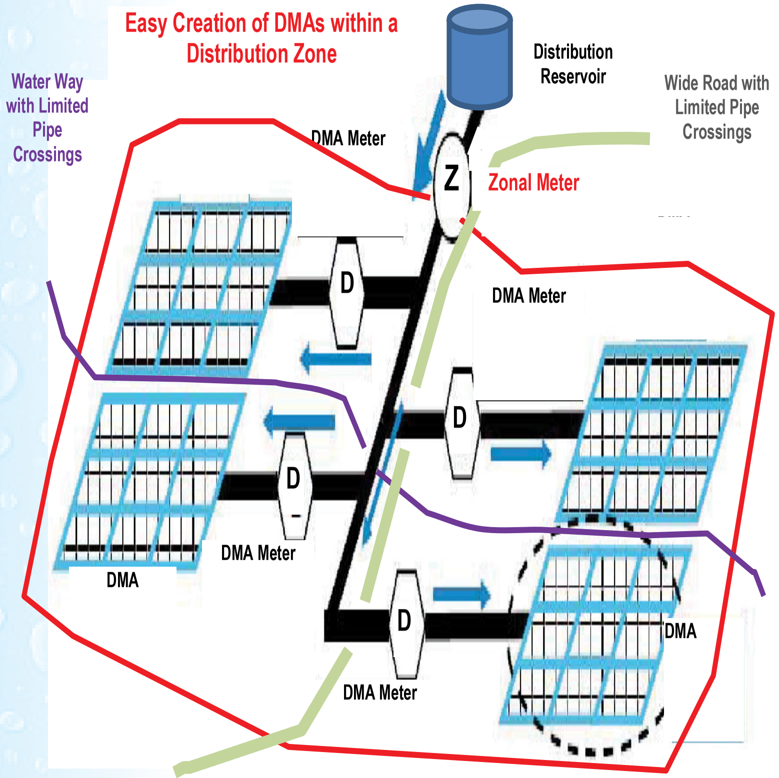


Figure. 5.5: Concept of Subdividing a Large Distribution Zone into DMAs

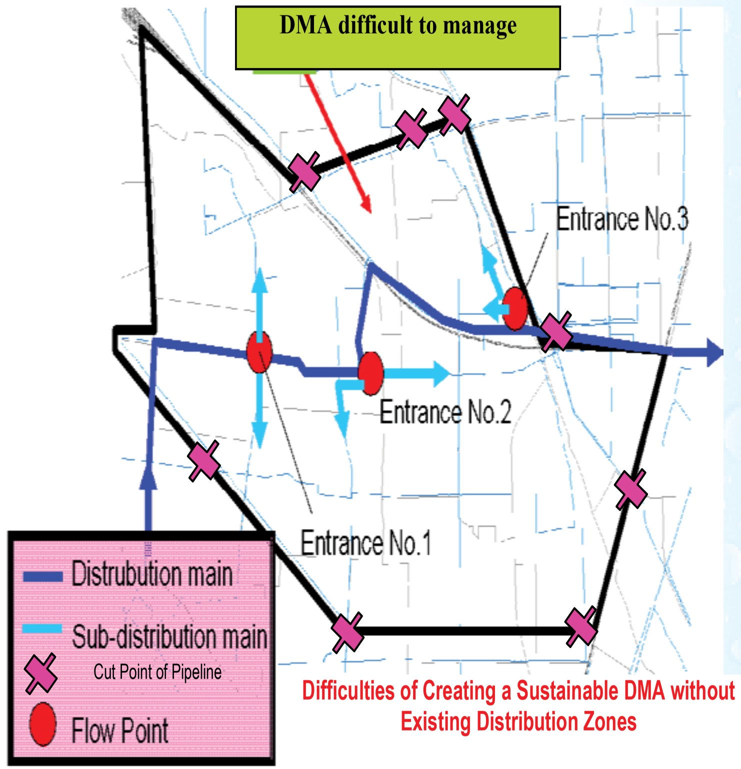


Figure. 5.6: Example of a DMA with Multiple Inlets & Many Cuts of Existing Pipes that are Difficult to Manage

5.3.3 Difficulties of Creating DMAs in Urban Areas without Hydraulic DZs

If a WSP has no technical capacity and resources to separate the distribution systems hydraulically into DZs, it may rush to create a small-scale isolated area as a DMA for the sake of a new trial of NRW reduction. It may create a pilot DMA in a peripheral rural area where distribution system can be separated easily.

However, if a WSP is suffering from a large amount of NRW occurring within built-up areas, establishing a trial DMA in a peripheral area does not make much sense although it is much easier than establishing a DMA in the built-up area.

As illustrated in Figure 5.5, if DZs are well-established even in built-up areas, a WSP may be able to start creating multiple DMAs easily just by dividing one of the DZs along the rivers and/or wide roads, etc; which have a few pipe crossings. On the contrary, a WSP would probably face many failures if it tries to establish a DMA within built-up areas where distribution systems are intermingled without clear separation of DZs. The failures may include incomplete isolation of the area, installation of an unmanageable number of bulk meters on many inlets/outlets, creation of obstacles against proper separation of DZs in the future, etc.

As shown in Figure 5.6, if a WSP does not have well-established DZs, establishing a DMA in a built-up area would require creation of an encircling boundary by cutting many existing pipes and installing multiple DMA meters. The pipes disconnected while establishing a DMA in a built-up area may be reconnected whenever there is water shortage occurs in the area in order to obtain emergency water supply from the adjoining area. This would undermine NRW calculation in the DMA. Moreover, the more meters a DMA has on its inlets/outlets, the more difficult it is to ensure their accuracy.

In realization of these points, a WSP may feel lost on what to do next for NRW reduction. There is an answer to this. While gradually separating the distribution system into hydraulically isolated DZs based on sound engineering considerations (see Chapter 10), a WSP should prioritize expansion of the basic NRW reduction activities which do not require hydraulically isolated areas to implement. Examples are reduction of estimated consumptions in billing through replacement of faulty meters, reduction of visible leaks and obvious water thefts, internal standardization of service connections, etc.

5.3.4 Other Benefits of Having Well-established Hydraulic DZs

Under intermittent water supply, a large portion of water flows down to low-lying areas especially if the distribution system is heavily interconnected. Under continuous water supply, the water pressure in low-lying areas may build up quite high. Therefore, separation of DZs needs engineering considerations to limit the unevenness of water distribution and the high pressure, besides considerations of monthly NRW monitoring and minimum night flow measurement for leakage amount approximation. These engineering considerations for even water supply and adequate pressure is further explained separately in Chapter 10.

A WSP may have administrative boundaries in the distribution systems which it uses to assign the various teams to different areas in customer meter reading, O&M of distribution networks, etc. These administrative boundaries should be converted to hydraulic boundaries once the hydraulic separation of DZs is done for better management of water supply services including NRW reduction.

5.3.5 Refining Universal NRW Monitoring into Individual DMAs

Division of the distribution networks into small DMAs needs a lot of resources and probably cause many technical difficulties such as failure in sustaining hydraulic isolation and reliable inflow measurements; and in identifying all the customers within each DMA. Therefore, reliable calculation of NRW volume and ratio should be established well through monthly monitoring practices; first for the entire service area, then for each DZs before dealing with the DMA level. If monitoring starts at DMA level (like in a pilot DMA) before the higher levels (universal and zonal), not much impact on the overall NRW reduction can be expected. If a WSP faces difficulties to reduce NRW effectively in some DZs even through monthly NRW monitoring for each of those zones is properly done, then only those particular DZs with difficulties may be further subdivided into DMAs so that the WSP can avoid using too much resources for the subdivisions. If a WSP has a relatively high technical capability and resources, the subdivision of established zones into many DMAs (and division of large existing zones into more DZs by constructing new transmission lines and distribution tanks, etc.) can be planned as shown in Figure 5.7.

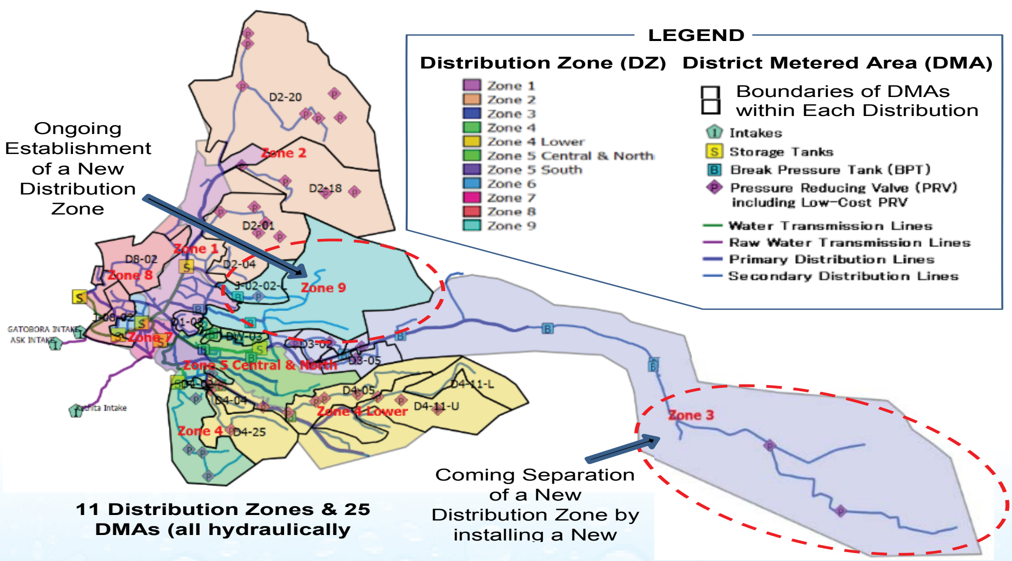


Figure. 5.7: GIS Plan Development to Increase Zones & DMAs at Meru WSP

The total inflow and total billed consumption can be determined to calculate the volume and ratio of NRW by hydraulically isolating a distribution network, installing bulk meters at all the inlets, and identifying all the customers within the isolated area. (Note: NRW in the entire service area, each zone or DMA are calculated by deducting Total Billed Consumption from Total Amount Supplied. In calculating universal NRW, the total production should be used as per WASREB definition of NRW. Outflows should be deducted from the total supply if the DZ or DMA has outlets).

5.3.6 Leak Detection at DZ Level to Minimize Costly Subdivision into DMAs

Under continuous water supply condition, in addition to DZs, DMAs can also be used to regularly measure minimum night flow that indicates the amount of leakage. However, before creating many DMAs which require a lot of resources not only to establish but also to maintain their effectiveness, it is important to consider the use of step test to reduce leakage at DZ level. In a step test the changes of minimum night flow (MNF) need to be measured continuously while closing branch distribution pipelines one by one in order to identify the areas causing a large amount of leakage. Each branch distribution pipeline needs to have operational isolation valves at their roots for the temporary closure. However, unlike establishment of permanent DMAs for each branch pipeline, identification of all the customers connected to each branch directly or indirectly and installation of bulk meters at their roots are not required for step test.

DZs can also facilitate real-time identification of incidences such as pipe bursts within each zone by installing pressure gauges or loggers in addition to flow meters on the inlet pipes. The zonal meters and pressure loggers are sometimes linked to a central control station via telemetry (e.g., part of a supervisory control and data acquisition (SCADA) system) so that flow data are continuously recorded and displayed. Effective abnormal flow monitoring for quick identification of bursts, leaks and water thefts may require installation of additional flow meters (including DMA meters) at strategic points within DZs.

5.3.7 Zoning of Existing Distribution Networks

1) Ensure that establishment or improvement of hydraulically isolated DZs is planned well with a map (preferably on GIS) showing boundaries of the planned DZs, required network modifications and existing/additional required zonal bulk meters for water distribution improvement and zonal NRW monitoring. This is, for example, aimed at limiting the elevation differences within each DZ to reduce pressure and pumping-power consumption; balancing the capacity of production facilities and the water demand in the different geographical areas; and full utilizing the storage capacities. Construction of new distribution reservoirs, transmission pipelines, pumping stations, etc. required for optimizing zoning may need to be compromised for quick and economical implementation of zoning.

2) Ensure that establishment or improvement of priority DMAs to split the large and/or problematic DZs is planned well with a map showing the boundaries of the priority DMAs, required network modifications and existing/additionally required zonal bulk meters (preferably on GIS) for more effective zonal NRW monitoring.

3) Ensure that the planned establishment or improvement of DZs is successfully implemented by hydraulically isolating the DZs.

   An example is to permanently cut existing interconnecting pipes, installing isolating valves on interconnecting pipes, installing standby bulk meters for measuring inter-zonal flow in case of emergencies requiring opening of isolating valves, confirming isolations by conducting zero-pressure test and properly installing all the zonal bulk meters required for the planned zonal NRW monitoring (e.g. with improved meter chambers in which portable clamp-on UFM can be mounted for testing the bulk meters, with strainers to prevent trash entering zonal bulk meters, and with air valves to release air from the meters, etc).

   Note: to conduct a zero-pressure test, close all the inlets/outlets first. Check whether the water pressure within the DMA drops to zero, since no water should now be able to enter the area.If the pressure does not drop to zero, then it is likely that another pipe is allowing water into the area and therefore needs to be addressed.

4) Ensure that the planned establishment or improvement of DMAs is successfully implemented by hydraulically isolating the priority DMAs and properly installing all the bulk meters necessary for the DMAs.

5) Based on the results of ongoing zonal NRW monitoring, ensure that additional DZs, DMAs or sub-DMAs are planned and established with additional bulk meters (as the need arises in cases where further subdivision of monitored DZs or DMAs with high NRW ratio and/or leakage is necessary to focus on the areas causing high NRW and/or leakage).

5.3.8 Zoning of Existing Distribution Networks

Monthly Calculation of NRW Volume and Ratio

1) Ensure that bulk meters of each DZ and DMA are always read monthly to accurately calculate monthly total inflow into each DZ and DMA (and Sub-DMA if required). It is recommended that all bulk meters should be read once daily by 9.00am for effective flow monitoring and to detect leakage/bursts problems early before too much water is lost.

2) Ensure that the accuracy of each zonal bulk meter is monitored based on the fluctuation of its monthly flow and periodically tested with a portable clamp-on UFM (e.g., semi-annually, annually, etc.) for timely servicing, replacement and/or calibration of any inaccurate bulk meters.

3) Ensure that:

   i) the monthly total billed consumption in each DZ and DMA is always calculated as scheduled without delay, and

   ii) the calculation is accurately done based on an accurate sorting of customers into each DZ and DMA. The meter reading route assigned to each customer in the meter reading/billing system may be usedto sort customers data. However, accurate sorting of customer datanormally requires locations of customer meters to be overlaid with DZ or DMA boundaries on GIS for confirmation. Addition of new data fields to the meter reading/billing system may be required at this stage to assign DZ and DMA names/codes to each customer for accurate sorting of customer data into DZs and DMAs.

4) Ensure that monthly calculation of NRW volume and ratio (and other prioritized PIs related to NRW volume if any) for each DZ and DMA is continuous and accurate based on synchronized bulk meter reading and customer meter reading in each DZ and DMA.

5) Ensure that fluctuations of monthly inflow, total billed consumption, NRW volume and NRW ratio of each DZ and DMA over the previous several months (i) are tabulated and plotted on graph(s) that are updated every month to analyse the causes of fluctuations and effects of NRW reduction activities.

6) Ensure that tables and graphs updated every month for zonal NRW monitoring are used effectively in monthly and other meetings held among relevant staff including manager(s) to improve NRW reduction activities, such as the prioritization of certain DZs or DMAs.

7) Ensure that monthly calculation of NRW volume and ratio in each DZ and DMA is integrated into a NRW management module of the existing meter reading /billing system.

5.3.9 Abnormal Flow Monitoring

1) Ensure that the zonal bulk and DMA meters are frequently read (e.g., daily, every few days or weekly, etc.) to monitor abnormal flow take timely intervention measures.

2) Ensure that the bulk meters on high-risk transmission and distribution pipelines (with recurrent bursts, leaks and illegal water uses) are selected and read frequently to monitor abnormal flow.

3) Ensure that additional bulk meters are installed on high-risk pipelines and frequently read to improve abnormal flow monitoring.

4) Ensure that fluctuations of flow rate at each bulk meter used for abnormal flow monitoring are quickly analysed based on the meter readings in order to identify any unusual increase in flow. Such an increase may be a hint that there is a burst, large leak or large illegal water use (e.g., irrigation at night).

5) Ensure that immediately there is any unusual flow increase hinting that there may be a problem, quick action is taken to confirm and resolve the problem on site.

6) Ensure that a free cloud-based online spreadsheet (e.g., Google Sheet in Google Drive) is created and is always used for recording bulk meter readings on site using smartphones; and promptly obtaining results of an automated analysis on abnormal flow; followed by quick intervention (without going back to the office to report the readings and receive result of analysis).

7) Ensure that abnormal pressure drops which may be hints of bursts, large leaks or large illegal water use are adequately monitored on high-risk pipelines including the outlet pipes of high-head pumps through frequent pressure measurements.

8) Ensure that GSM, GPRS, AMR or SCADA is introduced and frequently used to collect bulk meter readings and/or pressure data to monitor abnormal flows or pressure drops.

5.4 Preparation and Useof a Water Balance Table

5.4.1 Difficulties in Creating Reliable Water Balance Table

In developed countries, the entry point of NRW measures for a relatively large water utility may be to develop a global picture of how much and where water is being lost in the system. This process is called the water balance analysis or water audit. Table 5.3 shows the Water Balance Table defined by the International Water Association (IWA).

Table 5.3: Water Balance Table

<table>
<tr><td rowspan="9">System Input</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="4">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td></tr>
<tr><td>Unbilled Unmetered Consumption (e.g., Hydrant)</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Commercial (Apparent) Losses</td><td>Unauthorized Consumption (e.g., illegal connections)</td><td rowspan="5">Non- Revenue Water (NRW)</td></tr>
<tr><td>Customer Metering Inaccuracies, Estimations and Data Handling Errors</td></tr>
<tr><td rowspan="3">Physical (Real) Losses</td><td>Leakage on Transmission and/or Distribution Pipes</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer Use</td></tr>
</table>

Source: IWA

This table shows the components of NRW and focuses on how much water is physically lost in which part of the water supply system, how much water is legally or illegally consumed, billed, etc. System Input Volume is obtained by measuring the volume of water distributed, and Billed Metered Consumption is obtained from customer water meters. Many components of the Water Balance Table are often very difficult to estimate accurately. Table 5.4 explains the terminologies used in the Water Balance Table and defined by IWA. In reality, it is impossible to calculate the volume and percentage of each water component described with reliable accuracy based on the many assumptions in most WSPs in Kenya especially in WSPs which have not fully analysed their commercial losses and/or where water supply is intermittent. When the supply is intermittent, minimum night flow cannot be measured to cross-check the amount of leakage calculated by deducting the amount of estimated commercial losses from the amount of NRW.

Table 5.4: IWA Terminology for Water Balance Table

System Input Volume	**This is the Volume of treated water that is input into the supply system where water balance is to be calculated.**
Authorized Consumption	This is the Volume of metered and/or unmetered water consumed by registered customers, water supplier and others who are authorized by the water supplier. This can be residential, commercial and industrial use. It also includes water exported across operational boundaries. Authorized consumption may include water for firefighting and training, flushing pipes and sewers, street cleaning, watering municipal gardens, public fountains, frost protection and for building works etc. These may be billed or unbilled, metered or unmetered consumption.
Water Losses	This is the difference between System Input Volume and Authorized Consumption. Water losses consist of Physical (real) Losses and Commercial (apparent) Losses.
Billed Authorized Consumption	This is the part of Authorized Consumption that is billed and earns revenue (also known as Revenue Water). This is the sum of Billed Metered Consumption and Billed Unmetered Consumption.
Unbilled Authorized Consumption	This is the part of Authorized Consumption that is legitimate but not billed, therefore does not earn revenue. This is the sum of Unbilled Metered Consumption and Unbilled Unmetered Consumption.
Commercial (apparent) Losses	This includes all types of inaccuracies associated with customer metering as well as data handling errors (meter reading, estimates on flat rates and billing), plus unauthorized consumption (theft or illegal use). **Note:** over-registration of volume of use by customer meters leads to under-estimation of Physical Losses. Under-estimation of volume of use leads to over-estimation of Physical Losses.
Physical (Real) Losses	This is water lost starting from the storage tank to the point of customer use. In metered systems, the point of customer use will be the customer water meter and in unmetered situations this will be the point of use (tap) within the property. The total annual volume of water lost through all types of leakages, breaks and overflows depends on the frequency, flow rate and average duration of individual leakages, breaks and overflows.

System Input Volume	**This is the Volume of treated water that is input into the supply system where water balance is to be calculated.**
	Note: Although leakages occurring after the point of customer use (tap) are not included as Physical Losses, this does not mean that these leakages are insignificant or should be ignored.
Billed Metered Consumption	This is all metered water consumption that is billed. It includes all categories of customers such as domestic, commercial, industrial or institutional. It also includes water transferred across operational boundaries (water exported), which is metered and billed.
System Input Volume	This is the Volume of treated water that is input into the supply system where water balance is to be calculated.
Billed Unmetered Consumption	This is all billed water consumption based on estimates or norms but is not metered. This may be a very small component in a fully metered system but can be a key consumption component in systems without full meter coverage. This may also include water transferred across operational boundaries (water exported), which is unmetered but billed.
Unbilled Metered Consumption	This is metered water consumption, which is unbilled. This may include metered consumption by the utility itself or water provided to institutions free of charge and water transferred across operational boundaries (water exported) which is metered but unbilled.
Unbilled Unmetered Consumption	This is any kind of authorized consumption that is neither billed nor metered. This component typically includes water used for firefighting, flushing of pipes and sewers, street cleaning, frost protection etc. In a well-run utility, this component is small, but very often over-estimated. In rare cases, this component may also include water transferred across operational boundaries (water exported) which is unmetered an unbilled.
Unauthorized Consumption	This is any unauthorized use of water. This may include illegal water use from hydrants (for example, for construction purposes), illegal connections, bypassing meters or meter tampering.
Customer Metering Inaccuracies and Data Handling Errors	These are Commercial (Apparent) Losses caused by customer meter inaccuracies and data handling errors in meter reading and billing system.

System Input Volume	This is the Volume of treated water that is input into the supply system where water balance is to be calculated.
Leakages in Service and/or Distribution Pipes	This is water loss from leakages and breaks on service and distribution pipes. These may be small leaks which are unreported (for example small leaks at joints) or large leakages that are reported and repaired but stayed leaking for some time.
Leakages and Overflows at Utility Storage Tanks	These are leakages from leaking storage tanks or overflows of tanks caused by operational or technical problems.
Leakages in Service Connections up to point of Customer Metering	This is water lost between the service connection (customer meter in case of metered systems and first point of use (tap) within a property in case of unmetered systems) to the point of customer use. These kinds of leakages are predominantly small and those that do not surface therefore will run for long periods (often years).
Revenue Water	This is authorized consumption, which is billed and produce revenue (also known as Billed Authorized Consumption). It is equal to Billed Metered Consumption + Billed Unmetered Consumption.
NRW	This is the component of System Input that is not billed and do not produce any revenue. It is equal to Unbilled Authorized Consumption + Physical (Real) and Commercial (Apparent) Water Losses.

5.4.2 Water Balance Table Part 1

Authorized Unbilled Consumption and Commercial Losses

Note: This part of the table can be prepared before WSPs shift focus to the difficult underground leak detection and expensive pipe replacement.

- Authorized Billed Consumption (Revenue Water) and Authorized Unbilled Consumption (Part of NRW)

1) Ensure that preparation of IWA universal water balance table for the entire SA of WSP for a recent year (or the last 12 months) is commenced by filling the annual billed metered authorized consumption (including sold exported water) and the annual billed unmetered authorized consumption (e.g., unmetered use of hydrant for firefighting). The World Bank Easy Calc (free Excel-based software) can be used to preparethe water balance table.

2) Ensure that annual metered authorized unbilled consumption for the SA is estimated with good accuracy based on metered consumption of each metered authorized unbilled water use type.

3) Ensure that annual unmetered authorized unbilled consumption for the SA is estimated based on the type of each unmetered authorized unbilled consumption. For example, if a formular is used, the calculation should be based on reliable records of each occurrence.

◆ **Commercial Losses (Data Handling Error, Meter Accuracy Error and Illegal Water Use)**

4) It is well understood by WSP staff working for NRW reduction that the accuracy of water balance table is largely dependent on the accuracy of estimating different types of commercial water losses and that the WSPs not actively trying to reduce commercial losses have a very strong tendency to underestimate their levels of commercial losses (and thereby overestimating physical losses) due to limited reliable data for estimating commercial losses. Therefore, active reduction of all components of commercial losses is prerequisites for establishing a representative (not misleading and harmful) water balance table of the WSP).

5) Ensure that commercial loss of the most recent year that was not accurate due to data handling errors (inaccurate and/or improper estimates of customerconsumptions due to missing meters, unreadable meters, obviously stalled meters, estimating without analysing past consumption data, etc.) is accurately estimated.

6) Ensure that commercial loss of the most recent year that was not accurate due to customer meters errors (metered consumptions were used for billing without being replaced with properly estimated figures) is accurately estimated. These components should be estimated based on the results of active meter accuracy tests to a sufficiently large number of sampled customer meters having different consumption levels (but not those tested passively to deal with complaints on meter accuracy or suspected over-registration from customers).

7) Ensure that commercial loss due to found and unfound illegal water uses is accurately estimated based on records of illegal water use identified in the past including results of active investigation of a sufficient number of suspected customers.

8) Ensure that the percentages of authorized unbilled consumption and commercial losses are continuously calculated in the universal water balance table to confirm the extent of reduction and the outstanding volumes; and shared with relevant staff for discussions.

5.4.3 *Water Balance Table Part 2:*

Physical Losses and Additional Zonal Analysis

◆ **Physical Losses (Completion of the Universal Water Balance Table)**

1) Ensure that the total annual physical water loss in the SA is estimated by deducting the total of annual authorized unbilled consumption and annual commercial losses from the total annual NRW volume.

2) Ensure that the estimated total physical loss is subdivided into:

   (a) leakage and overflow at water treatment, storage and pump facilities,

   (b) bursts and leaks from transmission and distribution pipelines, and

   (c) bursts and leaks from service connections up to customer meters.

   These should be based on the annual number of found overflows, bursts and leaks, the estimated number of remaining overflows and leaks and their estimated lost water volume for the three components.

3) Ensure that the universal water balance table is prepared (by entering the estimated volume and percentage of each physical loss component) and shared with relevant staff for discussions to improve NRW activities.

◆ **Additional Analysis on Physical Losses and Illegal Water Use in Each DZ/ DMA**

   Note: In preparing the IWA universal water balance table, all commercial losses need to be estimated first to calculate the total volume of physical losses. In the following measures, the physical losses and illegal water use are estimated first

4) Ensure that the MNF at the inlet point(s) of DZ(s) or DMA(s) is recently measured with zonal bulk meter(s) and/or portable UFM(s) to roughly estimate the total volume of physical water losses and illegal water uses (part of it occurs at night) in each DZ or DMA.

   Note: MNF measurement is difficult to conduct under significantly intermittent water supply conditions.

5) Ensure that thorough active leak detection on distribution and service pipes is conducted recently in DZ(s) or DMA(s) to estimate the physical losses from distribution pipes and service connections separately.

6) Ensure that any results from the above two measures of analysing NRW components at DZ or DMA level (preferably from multiple areas of different characteristics) are used to cross-check the percentages of different NRW components shown in the universal water balance table of a recent year.

Chapter 6

Reduction of Commercial (Apparent) Water Losses

6.1 Metering of Customers

Connections of large consumers should be mapped well priority so that they receive special attention regarding accurate metering, billing, consumption pattern and water availability. Analysis of these parameters for large consumers should be done continuously to detect any abnormality for quick intervention where appropriate.

In order to determine the total consumption volume, full knowledge of all customer meters is crucial, hence 100% operational and accurate customer metering is necessary. Flat rates (where a meter is not installed) are still used in many WSPs. Some WSPs are still using flat rate connections because they lack fundsto procure and install meters. Consumers on flat rate connections are normally not cautious on water conservation, take advantage to use large amounts of water and generally misuse water by leaving it running for no purpose.

Water demand increases with increase in the number of customers. In order to meet the increased demand, additional water resources may need to be developed.

Without accurate water consumption data, the appropriate water resources would be difficult to develop and more funds than necessary would be used. The aim of managing NRW is to reduce water wastage. For this to happen, the general policy requires that all customer connections be installed with working and accurate meters. Even in areas where flat rate is applied, the zones should have bulk water meters to measure the water volume consumed within the area. Installation of water meters require funds and time. It is not always easy for WSPs with financial difficulties to prioritize meter installation. This can be better addressed by giving special attention to large consumers because they are the ones that can providethe desired large amount of revenue. It is important to plan for meter installation during project formulation, planning and design stages because in the long term, it is more beneficial to have fully operational meters for all customer.

The accuracy of customer meters depends on several factors such as meter type, brand, replacement policy and maintenance. Water quality is not good in some regions and it is advisable to install strainers on distribution pipes (Figure 6.1 and 6.2) to protect the moving parts of the meters from damage by debris. Therefore, WSPs should install water meters that are appropriate for the supplied water quality.

Figure 6.1: Strainer (Installed at outlet of Water Treatment Plant) (Meru WSP)

Figure 6.2: Roots at Customer Meter (Embu WSP)

6.2 General Condition of Commercial Losses

Reducing commercial losses is a key factor for NRW reduction in developing countries. NRW ratio can be reduced to as low as 30%, by only reducing commercial losses. In Kenya, lack of integrity of WSP staff was identified as one of the challenging factors that significantly contribute to commercial losses.

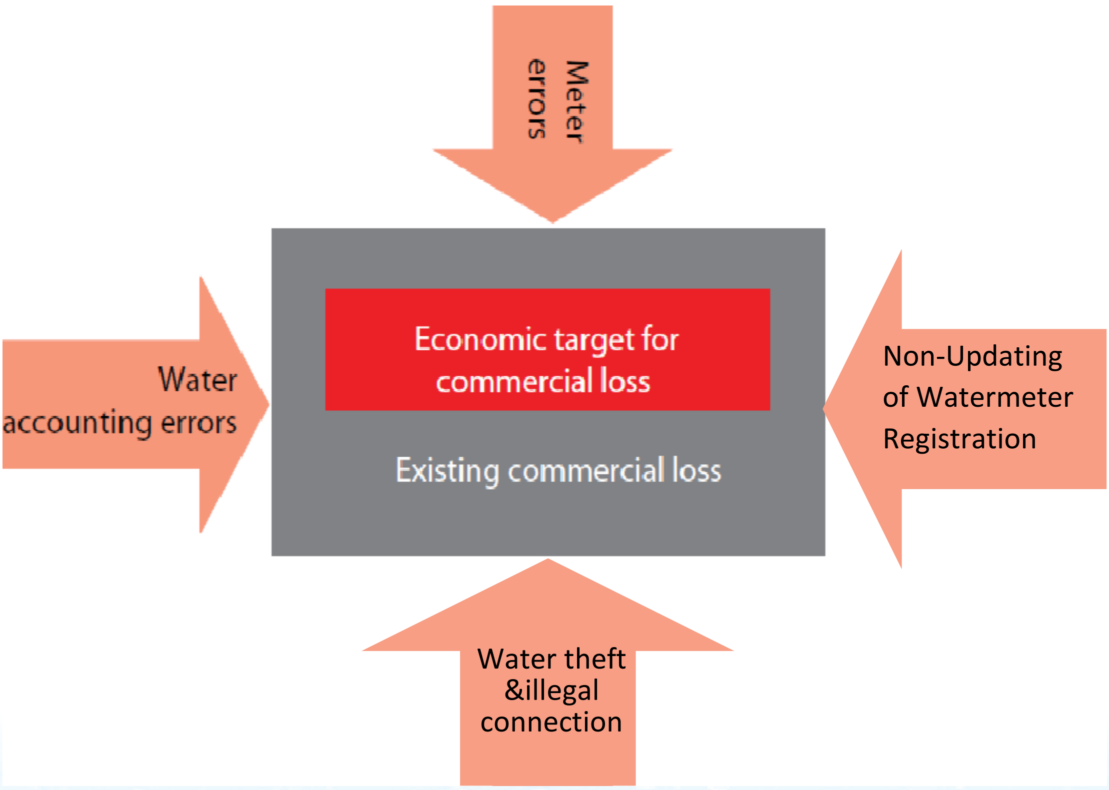


Figure 6.3: Four Pillars of Commercial Losses

Water lost through Commercial Losses, also known as Apparent Losses is not a visible loss and is therefore often overlooked by WSPs which, in most cases, focus on physical losses.

Commercial loss can result in a higher volume of water loss than physical loss and often has a greater value since reducing it increases revenue, whereas physical loss reduces production costs. For any commercially viable utility, the water tariff will be higher than the variable production cost. Therefore, even a small volume of commercial loss will have a large financial impact. An additional benefit in reducing commercial losses is that it can be accomplished quickly and effectively. This chapter reviews the four main elements of commercial loss and the options of addressing them.

6.3 Reduction Measures for Commercial Losses

6.3.1 Introduction

Commercial Losses can be broken down into four fundamental components:

- Meter errors (customer meter inaccuracy)
- Under registration of connected meters
- Water theft and illegal connection
- Water accounting error

Measures to reduce commercial loss do not require high investment but the results can be attained relatively quickly. For these reasons, measures for reducing commercial losses should be focused at the beginning of the NRW reduction program. It however requires continuous commitment of the management, political will and support by the local community.

The “customer meter reading and billing analysis tool” also known as the “frequency analysis” is an MS Excel template that was developed by the JICA Project for analysing meter reading and billing data over a period of time. It is recommended that the meter reading and billing data should be for a period of6 to 12 months. The analysis categorises customers based on the WSP’s tariff bands starting with the highest consumption tariff band (e.g., consumption>300m3/month =C1, 101 to 300 =C2, etc. (Figure 6.1)). The tariff bands are also categorized as Very Large (C1 & C2) Large (C3 & C4) etc. Conducting the analysis reveals the following information:

- Customer meters that were not read, in which months and the frequency of not reading
- stopped meters and the months of stoppage
- meters that malfunctioned and the months

- meters that need resizing
- accounts not billed and the months
- accounts billed on estimate and the months
- category of each customer based on water consumption amount (very large, large, medium, small)

Table 6.1: Customer Categorization and Frequency Analysis of Consumption Estimation

Customer Categories by Consumption		Customers with Billed Consumption Data		Ratios of Customers by the Number of Months when Consumption was Estimated during the 12 Months from June 2017 to May 2018			
		Num.	Percentage	○ 0 Time	[1] Only 1 Time	[2] 2 Times	[X] 3 Times or More
Very Large	C1: > 300 m3/month	19	0.1%	26%	16%	37%	21%
	C2: 101-300 m3/month	219	1%	27%	23%	13%	37%
Large	C3: 51-100 m3/month	701	3%	20%	15%	12%	53%
	C4: 21-50 m3/month	2,796	13%	12%	14%	11%	62%
Medium	C5: 7-20 m3/month	14,575	69%	6%	8%	8%	78%
Small	C6: 0-6 m3/month	2,721	13%	18%	20%	19%	43%
Total		21,031	100%	9%	11%	10%	70%

Other information such as identifying the category of specific customers can be obtained through filtering.

The results from the analysis provides an indicator of the level of commercial loss that is incurred in the system and is a powerful tool for guiding WSPs in prioritising NRW reduction activities that bring quick wins. It is therefore recommended that whenever a WSP conducts a capacity self-assessment, it should always include a frequency analysis of all customers to reveal the level to which customer bills are being estimated.

Frequency analysis of estimated consumption is especially important for those WSPs that do not give enough attention to commercial losses despite their high NRW ratio (e.g., NRW> 30%). All WSPs in Kenya can greatly benefit from and need to carry out periodic analysis (see Sec. 6.4 for further explanation).

It is therefore recommended that WSPs conduct the analysis annually or semi-annually and follow up by prioritizing the large consumers as they narrow down to the small consumers.

The most effective prioritization of tackling the meters is: -service the meter →test the meter →resize if necessary and replace the meter

- Start by tackling stopped meters of very large consumers
- Tackle under-registering/malfunctioning meters of very large consumers
- Tackle stopped meters of large consumers
- Tackle under-registering/malfunctioning meters of large consumers
- Tackle stopped meters of medium size consumers
- Tackle under-registering/malfunctioning meters of medium size consumers
- Tackle stopped meters of small size consumers
- Tackle under-registering/malfunctioning meters of small size consumers
- Continue monitoring the very large and large customers, as a priority, without ignoring the medium and small customers.

The WSP must be proactive in making quick decisions. If servicing a meter is not possible, replace it and try to service it later in the workshop. If testing of a meter for accuracy is not possible, replace the meter and try to test it later in the workshop. If resizing of a meter is not possible, replace it anyway and resize later. Always give priority to customers with potential for the highest revenue loss if the meter stops/ under-registers/malfunctions.

This way, the WSP can increase their billed consumption which in-turn results to revenue increase within a short period of time and with little investment.

6.3.2 Meter Errors

Normally, inaccurate meters have the tendency to under-register water consumption and very rarely over-register. This means that inaccurate meters result into revenue loss. To reduce inaccurate meters, meter testing exercise should be carried out by an experienced team (maybe NRW Team). Use of simple testing methods like calibrated buckets and test meters of known accuracy (Figure 6.4) is highly recommended especially for small WSPs which may not have a meter testing bench.

Figure 6.4: Meter Testing using Portable Test-meter and Calibrated bucket

When surveying for inaccurate meters, water meters of large consumption consumers should be prioritized first, as the revenue lost from such consumers isa lot. Billing customers based on actual consumption is always preferable to flat rate billing.

Below are typical causes of meter inaccuracies and their solutions:

a) Proper installation of customer meters

A water meters should be installed in accordance with the manufacturer's specifications to avoid unnecessary inaccuracies that may occur due to poor installation.

b) Water quality

Poor water quality due to inadequate treatment or dirt infiltration into pipes may cause sediments to settle in the water meters thereby leading to inaccuracy.

c) Intermittent water supply

Water meters in areas that receive water intermittently (or where water rationed) register the air volume at the begin before the arrival of water. This normally happens when supply is resumed after a certain period of no supply. The sudden increase in water pressure can also damage some components of a meter. Intermittent water supply should therefore be avoided as much as possible since it greatly affects the accuracy of meters and hence the readings.

d) Meter Size

Each customer meter is made to function within a defined flow range. Maximum and minimum flow volumes are normally defined by the meter manufacturer, and in many cases, large meters will not register water flow when the flowrate is lower than the specified minimum flow rate. It is therefore important to conduct customer survey to understand the nature of each customer's water demand and their likely consumption This helps to determine the size of meter required for each customer (refer to Chapter 7 for more details).

e) Class and Type of meter

Choosing the correct class and type of meter for each customer will ensure accuracy of customer consumption reading.

(i) Class of Meter

Classification of meters is based on the accuracy with Class A being the least accurate and Class D the most accurate.

(ii) Type of Meter

There are different types of flow meters which can be used to measure the flow with the mechanical type of flow meter being the most commonly used in Kenya. Different types of meters have different levels of accuracy as indicated in Table 6.2. The accuracy level of the flow meters must be put into consideration before installation since any errors will have a great impact on the measurement of the total water volume.

Table 6.2: Indicative Example of Meter Accuracy

Equipment / Method	Approximate Accuracy Range
Electromagnetic Flow Meters	<0.15-0.5%
Ultrasonic Flow Meters	0.5-1%
Insertion Meters	<2%
Mechanical Meters	1.0-2%
Venturi Meter	0.5-3%
Meas Weirs in open channels	10-50%
Volume calculated with pump curves	10-50%

Source: World Bank Institute, 2007

f) Maintenance of meters

Water meters should be replaced systematically, beginning with the oldest meters and those that are in bad conditions. Poor maintenance of meters results in meter inaccuracy and shortens their lifespan. A scheduled maintenance and replacement plan should be established to manage this problem such as tracking the age of each meter through the billing system. In some countries like Japan, meters are replaced at the age of 8 years. However, in developing countries, each WSP should formulate and periodically review a policy to ensure regular meter replacement,taking its financial capacity into account.

6.3.3 Updating Water Meter Register

It is important to continually update water meter registers, as water consumption bills are based on information in the register. Updating may range from a simple change of customer name or change from domestic to commercial user, to correcting information errors in the register.

There may be cases where information of newly installed water meters/connections is not entered in the billing system. In such cases, customers are not billed leading to revenue loss. It is possible for trained and diligent meter readers to detect unregistered water meters during regular meter reading cycles, as unregistered meters will not appear on the meter reading book.

The best method for identifying billing system errors is by conducting a complete customer survey in the supply area. In this survey, each property, whether registered or not, should be visited to determine whether the connection is registered or not.

Customer survey should confirm the following information: name of customer, property address, type of meter and meter number, active or inactive meter, whether it is a high consumption meter, and year of installation, etc.

Figure 6.5: Updating of Water Meter Register

6.3.4 Water theft and illegal connections

Illegal water connections and meter bypasses (water theft) are all part of unauthorized consumption.

Some of the more common problems and possible solutions are described below:

a) Detecting and Reducing Illegal Connections

An illegal connection involves establishing a physical connection to a water distribution pipe without the knowledge of the service provider. Meter readers should always be aware during their rounds and report any illegal connections immediately. Customers should also be made aware of the negative impacts of illegal connections and encouraged to report illegal connections when found. At the same time, strict regulations should be set in place to penalize illegal connections.

b) Meter Bypassing

An additional pipe can be installed around the water meter, so that water bypasses the meter. In such a case, water bills are reduced, as true consumption volumes are not recorded. Often, the bypass pipe is buried underground and it is very difficult to detect it. Customer surveys and conducting leakage Step-Test can help in determining meter bypassing.

c) Meter Tampering

This is manipulating a meter so that it records a lower reading than the true reading. Meter functionality is tampered with or disrupted by inserting a pins or other small objects into the meters. Most reputable meter manufacturers now produce meters that are difficult to tamper with. Such meters are non-metallic with strong clear plastic windows and casings that are difficult to penetrate.

d) Impact of informal Settlements on commercial losses

The low social-economic status in informal settlements renders it difficult to install customer meters for each household. This results to insufficient focus being given to the water supply in informal settlements. Nevertheless, since it is generally impossible to correctly determine the volume used in each house-holds, it is important to at least know the amount of water distributed in the slum areas.

In order to determine the volume of water distributed in an informal settlement, the area should first be isolated. The water entering the area should then be measured at the few created entry points - indicated in red dots (Figure 6.6).

Another method of determining the volume of distributed water is to use basic unit for consumed water volume per capita.

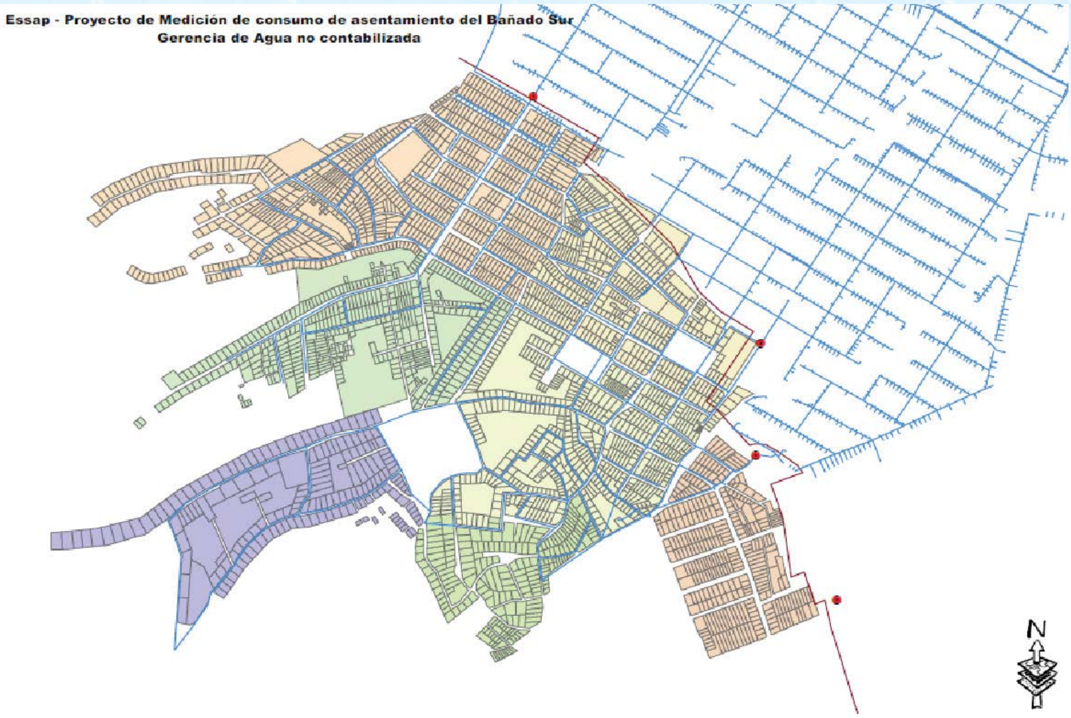


Figure 6.6: Measurement of consumption in informal settlements

6.3.5 Water Accounting Errors

a) Corrupt Meter Readers

Corrupt meter readers can cause significant impact on a WSP's monthly revenue. When the same meter reader is assigned to the same route for a long period of time, he/she may become very familiar with the customers in that route and collude with them to record lower meter readings in exchange for monetary incentives. In order to reduce this risk, the reading routes of meter readers should be rotated regularly.

b) Meter Reading Errors

Meter reading errors may occur due to incompetent or inexperienced meter readers, or simple errors while recording the readings by e.g., putting the decimal points in the wrong place. Errors can also occur due to dirty or faulty meter dials.

Meter readers should immediately report any problem observed, and the maintenance team should take immediate action to remedy the problem. Meter readers' activities are in the frontline; liaising directly with customers therefore their activities have an immediate impact on the cash flow. Investments should be made in training and motivating meter readers for accurate and efficient work.

c) Data Handling and Accounting Errors

Typically, the procedure for data handling and billing starts with meter readers visiting each water connection to read the customer meters. The data is recorded by hand on a form and submitted to the billing office. The billing office then keys the readings into the billing system and prints and mails the bills to the customer.

In this process, a variety of errors may occur at various stages of the process. Firstly, the meter reader may read incorrectly and/or record the reading incorrectly; secondly, the incorrect data may be logged into the billing system at the billing department; thirdly, the bill may be sent to the wrong address.

One of the key factors in minimizing errors is to have a robust billing database and such a database should be the first investment for any WSP that is striving to improve its revenues.

The latest billing software has built-in analysis functions that can identify data irregularities, which could lead to potential identification of data handling errors.

If a WSP is financially capable, it should invest in electronic meter reading devices. The devices can electronically transfer data to the billing system thereby drastically reducing data handling errors.

Figure 6.7: Water Meter Covered in Mud

It is common to see customer meters buried in mud, garbage or submerged in water causing the readers to read them incorrectly.

Meters should be installed in accessible locations where readers can easily read them.

6.3.6 Others Issues

a) Introduction of GIS Database

GIS was introduced as a platform for water network management, especially due to its characteristic capacity to manage maps and databases comprehensively. GIS is used in areas such as graphic management, customer registers, revenue collection, etc to ensure develop maintain maps of water networks including customer meter locations among other system facilities which is crucial in NRW management.

b) Efficient Billing System

For efficiency and accuracy, a computerized billing system should be used. Among the in-built reports produced by an efficient billing system should be DMA/Zonal and overall NRW water volumes and ratios once supplied volumes are keyed in. The efficiency of a billing system can contribute greatly in NRW management by maintaining accurate data and producing relevant reports as needed.

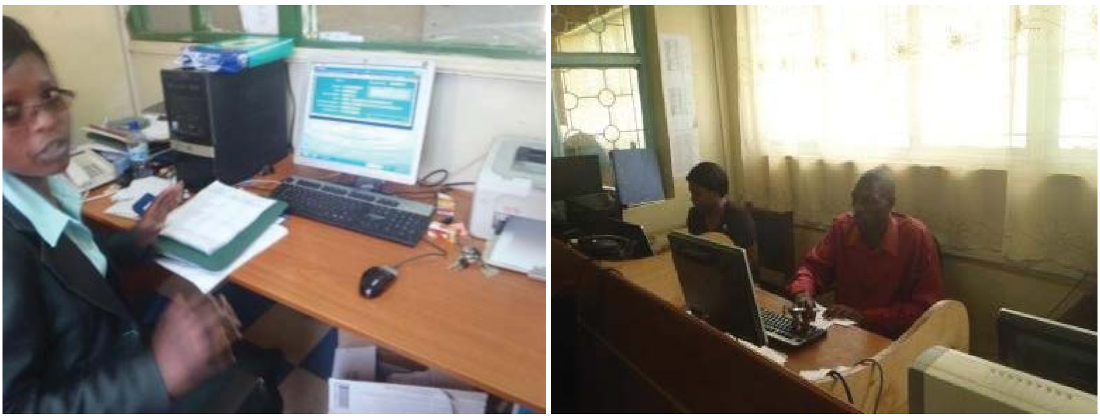


Figure 6.8: The Billing Unit for Narok and Embu respectively

c) Customer Care System

To manage customer complaints, a customer care system such as Enterprise Resource Planning (ERP) should be installed to easily share information among all the company staff. The system should handle problems related to meter reading errors, lack of water supply, dirty water or insufficient water pressure in a quick and efficient manner. Giving customers careful attention increases customer trust leading to better payment of bills and hence stable revenue.

Figure 6.9: Customer Care System

6.4 Analysis of Meter Reading and Billing Data

Even WSPs with a metering ratio close to 100% often have many faulty and inaccurate meters at customer points. This causes frequent and unending estimation of customers' consumption resulting in a huge volume of NRW. Therefore, the status of recent metered and billed consumption data for each customer should be analysed to understand the following:

a) The composition (frequency analysis) of the customers categorized by average billed consumption (preferably 12 months), e.g., large customers consuming more than 100m3/month on average.

b) Monthly percentage of estimated consumptions by customer category. All the estimations can be found in the analysis by identifying the billed consumptions which are different from their corresponding metered consumptions.

c) The main and other reasons for the identified consumption estimations.

d) Inconsistency between current status of disconnected customers and their recent meter reading and billing records (customers with disconnected status may currently have metered consumption, and/or may be receiving bills, or may be using water illegally).

e) The frequency of estimated consumption for each customer during the last 12 months (e.g., categorized into 1 time, 2 or 3 times, more than 3 times, etc) and its continuity (e.g., the number of months that usually pass before stopped or obviously-faulty meters get replaced) by customer category.

Results from the above analyses should be shared widely among WSP staff including managers and discussed to improve commercial loss reduction activities (especially those of large customers).

6.5 Reduction of Commercial Losses starting from Large Customers

The frequency of the estimated customer consumption (especially those of large customers) should be reduced through:

1) Servicing and/or replacing obviously faulty meters. Installation of strainers and, elimination of visible leaks and overflow can be done at the same time.

2) Conducting active on-site accuracy tests of customer meters. The passive customer meter accuracy test that is normally conducted for complaining customers should not be considered as part of this active accuracy tests.

   (**Note:** meters of large consumers should be checked more frequently. The costly replacement of old meters for small customers (those consuming less than the upper limit of the lowest tariff bracket may not decrease NRW or increase revenue significantly.

3) Investigating illegal connections and underground leaks (e.g., with DPD chlorine tablets, listening sticks, etc) around customer meters can be conducted at the same time with servicing and replacement of faulty meters and/or accuracy testing of active meters.

4) The above activities should be supported by the following activities:

   i) Use of printed GIS maps showing target customer meters to identify their locations on site

   ii) Use of online map (e.g., QGIS Cloud), mobile mapping/GIS software installed on smartphones (e.g., MAPinr) and/or PC-based GIS software on Windows tablets (e.g., QGIS) to navigate to the target customer meters.

   iii) Use of electronic form(s), e.g., Kobo Toolbox/Collect to collect data.

5) The following equipment and facilities are used to conduct meter accuracy tests on site or in the workshop:

   i) 10 or 20 litres ready-made calibrated buckets/jerry cans (larger sizes can be fabricated in the workshop.

   ii) Portable clamp-on UFM (see Sub-section 13.2.4)

   iii) Portable meter tester (e.g., ready-made having a 15mm test-meter inside or hand-made with Class C copolymer piston-type meters up to 25mm and hose pipes)

   iv) Meter test bench (e.g., ready-made with flow rate control and calibrated tanks or hand-made with a table, valves, calibrated buckets, inline UFM of known accuracy, etc. (See Sub-section 13.2.4)

   v) Workshop well equipped for servicing of removed meters

6.6 Additional Focused Management of Large and Medium Customers

1) Frequent visual inspection, additional reading of large consumer meters (e.g., weekly, etc) and/or installation of additional meters in series should be conducted to minimize revenue loss caused by meter inaccuracy that may worsen between monthly meter readings.

2) Proper customer meter sizing for large consumers based on maximum flow rate should be implemented.

(Note: Small customer meters (may have low “maximum” or “cut-off flow” rate that is lower than the expected high water flow rate” at the beginning of each intermittent water supply period should be avoided especially in low laying areas with high water pressure and short water supply hours.

3) Multiple customer meters serving the same customer should be integrated into one account for each customer so that the billed amount increases properly in accordance with the incremental water tariff (also possibly by replacing them with a single larger customer meter).

4) Metering for residents in large residential buildings (where water theft may exist inside the building) should be effective and/or improved to reduce illegal connections and leakages (e.g., by relocating individual meters outside of buildings or by installing a master meter for the building owner/landlord outside and collecting water charge based on master meter readings).

5) Installing large high accuracy non-mechanical (i.e., electromagnetic and/or ultrasonic) meters which cannot stall easily and that have long-life battery, data logging ability and anti-tamper function (may have remote reading function such as GSM and AMR) for very large customers.

6) Installing small high accuracy ultrasonic smart meters with built-in battery and; AMR and anti-tamper function (or anti-tamper mechanical meters with mounted AMR devices) and; compatible software and data receivers for AMR (e.g., many relay antennas and a mobile antenna mountable on automobile, etc) for large and/or medium customers.

6.7 Reduction of Unbilled, Unmetered and Illegal Water Uses based on Customer Identification Survey

◆ **Unbilled Authorized Consumption**

1) The necessity and actual conditions of authorized unbilled public water uses (e.g. public parks, public toilets, public taps, fire hydrants and supply to special areas such as low income areas) should be well assessed, and the relevant policies developed/improved (including those for reducing authorized unbilled

consumption and, improving its metering) (e.g. through introducing subsidies or instalment payment plans of connection fees for low income population, identifying excessive public water uses and awareness raising).

2) Actual conditions and necessity of authorized unbilled consumption for WSP's institutional uses (e.g., flushing of distribution pipes with water, cleaning of distribution tanks, losses during installation of service pipes and customer meters, etc) should be assessed and relevant policies developed/improved (e.g., through identification of excessive institutional water uses and awareness raising).

◆ **Unmetered, Unregistered and illegal Water Users/Customers**

3) Customer meters should be installed for all customers who are supposed to be billed based on metered consumption to reduce commercial losses and excessive water use.

4) CIS should be conducted to identify unregistered consumers (missing from the meter reading/billing system) and illegal users (including customers recorded as disconnected but still consuming water for free after illegal reconnection or unsuccessful disconnection; NB: disconnection at the offtake/tapping point may be required), etc. Accurate GPS coordinates of customer meters (and possibly offtake point), connection No. of each customer, meter type and conditions etc should be captured in a CIS preferably with free data collection software (e.g., Kobo Toolbox/Collect) or free mobile GIS (e.g., QField) on smart-phones and hand-held GPSs (i.e., a combinational use for higher GPS accuracy).

◆ **Problematic Customers and Areas with Recurring Illegal Water Use**

5) Cases and scale of illegal uses (e.g., meter tampering, meter bypass, illegal connection, Illegal reconnection, meter reversal, fetching before meter) in informal settlements, at large non-residential customers and high-income customers with large gardens, should be well analysed and discussed for prioritizing customer types or areas for reducing illegal uses. (Note: Both Illegal self-reconnections of disconnected customers having stopped meters and unsuccessful disconnections with faulty stop cocks and stopped meters can cause large a NRW amount without being noticed for a long time if they are not given special attention).

6) Active patrolling for recurring illegal water uses at problematic customer types (e.g., factories, farms, construction sites) and/or in certain types of areas (e.g., illegal connections, meter tampering, meter bypass, illegal self-reconnections) should be conducted by dedicated inspectors supported by the WSP's top managers (with the use of chlorine DPD tablets, electronic conductivity meter, leak detection equipment, etc).

6.8 Preventive Measures at Installation of Service Connections and Customer Meters

6.8.1 Installation of Customer Meters

Factors to take into consideration when installing customer meters are the reliability of meter performance, ease of reading and ease of replacing and maintenance.

Figure 6.10: Actual Installation of Customer Water Meter

(1) Location for Installation of Water Meters

The following factors should be considered when selecting a site for installation of meters:

i) Meters should be located at points where meter reading, inspection, and maintenance can be easily performed.

ii) Selected sites should be located in dry areas away from wastewater

iii) Meters should be installed in locations away from contaminated air or exhaust fumes.

iv) Meters should not be easily exposed to vandalism, theft or accidents

v) Meters should be located in areas free from water logging and flooding

vi) Meters should not be installed in areas with excessively high temperatures

vii) Meters should not be installed in a location where water pressures fluctuate excessively

viii) Meters should not be located in areas where they are subjected to shocks or vibrations

ix) The GPS location of each meter should be taken and updated on the GIS map for ease of management like meter reading, etc.

Figure 6.11 and 6.12 show recommended installation for customer meters

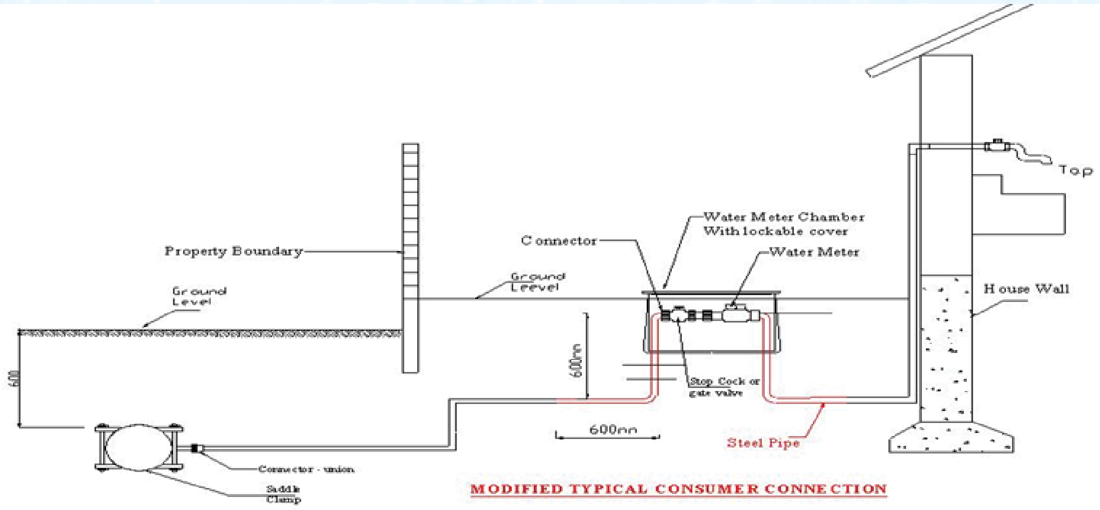


Figure 6.11: Recommended customer meter installation with meter box

There are many cases in Kenya where meter readers cannot read customer meters as they are buried underground. This can cause errors in meter reading. It is recommended to install water meters above the ground in order to facilitate meter reading. In Kenya, water meter installed above ground are more susceptible to theft. In theft-prone areas, copolymer resin body meters are recommended.

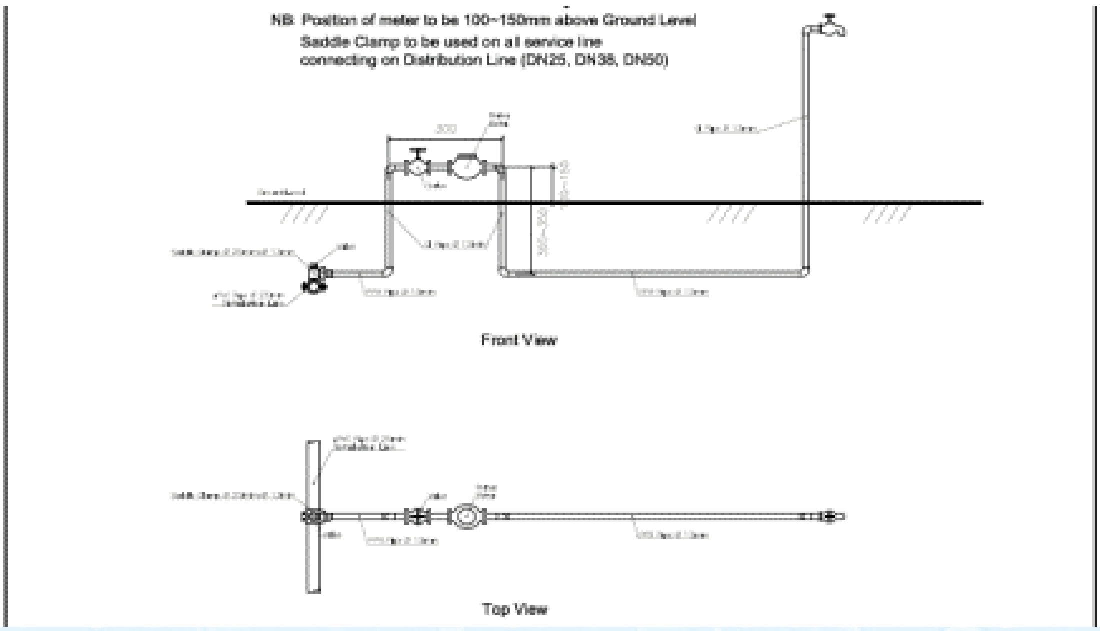


Figure 6.12: Recommended customer meter installation without meter box

(2) Precautions for Installation

Poor installation can impact negatively on the performance of meters. The following precautions should be taken at the time of meter installation to minimize sub-standard performance of meters.

i) Clean the interior of pipes thoroughly of any sand and foreign debris. “Recording errors” occur if the strainer of a meter is clogged. The meter can also be damaged by foreign objects.

ii) Install meters horizontally at the designated location, with the arrow on the lower case facing towards the direction of the flow of water. When meters are not installed horizontally, meter sensitivity and durability can be highly compromised.

iii) Meters should be installed with enough pipe length on both sides of the meter. Inadequate length or bent pipes will affect the accuracy of meters and may also strain the meters. In cases where the length of pipes is too long, it will be necessary to make sure the meters are structurally well supported for stability.

iv) Use gaskets that properly match the diameter of the meters. Instrumental errors may occur when gaskets are projecting inwards.

v) For Woltmann horizontal type, Venturi-tube bypass type and propeller meters, a straight tube should be installed on the upstream of the meter. The straight tube should be at least five times longer that the meter diameter and at least three times longer than the meter diameter on the downstream.

vi) Upon completion of installation, care should be taken to open the stop valve slowly when admitting water for the first time, in order to prevent water hammer.

6.8.2 Maintenance

Maintenance of water meters means making sure that meters remain accurate at all times. It involves always being ready to replace meters.

(1) Maintenance for Accuracy

In order to maintain meter accuracy, the following must be done:

i) Analyse actual consumption based on the data obtained from meter readers on a monthly basis

ii) Conduct surveys to keep track of actual consumption flow rate

iii) Replace meters based on the planned schedule for replacement

(2) Management of Meter Installation

Meters installation should be managed as follows:

i) Ensure that quality certification is properly affixed on the meter

ii) Ensure that meter boxes are not buried in sand or mud

iii) Ensure that meters are installed horizontally to ensure accuracy is maintained during operation

iv) Ensure that there are no leakages around meters

6.8.3 Measures against Meter Theft

In order to prevent theft of meters and metallic meter boxes in developing countries, meters are installed in concrete chambers with heavy hard-to-open concrete lids. This hampers meter reading and leak control activities.

Copolymer material was previously poor but has greatly improved. Hence, copolymer meters and boxes can now be used to replace metallic ones.

Chapter 7

Meter Selection and Commercial Loss Reduction

7.1 Customer Meters

7.1.1 Introduction

Customer water meters provide important basic data necessary for billing and NRW ratio calculation. It is therefore crucial to connect customer meters to each household.

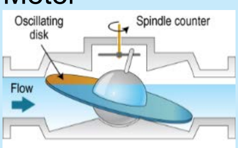
Selecting water meters involves both size and type of meter. Too often, size is chosen merely to match the pipe size; but oversized pipe is often installed to allow for possible future increase in water use or to reduce pressure loss in long pipes. The tendency to install oversize meters is sometimes driven by the desire to use meters large enough to meet the customers' maximum demand and not to incur additional expense in case a small meter becomes inadequate. However, it is recommended to always install the right size meter as the overall commercial loss due to over-size meter can be quite large over time. WSPs should ensure that meter sizing activity is scheduled to ensure the performance of existing meters is review regularly.

a) Meter Type

Four types of water meters used in Kenya are (i) displacement meters, (ii) velocity meters, (iii) UFM and (iv) electro-magnetic Meters.

Table 7.1 briefly describes the types of water meters and their applicability. Table 7.2 elaborates the meter types and lists their merits and demerits.

Table 7.1: Water Meter Technology Options

Meter Type	Description	Applicable under the following conditions
Displacement Meter 	Displacement water meters rely on the water to physically displace the moving measuring element in direct proportion to the amount of water that passes through the meter. The piston or disk moves a magnet that drives the register. There are two main types of displacement meters: nutating disc and oscillating piston (rotary piston).	o Displacement water meters are suitable for low to medium water flow rates with diameters typically ranging from 13 to 50 mm. They tend to be more accurate than velocity meters at low flow rates.

<table>
<tr><th>Meter Type</th><th>Description</th><th>Applicable under the following conditions</th></tr>
<tr><td></td><td></td><td>o Due to its inner structure, displacement meters are sensitive to turbid water. Hence, an external strainer needs to be installed upstream when metering water with considerable amounts of suspended particles. The additional external strainer and the often-in-built sieve/ strainer have to be regularly cleaned.
o In case of high possibility for meter air flow, displacement meters have shown to be less sensitive.</td></tr>
<tr><td>Velocity Meter
</td><td>A velocity meter measures the velocity of the flow through a meter of a known internal capacity. In order to determine the actual consumption, the speed of flow is converted into flow volume. Two main types of velocity meters are used in Kenya: single jet meter and multi-jet meters.
o Single jet meters incorporate a single tangential jet.
o In a multi-jet meter, a tangential opening in the chamber directs the water flow across a multi-vanned rotor. The output speed of the rotor is proportional to the quantity of water passing through the measuring chamber. The meter works mechanically much like a single jet meter except that the flow at the rotor is directed equally from several points, not just one; this minimizes uneven wear on the rotor and its shaft.</td><td>o The single jet meter is applicable for small flow rates (diameters typically range from 15 to 50 mm).
o The multi-jet water meter is suitable for small and medium flow rates (diameters typically range from 15 to 150 mm).
o When metering water with considerable amounts of suspended particles, velocity meters tend to be less prone to clogging compared to displacement meters. This results in less additional effort for servicing. If the specific turbidity level is very high, an additional external strainer should be installed as well. Both, the external strainer and the often-in-built sieve/strainer have to be cleaned regularly.</td></tr>
</table>

Meter Type	Description	Applicable under the following conditions
Ultrasonic Flow Meter 	Ultrasonic Flow Meters (UFMs) use sound waves to determine the velocity of a fluid flowing in a pipe.	o UFMs are mainly used for measurement of bulk flows (diameters typically range from 15 to 1,800 mm) and commonly used as 'clamp-on' meters to calibrate large diameter velocity meters. UFMs are typically supplied with a transducer that can be used in a range from 75 to 1,800 mm. By procuring a second transducer (smaller), the UFM can be used in a range of 15 to 75 mm.
Electro- magnetic Meter 	An electromagnetic meter measures the flow rate of water by its electromagnetic properties instead of measuring it mechanically. The installation configuration should be such, that the transmission main is filled with water at all times (e.g., through installed non return valves).	o Since no moving parts are incorporated, waste water and water even with high number of suspended particles can be metered accurately. o Electromagnetic water meters are more sensitive to low flows. o Its usual diameter ranges from 2 to 1,800mm.

Table 7.2: Merits and Demerits of Common Water Meters Types

Type of Water Meter			Merits	Demerits
Small and Medium Customer Meters	Conventional Mechanical Meter[1]	Volumetric/ Piston	• Sensitive at low flow • Vertical installation is allowed	• Easily clogged by silt, etc. • Over-registers with air • Rather expensive compared to single and multi-jet meters

Type of Water Meter			Merits	Demerits
		Single-Jet	• Low cost	• Deteriorates rather quickly over time (years) • Over-registers with air
		Multi-Jet	• Rather sensitive at low flow	• Deteriorates rather quickly over time (years) • Over-registers with air
	Smart Meters	Mechanical Meter + Data Transmission Unit	• Relatively low cost • Data transmission unit for remote meter reading can be attached later to avoid a large initial investment	• Vulnerable due to attachment of data transmission unit. • Over-registers with air • Often stalls and breaks down due to mechanical parts
		Ultrasonic Flow Meter with Data Transmission Functions	• Robust against meter tampering • Does not stall unless battery runs out	• Very expensive • High flow above cut-off rate at start of supply after shut-down cannot be registered • Under-registers with air
Large Customer and Bulk Meters	With or Without Data Transmission Device	Mechanical (Woltmann) Type	• Low cost • Does not need power (or battery) for measurement	• Relatively low accuracy • Stalls and breaks down due to mechanical parts (Y strainer required for protection) • Over-registers with air

Type of Water Meter			Merits	Demerits
		Ultrasonic (In-line type)[2]	• Does not stall • Relatively sensitive even at low flow	• Relatively high cost • Under-registers with air • Battery often runs out fast
		Electromagnetic (In-line type)	• Does not stall • Higher flows can be measured	• High cost • Under-registers with air • Battery often runs out rather quickly
		Electromagnetic (Insertion type)	• Possible to be installed later on straight pipes • Higher flow can be measured	• Relatively high cost • Difficult to install and maintain accuracy through calibration • Under-registers with air

Notes: *1. Copolymer body is recommended for mechanical customer meters to avoid meter theft.*
2. Clamp-on (not in-line) portable ultrasonic flowmeter is recommended for on-site bulk meter testing

b) Old Meter Classification

Based on ISO 4064:2005 and OMIL R49:2003, water meters can be divided into four classes: A, B, C and D. Each class sets a range of flow rates within which the meter must maintain its accuracy. A has the narrowest range and D is the widest. Each meter can be considered perfect in the range of flow rates for which it is designed.

i) **Class B:** used for low water quality areas since it's not easily affected by sediments.

ii) **Class D:** used where water quality is good since it's easily affected by sediments. It can measure low flow rates. However, it is more expensive than class B.

iii) **Class C:** is a compromise between Class B and D i.e., less affected by silt and can measure low flows better than class B, but it's cheaper than class D.

iv) **Class A:** is not normally used in water supplies in Kenya.

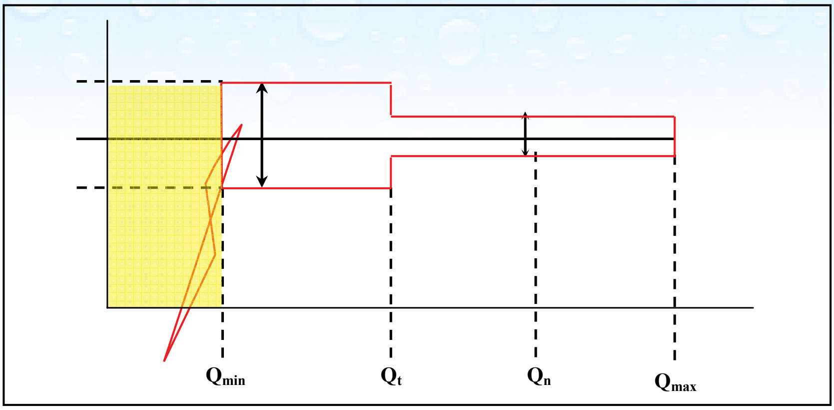


Figure 7.1: Curve of Relative Error in Water Meters

Table 7.3: Water Meter Classification (Flow rates in Litres/Hour)

Nominal dia, mm (inch)			Class A		Class B		Class C		Class D	
	Q_n	Q_{max}	Q_{min}	Q_t	Q_{min}	Q_t	Qmin	Q_t	Q_{min}	Q_t
15 (½”) V	1,000	2,000	-	-	-	-	-	-	7.5	11.5
15 (½”) H	1,500	3,000	60	150	30	120	15	22.5	11.25	17.25
20 (¾”) H	2,500	5,000	100	250	50	200	25	37.5	18.75	28.75
25 (1”) V	3,500	7,000	140	350	70	280	35	52.5	26.25	40.25
25 (1”) H	6,000	12,000	240	600	120	480	60	90	-	-
32 (1¼) H	6,000	12,000	240	600	120	480	60	90	-	-
40 (1½) H	10,000	20,000	400	1000	200	800	100	150	-	-

Key

- V-Vertically installed (for volumetric meters only); H - Horizontally installed
- Minimum flowrate (Qmin) - The lowest flow rate at which the water meter is required to operate within the maximum permissible error.
- Transitional flowrate (Qt) - Flow rate which occurs between the nominal flow rate and the minimum flow rate and that divides the flow rates into two zones, the upper flow rate zone and the lower flow rate zone, each characterized by its own maximum permissible error.
- Nominal flowrate (Qn) - The highest flow rate within the rated operating conditions at which the water meter is required to operate in a satisfactory manner within the maximum permissible error.
- Maximum flowrate (Qmax) - The highest flow rate at which the water meter is required to operate for a short period of time within its maximum permissible error whilst maintaining its metrological performance when it is subsequently operated within its rated operating conditions.

Note:

(1) Qn and Qmax remain constant across the classes and only Qmin and Qt decrease from Class A towards D, thereby widening the accurate range.

(2) Between Qmin and Qt, the meter accuracy is ±5%. From Qt to Qmax the accuracy is ±2

(3) Vertically installed meters have a shorter accurate range hence cause higher NRW and are easily overloaded and damaged than horizontally installed.

Class B was the most commonly used due to its acceptable minimum flowrate and affordability.

This classification by ISO 4064:2005 is no longer in force and it has been replaced by OIML R49:2013.

c) New Water Meter Classification (R-Series)

In the latest standards (ISO 4064:2014 and OIML R49:2013), a new system based on the Reynard series was established and the flowrates on Figure 7.1 renamed as follows: Qmin → Q1, Qt → Q2, Qn→ Q3, and Qmax→ Q4; but the system yields completely different values.

Also note that values of “Q3” and “R” (R = ratio Q3/Q1) are marked on the meter instead of the old system where Qn and Qmax were the values marked.

The value of the normal flow Q3 shall be chosen from Table 7.4.

Table 7.4: Value of normal flow, Q3 (in m3/hr)

1	1.6	2.5	4	6.3
10	16	25	40	63
100	160	250	400	630
1,000	1,600	2,500	4,000	6,300

The value of the ratio R (R = Q3/Q1) shall be chosen from Table 7.5.

Table 7.5: Value of Ratio R (R = Q3/Q1)

40	50	63	80	100
125	160	200	250	315
400	500	630	800	1,000

Further, the values of Q2 and Q4 shall be as per the formulas below:

Q2 = 1.6Q_1

Q4 = 1.25Q_3

Note: The WSP has to decide on the value of R and Q^3 from the tables above. The higher the R value for the same Q_3 value, the lower the Q_1 and Q_2 values hence the more the accuracy of the meter. But the value of Q_4 remains the same.

Example 1: Let us assume 15mm diameter class B meter (old classification system) is subjected to the new system analysis, taking R=200:

Q3 = Qn = 1.5 m3/h

Therefore, Q1 = Q3/R

Q1 = (1.5 x 1000)/200	= 7.5 lts/h (compare with Qmin = 30 lts/hr – Table 7.3)
Q2 = 1.6 x 7.5	= 12 lts/hr (compare with Qmin = 120 lts/hr)
Q4 = 1.25 x 1.5	= 1.875 m3/hr (compare with Qmin = 3m3/hr)

From the above calculation, choosing Q3 = 1.5 and R = 200 yields a more accurate meter than class B but fairly low maximum flowrate compared to class B.

Example 2: Let us assume that we need a 15mm diameter meter with Q_4 that is similar to Q_{max} of 15mm diameter class B meter i.e., Q_{max} = 3m^3/hr), keeping R=200:

The value of Q_3 must be more than 1.5m^3/hr used in example 1 above. Let us take the next Q^3 value on Table 7.3 = 2.5 m^3/hr

Q_3 = Qn =2.5 m^3/hr

Therefore, Q_1 = Q_3/R

Q_1 = (2.5 x 1000)/200 = 12.5 lts/hr (compare with Qmin = 30 lts/hr – Table 7.3)

Q_2 = 1.6 x 12.5	= 20 lts/hr (compare with Q_{min} = 120 lts/hr)
Q_4 = 1.25 x 2.5	= 3.125 m^3/hr (compare with Q_{min} = 3m^3/hr)

From the above calculation, choosing Q_3 = 2.5 and R = 200 yields a more accurate meter than class B but maximum flowrate is equivalent to 15mm diameter class B meter.

The same calculation can be carried out using other values from Table 7.4 and Table 7.5 to come up with other meter sizes, accuracy and capacity including bulk meters.

It is important to note that the two tables do not specify the diameter of the meter and the WSP is free to decide.

However, WSPs should carry out market surveys to find out whether the meter design they have decided on is easily available in the market.

From the examples above, it is clear that it is not easy to compare meters under R-series and Precision system on a table and any confirmation has to be through calculation.

Under the old classification system, class B is the most commonly used meter and its performance is satisfactory under the prevailing conditions.

An equivalent size 15mm diameter meter to class B under R-series is R250 and Q_3 = 2.5 m^3/hr as shown in example 2 above.

7.1.2 Selection of Customer Water Meters

In selecting customer water meters, it is important to select the meter that is most suitable for the consumption trend of each customer. Considerations to the maximum monthly consumption and maximum flow rate are important for selecting a meter that will assure steady performance for a long period of time.

The following are the criteria to use when selecting meters:

a) Material used in meter construction

Meters are made from brass, copolymer resin, cast iron, electronic, etc. Metallic meters are more prone to theft in Kenya. As a result, some WSPs install copolymer resin meters instead.

Figure 7.2(a): Metallic Type

Figure 7.2(b): copolymer resin meter

Figure 7.2 shows the various types of customer meters. Metallic water meters are better in terms of accuracy and durability, but they are more expensive and prone to theft. On the other hand, copolymer resin water meters are cheaper and have a low vulnerability to theft but relatively less durable.

b) Using consumption data to size customer meters

Undersize meters can cause huge NRW especially when used for customers that consume large volumes of water because of under-registering during low flowrate periods. Proper sizing (or resizing) of meters, especially for large and medium non-domestic customers, is therefore quite important.

In order to correctly size customer meters, typical consumption patterns must be summarized and the monthly maximum and minimum consumption determined.

Table 7.6 is a guide on meter sizing (or resizing)

Table 7.6: Meter Sizing based on Maximum Monthly Consumption that Each Meter Size Can Handle

Meter Size (DN)		**Nominal Flow (m^3/hr)**	**Meter Capacity (m^3/hr)**	**Maximum Monthly Consumption (m3/connection/month) that Each Meter Size Can Handle for Each Assumed Total Time of Passing Water Listed Below**						
inch	mm	ISO: Qn (or OIML: Q_3)	Required Qmax (or Q4)[5]	Assumed Total Time Each Customer Takes Water Through Meter (Heavily Intermittent ← Common Intermittent → Continuous)						
				0.5 hr/ day3	0.75 hr/ day	1 hr/day[2]	1.5 hr/day	2 hr/day	4 hr/day[4]	8 hr/day
1/2	15	1.5 (2.4)	3 (3.125)	45	68	90	135	180	360	720
3/4	20	2.5 (4)	5 (5)	75	113	150	225	300	600	1,200
1	25	3.5 (6.3)	7 (7.875)	105	158	210	315	420	840	1,680
1.25	32	6 (10)	12 (12.5)	180	270	360	540	720	1,440	2,880
1.5	40	10 (16)	20 (20)	300	450	600	900	1,200	2,400	4,800
2 (m)1	50	15 (25)	30 (31.25)	450	675	900	1,350	1,800	3,600	7,200
2 (u)	50	25 (40)	50 (50)	750	1,125	1,500	2,250	3,000	6,000	12,000
3 (m,u)	80	40 (63)	80 (78.75)	1,200	1,800	2,400	3,600	4,800	9,600	19,200
4 (m,u)	100	60 (100)	120 (125)	1,800	2,700	3,600	5,400	7,200	14,400	28,800
6 (m,u)	150	150 (250)	300 (312.5)	4,500	6,750	9,000	13,500	18,000	36,000	72,000
8 (m,u)	200	250 (400)	500 (500)	7,500	11,250	15,000	22,500	30,000	60,000	120,000

Notes 1: The values for meter size 2-inch (50mm) and larger are for flanged mechanical (m) bulk meters (specifically Woltmann type) and ultrasonic (u) bulk meters.

Note 2: 1 hr/day is recommended as the period a non-domestic customer takes water under intermittent (rationing) water conditions that is common in Kenya. During this period, non-domestic customers refill their water receiving tanks within a limited time when water becomes available after the daily rationing period. Since meter size 0.5 inch (15mm) is sufficient for almost all domestic customers, this table is not very relevant for sizing domestic customers' meters. However, 1 hr/day can also be recommended for domestic customers if the following daily water use is assumed: showering 5 persons x 5 mins, cistern flashing 5 persons x 3 mins, dishwashing 2 times x 5 mins, laundry and cleaning 10 mins (i.e., total = 1 hour/day).

Note 3: 0.5 hr/day may be applied for non-domestic customers under water rationing conditions such as getting water for a limited time every two days; hence, they have to fill their water tanks quickly within a very limited time every two days before the supply to their area ends.

Note 4: 4 hours/day may be applied for non-domestic customers under continuous water supply conditions in which they may take water from the distribution network for 4 hrs/day (i.e., half of 8hrs, the common business operating hours).

Note 5: If a high-performance meter capable of measuring higher than the standard value of Qmax is used, then meter sizing should be based on the actual Qmax. E.g., the Qmax of electromagnetic flowmeters can be much higher than the standard values shown in the table, hence calculate the maximum monthly consumption which the meter can handle based on the actual Qmax of such a meter (i.e., maximum monthly consumption the meter can handle (m3/month) = Actual Qmax (m3/hr) x hours of taking water (hr/day) x 30 (days/month)).

- Firstly, assume or estimate the number of hours in a day a customer would take water through the meter, and
- The amount of water each customer will consume per month based on experience and data obtained from the same or similar areas.
- From Table 7.6, determine the appropriate meter size for the assumed monthly consumption and hours of taking water.

Intermittent (rationing) water supply is predominant in most WSPs in Kenya. Therefore, to select the required meter size for each customer, it is recommended to assume that the total duration a customer takes water through the meter over a 24hr period as 1 hour/day as explained in Note 2.

Most normal domestic customers consume below 30m3/month. From the table, meter size ½" (15mm) can handle upto 90m3/month hence it's quite adequate.

Therefore, domestic customers should mostly be installed with meter size ½" (15mm).

Table 7.6 is therefore useful when sizing meters for medium and large customers.

c) Smart Metering

Meters can be upgraded by incorporating an automatic meter reading (AMR) device (that reads and stores data in memory card) onto any mechanical or other meter. The meter then becomes "smart".

The data can be retrieved by use of a data cable onto a computer or by a data communication module

Communication with the meter (to retrieve data or issue command) can be done using any kind of protocol such as GSM/GPRS mobile phone network (most common).

AnAMR is the technology of automatically collecting consumption, diagnostic, and status data from water (or electric, etc) meter and transferring that data to a central database for billing, troubleshooting, and analysing. This technology mainly saves a utility the expense of periodic trips to each physical location to read a meter.

Another advantage is that billing can be based on near real-time consumption rather than on estimates (based on past or predicted consumption). This timely information coupled with analysis can help both the WSP and customers control water consumption better.

AMR technologies include handheld, mobile and network technologies based on telephony platforms (wired and wireless), radio frequency (RF), or powerline transmission.

Figure 7.3 is a diagram of an AMR system. However, due to the specialized nature of the system, these guidelines cannot go into details and other suitable source of information is advised.

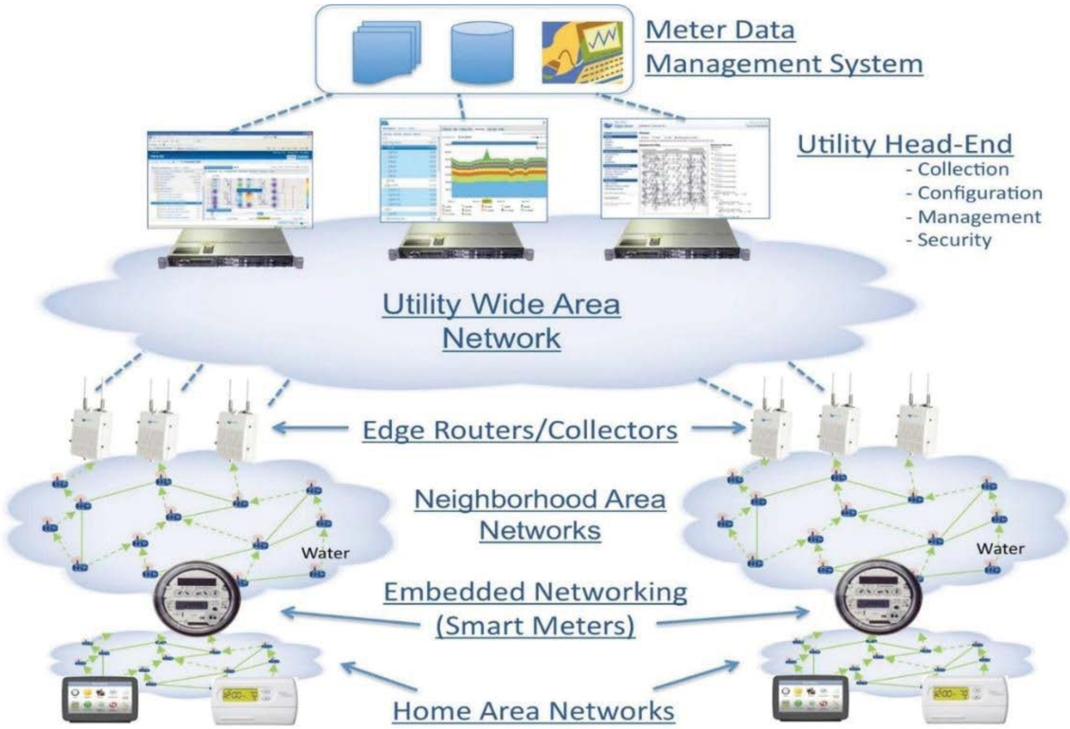


Figure 7.3: Typical AMR (Smart meter reading) system

7.1.3 Metering Objectives and Installation Site Considerations

Selecting the right meter requires identifying and addressing the considerations that may be unique to each metering objective and installation conditions as below:

a) Metering Objective

A meter needs to address objectives such as:

- Operational improvements – e.g., install smart meters to curb meter tampering
- Support water management initiatives and goals - e.g., billing and water bill verification from unmetered connections
- Water conservation programs and goals - metered data required to monitor consumption and costs review

b) Installation Site Consideration

- Determine the expected range of water flow and pipe size
- Determine the accuracy requirements over the flow range
- Identify any physical installation requirements for meter location, straight length of pipe, available communications (access road)
- Consider standardization on communication between meters and other data acquisition systems
- Determine how the data will be collected and processed
- Select and install the meter.

7.2 Meter Accuracy Test

7.2.1 Program of tests applicable to all water meters

All meters should undergo the following program of tests. Meters that pass this program should be considered safe to use.

Meter Test Programme

a)	Static pressure	e)	Flow reversal
b)	Error of indication	f)	Pressure loss
c)	Water temperature	g)	Discontinuous flow durability
d)	Water pressure	h)	Continuous flow durability

a) Static Pressure Test

Maximum permissible pressure is desirable to be 1.0 MPa including verification that there are no leakages.

b) Error of Indication Test

Error of indication should be used to determine meter accuracy. Although this is a program, each individual test must be thoroughly understood independently. Error of Indication test will be revisited with Meter Accuracy Test.

To test the relative error, the fundamental requirement is to maintain pressure constant. The tolerable range of pressure oscillation depends on the test method, but it should be maintained in the range of ±2.5%～±5.0%. To test the relative error in a specific meter, test of intrinsic errors is conducted with 7 points of flows and the measurement is conducted twice.

c) Water Temperature Test

Under standard conditions, the standard temperature is 20°C, and the test is conducted under 30°C.

d) Water Pressure Test

Minimum permissible pressure must be 0.03 MPa (0.3 bar) while the maximum permissible pressure must be at least 1 MPa (10 bar), except for meters of DN ≥ 500, where the maximum admissible pressure shall be at least 0.6 MPa (6 bar) (refer BS EN ISO 4064-1:2014).

e) Flow Reversal Test

The tolerance for this test is the same as the tolerance for normal flow.

f) Pressure Loss Test

Pressure loss within flow range from Q_{min} to Q_n should not exceed 0.063 MPa.

g) Discontinuous Flow Durability Test

This is the number of interruptions created in 100,000 with 15 seconds intervals.

h) Continuous Flow Durability Test

There may be variances in duration of durability test depending on the volume of maximum flow; however, the standard for 15 mm diameter meter is 100 hours.

7.2.2 Meter Accuracy Test

a) Relative error

Relative error occurs when volume of water measured by meters compared with the real volume of water shows excess or less volume. As the ISO Standard, relative error could be represented in percentage calculated as follows:

$$\text{Relative error E (\%)} = \frac{I - Q}{Q} \times 100$$

Where:

I: Indicated volume

Q: Real volume

b) Sensible water curve and relative error

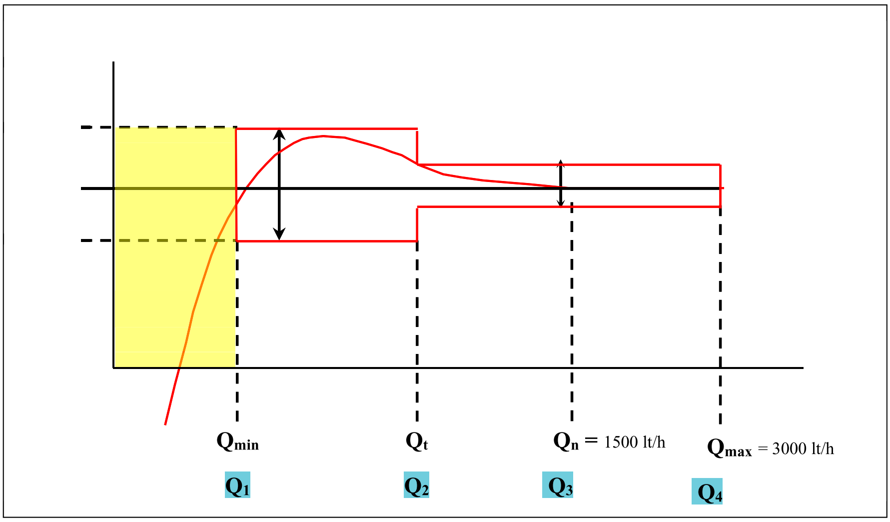


Figure 7.4: Curve of Relative Error in 15mm-dia Class C Meters

Where:

Q_{min} or Q_1 = Minimum flow

Q_t or Q_2 = Transitional flow

Q_n or Q_3 = Normal/Permanent flow

Q_{max} or Q_4 = Maximum/Overload flow

Metrological Requirements of Water Meter Classification

Before conducting a meter test, it is important to understand class specifications of each meter. Under the old classification (Class A, B, C and D) flowrates are denoted as Minimum flow (Q_{min}), Transition flow (Q_t), Normal or Permanent flow (Q_n) and Maximum or Overload flow (Qmax) (Section 7.1.2(d)). Q_n and Q_{max} are marked on the meter. Q_{min} and Q_t are normally derived from characteristic performance curves of the meter.

In the latest standards, ISO 4064:2014 and OIML R49:2013, a new system based on the Reynard (R-series) was established. Minimum flow (Q_1), Transition flow (Q_2), Normal or Permanent flow (Q3) and Maximum or Overload flow (Q4) (Section 7.1.2(e)). A number called Reynard, R (= Q_3/Q_1) together with Q_3 are marked on the meter. $Q_2 = 1.6Q_1$ while $Q_4 = 1.25Q_3$.

Figure 7.5: Water meter test bench

Approximately 10% of all water meters in a target area should be randomly selected for meter testing. The selected water meters should be categorized by class. Meters in Q_{min} (Q_1) to Q_t (Q_2) flow range must operate within 5% of specified tolerance. Meters in Q_t (Q_2) to Q_n (Q_3) to Qmax (Q_4) flow range must operate within 2% of specified tolerance.

c) Meter Class

Based on ISO 4064:2005 and OMIL R49:2003, water meters can be divided into four classes: A, B, C and D. Each class sets a range of flow rates within which the meter must maintain its accuracy. A is the narrowest, D is the widest. Each meter can be considered perfect in the range of flow rates for which it is designed.

However, in the latest standards, ISO 4064:2014 and OIML R49:2013, a new system based on the Reynard series was established. The Reynard number R, is determined by the ratio between permanent flow (Q3) and minimum flow rate (Q1).

7.3 Servicing and Replacement of Customer Meters

7.3.1 Meter Maintenance

Maintenance of water meters involves making sure that meters maintain accuracy and being ready to replace meters at all times.

a) Meter Maintenance for Accuracy

In order to maintain meter accuracy, the following must be done:

i) Analyse actual consumption based on data obtained from meter readings on a monthly basis

ii) Conduct surveys to keep track of actual consumption rates

iii) Replace meters based on planned replacement schedule

b) Management of Meter Installation

Meter installation should be managed by the following:

i) Ensure that meter boxes are not buried in sand or mud

ii) Ensure that meters are installed horizontally

iii) Check that there are no leakages around meters

iv) Check that quality certification is properly affixed on the meter

7.3.2 Expired Water Meters

Expiry date of water meters is established in accordance with the weights and measures Law. For example, in Japan, water meters expire eight (8) years from the date of installation. Expiry of meters is not regulated in Kenya. It is therefore recommended that WSPs start documenting the lifespan of the various meter models and use this data for future decision-making not only in meter expiry period but also during procurement.

7.3.3 Replacement of Defective Meters

In developed countries, customer meters are required, by law, to be replaced periodically (in Japan, customer meters must be replaced with new meters every eight (8) years whether the meter is malfunctioning or not).

Replacement of meters is not regulated by law in developing countries. Furthermore, low quality meters, cheap new meters and even used meters are sold in the market. Cases of recycled meters being installed as replacements is not uncommon.

Customer meters are the most important element for any utility; therefore, it is important to install customer meters that will give high performance and a long life. Using cheap and inferior new meters may seem economical. However, in the long run it will prove to be costly as it will not last long and accuracy is compromised.

Before replacement of defective meters, a “Notification for Replacement of Expired Water Meter”, and “Schedule for Replacement of Expired Water Meters” must be issued to the client whose meter is due for replacement. The schedule for meter replacements must be formulated by the relevant department in the utility and the meter replacements must be conducted in accordance with this schedule.

7.4 Improvement of Meter Reading and Billing System

1) A robust computerized meter reading/billing system with high data handling and reporting capabilities should be used for identifying stalled meters and possible illegal water uses (based on its abnormality reports) as well as for improving work efficiency and reducing data handling errors.

2) Updating and cleaning of customer data register in meter reading and billing system should be done (e.g., registration of illegal/unbilled water users identified through CIS and cleaning of previous customers having outstanding balances).

3) Hand-held meter reading devices (e.g., smartphones with meter reading software program linked to meter reading/billing system) should be used to improve meter reading accuracy and reduce data handing errors.

4) Rotation of meter readers’ routes (e.g., every 6 months) should be effectively done to reduce corruption and inaccurate meter reading.

5) Spot check of meter readings (e.g., by meter reading supervisor) and systematic validation of meter readings (e.g., automatically by a software system or manually by system operators) should be effectively done to improve meter reading accuracy.

6) The accuracy of estimated customer consumption (when required) should be improved by estimating based on reliable past consumption in order to reduce NRW resulting from improper estimation.

7) Warning and disciplinary action on staff who intentionally continue submitting wrong meter readings or unjustifiable underestimation of consumption should be exercised in order to reduce staff involvement in wrongdoing.

7.5 Improvement of Billing Software Utilization

7.5.1 Sorting Billing Anomalies on the Basis of Consumption

Most of the very large and large WSPs use sophisticated meter reading and billing software (e.g., Majics, ERP) which have meter-related anomalies reports. Nevertheless, many WSPs have too many stalled meters to handle in one month. This results to the anomalies report on stalled meters not being resolved on the basis of the billed (including estimated) consumption. This therefore causes difficulties in prioritizing the stalled meters of large (e.g., ≧ 100 m3/month) and medium (e.g., ≧ 20 m3/month) customers for meter servicing and replacement.

In such cases, the billing system administrator should, each month, export the billing data of each customer (including anomalies, billed consumption and billed amount in Ksh) to MS Excel (through .csv files) for the NRW Unit/Section to prioritize large and medium customers for meter servicing and replacement. These data (together with customers' contact information and their coordinates) may be extracted directly from the billing system by using free relational database management software such as MySQL and PostgreSQL for quick action. This simple improvement can make a huge reduction in NRW and a drastically revenue increase.

7.5.2 Rules for Estimating Consumption

In cases of meter stops, a policy for estimating consumption should be formulated and applied (e.g., average of the last three properly measured monthly consumption). Such a policy is not well formulated in the billing systems and many WSPs are forced to estimate manually. Manual estimation tends to underestimate consumption, resulting in huge revenue losses. Therefore, the automatic (billing system) and manual (billing clerk) estimates should be carefully reviewed as part of NRW reduction efforts.

The meter-related anomalies (e.g., meter reversing or meter tampering) reported by meter readers are quite useful to reduce metering errors and eliminate illegal water use. However, resolving anomalies of the active customers is not enough to effectively reduce illegal water use. Illegal water use often happens when disconnected customers illegally reconnect. Therefore, checking disconnected customers (by regularly reading their meters and investigating for possible illegal connections) is important.

However, the status of each customer connection (e.g., active, disconnected, terminated, etc.) in the billing system is often outdated, which make it very difficult for the NRW Unit/Section to detect suspicious customers who may have illegally reconnected. To reduce illegal water-use by disconnected customers, the connection status of each customer should be updated every month in the billing system.

7.5.3 Other problems

Other NRW-related problems observed in WSPs' billing systems are:

- Mis-categorization of non-domestic customers as domestic customers. These are the most serious issues because incorrect use of domestic water tariff by non-domestic customers reduces the revenue substantially.
- Miscalculation of total billed consumption,
- Errors in entering customer account numbers in the billing system,
- Outdated meter reading routes (or walk numbers) of some customers, etc.

7.6 Internal Improvements against Illegal Water Use

1) WSP's policies against illegal water use (e.g., heavy penalties) should be well incorporated in the county water act and/or supported by the county government.
2) Enhancement of law enforcement against water theft should be well supported on the ground by the county.
3) Effective legal procedures including settlement with illegal water users should be well established with strong support from the management.
4) Each occurrence of illegal water use should be quantified through a well-defined and documented formula (e.g., period water illegally used x typical flow (including analysis of the number and scale of illegal water uses)) or other transparent method for imposing illegal water use charge including a substantially deterrent penalty.
5) Prevention measures against involvement of WSP staff (e.g., plumbers and meter readers involved in illegal connections, meter bypass, meter tampering, etc) should be well established through better materials, stock management, interrogation of illegal users on their accomplices, etc.
6) Incentives for whistle blowers to report illegal use and vandalism to the water supply facilities should be well established.

Chapter 8

Reduction of Physical (Real) Water Losses

8.1 Components of Physical Losses

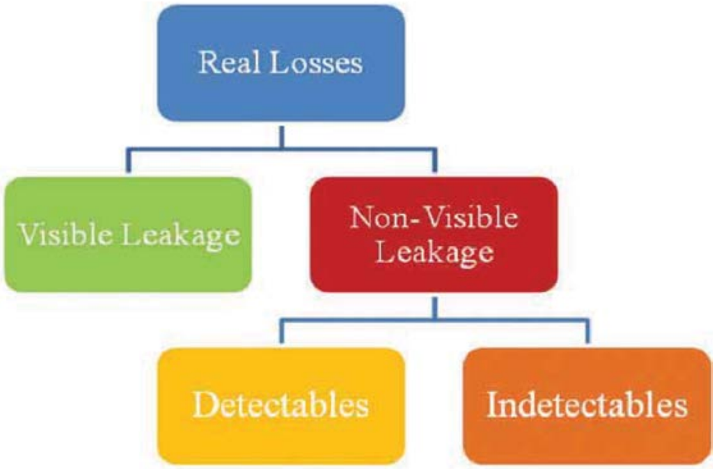


Figure 8.1: Component of Physical Losses

Physical Losses can be divided into visible leakage (surface leakage) and invisible leakage (underground leakage). Surface leakages occur in areas with high water pressure, whereas underground leakage occur in areas with low water pressure and therefore difficult to detect. In general, more leakages occur in service pipes compared to distribution pipes.

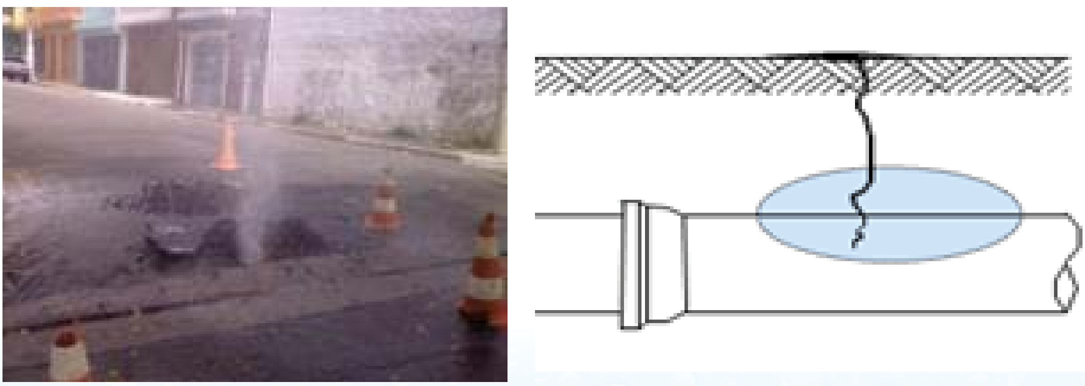


Figure 8.2: Visible Leakage (Surface leakage)

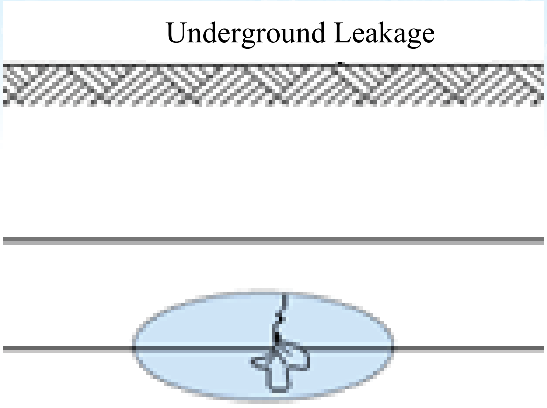


Figure 8.3: Underground (Invisible) Leakage

Generally, a leakage starts off as a small leak that develops into a medium then to a large leak as time passes. Small leaks may remain undetected underground for a long time. In cases of medium size leaks, some may stay undetected, but others will surface to the ground. Most large size leaks are detected on the surface within a few days of the leak appearing up to several months. Some leaks may remain underground for years or forever. This all depends on the surrounding conditions of the laid pipes such as the condition or type of soil, presence of underground structures, and pipe material.

Repairing surface leakages alone cannot reduce NRW ratio when the ratio is less than 30%. In order to decrease this ratio, underground leakages must be detected and repaired. Underground leakages can go without repair since they are difficult to detect, and underground leakages often overwhelmingly exceed the number of surface leakages by more than ten times.

Thicker pavements on roads usually indicate a higher ground water level, which indicates lower water pressure in the buried pipes. Detection of underground leakages become more difficult as depth of buried pipes increases.

When leakages occur, extending the area of repair around the point of leakage will decrease recurring leakages around the same area. Planning for replacement of pipes must take into consideration the number of leakage repairs in the pipe and the age of pipes.

8.2 Main Causes of Physical Losses

Leaks can occur anywhere in the pipeline due to various factors such as age of pipes and traffic loads on the road. Table 8.1 shows the factors that can cause leakages (physical losses).

Table 8.1: Main Causes of Physical Losses

Causes of Physical Losses	
Factors	**Causes**
Poor quality of pipe material and accessories (fittings)	• Material and/or mechanical defects • Lack of corrosion resistance • Age and/or deterioration • Galvanic corrosion
Technicality in pipe laying or poor workmanship.	• Design errors • Poor jointing of pipes • Inappropriate backfilling • Contact with other structural objects • Defective corrosion protection methods
Poor Conditions	• Unsuitable water pressure (usually high pressure) • Water Hammer • Water quality (internal corrosion)
Environment of underground pipes	• Increase in traffic loads • Corrosive soils such as marine clay • Ground subsidence caused by excessive pumping etc. • Effects of other construction works
Human interference	• Vandalism • Construction works, e.g., roadworks

8.3 Reduction Measures for Physical Losses

Table 8.2 shows measures to reduce physical losses.

Table 8.2 Reduction Measures for Physical Losses

Measures		Activities
Pipe Work	Pipe Mapping	• Development of accurate pipeline drawing (Refer to Chapter 4)
	Zoning	• Determination of DMA or measurement blocks • Isolation of measurement blocks (Refer to Chapter 5)
	Taking Measurements	• Understanding leakage volume in measurement blocks by measuring MNF and implementing Step-Test (Refer to Chapter 8)
	Leak Detection	• Detection of leakages by using leak detector (Refer to Chapter 9)
	Leak Repair & appurtenance maintenance	• Adoption of optimum leakage repair method and good quality materials • Adoption of appurtenance maintenance scheduling

Measures		Activities
Pipe Replacement	Planning	● Preparation of pipe replacement plan based on statistical analysis of the Pipeline network. ● Determine correct pipe type and pipe diameter
	Implementation	● Implementation of pipe replacement
Water Pressure Control	Pressure equalization (Refer to Chapter 10)	● Zoning of distribution network ● Installation of PRVs ● Installation of Flow Meters and Pressure gauges
	Setting up Pressure Control facilities	● Construction of distribution reservoirs and/or pumping station
	Pressure Control at pumping station	● Pressure control by proper pump sizing

8.4 Quantifying Physical Losses

8.4.1 General

In order to control leakages, it is a basic requirement for WSPs to know the existing leakage volume of the target leak survey area. Based on the existing leakage volume, the most appropriate and effective pipeline maintenance strategy can be established. At the same time, leak survey blocks can be selected; best maintenance methods can be determined whether it be simply repairing of pipes or total replacement of pipes and overall improved effective control of leakages can be implemented.

Leakage volume can be measured by the following methods: -

a) Estimation Method, by collecting leakage volume at the actual leakage point

b) Direct Measurement Method

c) Minimum Night Flow (MNF) Measurement

8.4.2 Estimation Method by collecting leakage volume at the actual leakage point

Leakage volume per minute can be established by measuring the actual leakage at the leakage point. By multiplying this value by the number of leakage points, the leakage volume of the target area can be estimated as follows:

Total annual volume of leakage = Number of reported bursts x Average leak flow rate x Average leak duration from mains

If no detailed data is available, utility managers can use approximate flow rates from Table 8.3 below.

Table 8.3: Approximate Flow Rates of Leakages/Bursts

Location of burst	Flow rate for reported bursts (l/hr/m pressure)	Flow rate for unreported burst (l/hr/m pressure)
Mains	240	120
Service connection	32	32

Source: IWA Water Loss Task Force

Utility managers can then add estimates for background losses and excess losses (current undetected leaks). Background losses are individual events (i.e., small leaks and weeping joints) that flow at rates too low for detection by an active leak detection survey. They are finally detected either by chance or after they have worsened to the point that only an active leak detection survey can discover them. Table 8.4 shows background losses from various components of the network with average infrastructure condition.

Table 8.4: Calculating Background Losses

Location of Bursts	**Litres**	**Unit of measurement**
Mains	9.6	Litres per km of mains per day per metre of pressure
Service connection: mains to property boundary	0.6	Litres per service connection per day per metre of pressure
Service connection: Property boundary to customer meter	16	Litres per km of service connection per day per metre of pressure

Source: IWA Water Loss Task Force

Leakage measurement is shown in Figure 8.4

Figure 8.4: Measurement at Actual Leakage Point

8.4.3 Direct Measurement (DM) Method

To measure leakage using the Direct Measurement Method, a measuring block consisting of approximately 3 to 5 km of distribution pipes and/or 100 to 500 customer meters needs to be selected. All peripheral valves in the measuring block as well as all customer valves must be closed. The flow rate into the measuring block is then measured at one point. It is preferable to conduct this method after midnight to avoid inconveniencing customers.

This method is time consuming and requires manpower and this makes it unpopular among WSPs.

Figure 8.5: Close all peripheral valves of the block and all the customer valves completely

Figure 8.6: Measure the flow volume into the block

8.4.4 Minimum Night Flow Measurement Method

Figure 8.7 shows a typical Water Demand Characteristic Curve. Water demand varies with respect to the time of day. Diurnal peaks typically occur in the morning and in the early evening, while lowest water usage occurs during night hours.

By studying the Minimum Flow of this diagram, it is possible to estimate the volume of water leakage.

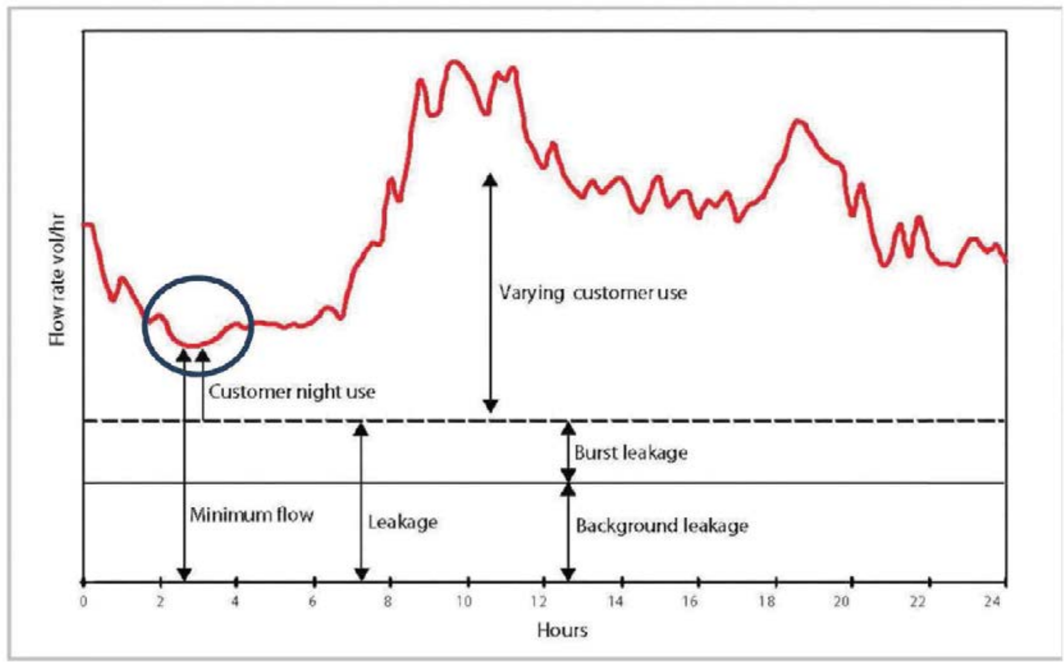


Figure 8.7: Typical Water Demand Characteristic Curve

MNF measurement method in NRW Management refers to a method of estimating the volume of leakage within a target area or a pilot area by accurately measuring the Minimum Night Flow (MNF). In a pilot area, MNF normally occurs between 1:00 am and 4:00 am. It is only necessary to accurately measure the volume of water flow during this particular time period. When mechanical flow meters are used for measuring, it is better to have shorter measuring periods, for example 10 minutes. The results of the reading should be put on a graph and the lowest point on the graph is the MNF. This method of measuring the volume of water flow does not require closing the customer meter valves. Therefore, there is no interruption of the water supply. Using an electro-magnetic flow meter or an ultrasonic flow meter can increase the accuracy of the readings. When implementing the MNF measurement, it is important to have the target area or the pilot area perfectly isolated from the adjoining areas. In general, the adequate size of a leak survey is considered to be 700 to 1,500 households, or 2,100 to 5,000 persons.

Based on the results obtained from the MNF Measurement, NRW Reduction measures should be implemented. Measurement “Before” and “After” the implementation of measures should be recorded to understand the effectiveness of the measures applied.

8.5 Reduction of Visible Leaks by Active Patrolling and Quick Quality Repair

1) Overflow from water retaining facilities such as distribution tanks/reservoirs and break-pressure tanks (BPT) should be reduced; e.g., by:

i) improving the operation of transmission pumps

ii) detecting whether tanks/reservoirs are leaking by observing water-level-gauge for 24 hours with closed inlet and outlet valves after filling up the reservoir,

iii) preventing tampering of BPTs/tanks float valves by locking lids with tamper-proof keys and regularly maintaining the valves, etc.

2) Active patrolling along pipelines should be adequately done for early detection of visible (surface) leaks from sluice valve, air valve, hydrant, wash-outs, exposed and buried pipes; and storage tanks/BPTs, etc; and water theft including illegal connections. (These patrols may simultaneously cover other aspects irrelevant to NRW such as sewage overflow and water quality problems to improve overall work efficiency of the WSP)

3) Customers should be advised well to stop overflows from their water tanks and visible leakage from the part of service pipes after customer meters to save water as WSP staff are patrolling along pipelines or working around customer meters.

4) The speed and quality of burst and leak repairs should be improved (e.g., by adopting optimum leakage repair methods, using cloud-based/online workflow/ task management system, etc)

5) Reports of bursts and visible leaks from the public and all WSP staff should be well registered and responded to without failure through improvement and utilization of relevant ICT system (e.g., WASREB's MajiVoice, WSP's customer care system, supervisors, etc).

6) Detailed records of bursts and leaks including GPS coordinates, pipe diameter, material, type and cause of burst/leak, amount of water loss, date of detection, time taken for repair, etc should be accumulated (e.g., by using free data collection software such as Kobo Toolbox/Collect) to analyse them later with tables, graphs and GIS.

8.6 Daily Use of Low-Cost Listening Sticks and Hand Pumps for Leak Detection

1) Listening sticks (also called sounding bars) should be used daily and extensively (by field staff in charge of initial installation, customer meter servicing and replacement staff, NRW task team, meter readers, etc) at and around customer meters to detect abnormal sound of invisible leakage (and/or illegal connections). Electrical leak detection equipment may be used to confirm the existence and location of suspected leaks and illegal connections.

2) Listening sticks should be used daily (by O&M staff) at appurtenances on transmission and distribution pipelines (to detect abnormal sound hinting at

invisible leakage from valves and hydrants, to locate buried valves and, to check water tightness of valves). Electrical leak detection equipment may be used to confirm the existence and location of suspected leaks.

3) Listening sticks should be used (e.g., by the staff in charge of disconnection and reconnection of customers) when investigating potential illegal water use at disconnected customers

   Note:

   - A listening stick can be used to check whether there is water flow for customer meters that have zero consumption on previously disconnected service pipes. The flow can then be investigated as to whether it is due to completely stopped faulty meters or not and whether the disconnected connection is illegally self-reconnected or not.
   - Illegally self-reconnected customers with stopped meters cause large amounts of illegal water use without being noticed for a long time.
   - Unsuccessful disconnections with faulty gate valves or stopcocks that do not close fully and stopped meters cause large commercial water losses without being noticed and for long periods.

4) Listening sticks should be used to detect leaks where new distribution pipelines of relatively small diameter are tested under pressure with hand pumps during installation to confirm non-existence of leaks from the pipelines

5) Larger pipelines including transmission lines should be tested at installation probably by the contractor with a powered pump.

6) The data collected should be analysed and remedial measures taken to prevent future recurrence.

8.7 Introduction of Quality Materials, Adequate Valves, and Small-Scale Pipe Replacement

1) Adequate sluice valves (AVK type or equivalent, but not brass gate valves which are commonly used and that are prone to leakage) should be installed on transmission and distribution pipelines and kept accessible and operational to:

   i) limit the volume of water losses, e.g., when draining the pipelines for burst and leak repairs which often require suspension of water supply,

   ii) limit the areas affected by the intermittent water supply, and

   iii) evenly distribute water to different areas especially under intermittent water supply conditions

2) Good quality pipe materials (e.g., HDPE pipes) effective in preventing leakage and illegal connections and should be used for installation of:

   i) new transmission and distribution pipelines, and

   ii) new service connections

   (Note: pipes and fittings; and customer meters for new connections should be provided by the WSP to customers at a fee for better quality control of service connections.

3) The few parts of transmission or distribution pipelines with frequent bursts and heavy leaks (e.g., heavily deteriorated GI pipes or low pressure-rated PVC pipes that are under high pressure, etc) that are assessed to be very difficult to stop, should be replaced selectively with good pipes.

4) Spaghetti service connections causing leakage should be replaced with branch/ tertiary distribution pipelines and shorter service pipes.

5) Old leaking pipelines that are aligned parallel with better pipelines with adequate capacity should be removed or completely closed.

6) Existing problematic pipelines passing through road-side vegetation, along watercourses, etc. should be relocated to road reserves to make the patrollers' work of detecting leaks and illegal use easier.

8.8 Large-scale Replacement of Deteriorated Pipelines and Service Connections

The procedure below is only for WSPs which would consider large-scale replacement of deteriorated pipes

1) Ensure that the types and sizes of problematic pipelines requiring replacement (e.g., asbestos cement pipes, old galvanized iron (GI) pipes, cast iron and steel pipes with corrosion holes or rust incrustation significantly blocking flow, pipes with low pressure rating (e.g., PN 7.5) in high pressure areas); or rehabilitations (e.g., relining) are analysed (preferably with GIS) based on available data (e.g., installation year of each pipeline and records of past bursts and leaks).

2) Ensure that the necessity and priority of large-scale replacement/rehabilitation of transmission, distribution and/or service pipes (and rehabilitation of leaking tanks, etc.) are discussed well among relevant staff and managers based on results from the above analysis before planning.

3) Ensure that large-scale replacement/rehabilitation of problematic pipes and appurtenances, leaking tanks, etc. are planned (including rough cost estimates) from long-term financial and technical prospects (such as expected reduction in NRW, increase in revenue, and future water demand increase).

4) Ensure that planned large-scale replacement/rehabilitation of problematic pipelines are incorporated into the latest strategic plan (partly for seeking external funds) and/or into the tariff adjustment application of WASREB with required budgetary provision.

5) Ensure that design, bill of quantities, detailed engineer's cost estimates and tender documents for the planned replacement/rehabilitation are prepared for bidding.

6) Ensure that the planned replacement/rehabilitation are implemented soonest or as funds permit.

8.9 Standardization of Pipe and Jointing Materials

a) Leakages still occur even when distribution and service pipes are all replaced, if excavation, pipe laying and construction workmanship are poor.

b) The Importance of a site manager and his/her supervisory role in construction work is often ignored leading to sub-standard pipe-work.

c) Leakages often occur at pipe joints, especially on service pipes, and many pipe breakage incidents occur due to shallow pipedepth.

d) Leakages also occur immediately the pipes are replaced if the construction work is poor. This is ineffective use of resources.

e) Customers should not be connected directly onto the transmission line, neither should they be allowed to provide their own materials, all materials should be procured by the WSP.

This section focuses on construction management and methods of pipe connection, particularly for sub-mains (PVC and HDPE pipes).

8.9.1 Standardization of Pipe and Jointing Materials

The most important issue in Kenya is adoption and consistent use of standards for materials and construction methods. Use of uPVC couplings and bends that are fabricated through heating on fire for pipe repairs and connections is common in Kenya. This is due to lack of knowledge and proper training on pipes and other materials standards, and good construction practices. It is also due to lack of collaboration with manufacturers to ensure quality control.

Kenya uses both inches and millimetres and, in addition, ISO standards in pipe specification in manufacturing. This leads to variations in thickness and external diameter of pipes and fittings; thereby requiring adjustments to fit them on site if from different manufacturers. There are also informal fabricators (Jua Kali sector) which manufacture pipe fittings without following any standard. Therefore, regardless of the construction quality, problem with water tightness still occurs.

WASREB should establish standards targeting improvement in the quality (both materials, manufacturing process and dimensions) of pipes and fittings.

Figure 8.8: Making Fire Coupling (used for pipe connections in Kenya)

Figure 8.9: Degradation of pipe caused by excessive heat on the UPVC pipe.

Figure 8.10: Plastic Pipe Bend (used for pipe connections in Kenya)

Figure 8.11: Checking Pipe diameter Internal and External using vernier calliper

Figure 8.12: Using Ultrasonic Thickness Gauge to determine Pipe thickness

Figure 8.13: Socket of pipe connection

Figure 8.14: ISO Standard Pipe Couplings（Meru WSP)

8.10 Inspection of Pipe-Work

8.10.1 Inspection of Pipe-Work

Leakages continue to occur if the quality of construction is poor. Construction management is vital to ensure good quality construction that prevent occurrence of many leakages. In cases where construction work is done in-house, the utility must ensure that the construction team is well trained in terms of quality. In cases where construction work needs to be outsourced, the WSP must effectively supervise the construction work to ensure quality work.

The following are some important quality standards:

(1) Pipe laying

- Pipe depth (top of pipe) should be more than the standards (0.3m)
- Pipe laying at the site should conform to the applicable design.
- There should be no cross connection
- Necessary and adequate pipe protection (thrust blocks, anchor blocks, etc) should be installed. The protection-pipe method should be confirmed with the design.
- Pipes should be appropriately jointed and laid?
- Distribution pipes should not be connected directly to rising mains since it introduces water hammer pressure in the pipes thereby weakening the pipelines. It is also difficult to control the pressure without special pumps.
- The pipes should satisfy the material and structural standards of installation.

(2) Equipment (e.g., customer meter, sluice valve, etc)

- The equipment should satisfy the material and structural standards of installation.
- The equipment should be appropriately jointed.
- Chambers or meter boxes should satisfy the material and structural standards of construction.

(3) Water pressure

- There should be no leakage from joints; or any other defects seen at the standard test pressure.

(4) Area Around Water meter

- Water meters should be appropriately installed without any obstruction to its reading and replacement.
- Chambers with lockable covers and strainers should be appropriately installed.
- Appropriate preparation for meter installation like ensuring proper meter spacing should be done.

(5) Others

- Line markers for pipelines should be installed.
- Confirmation of whether installation is good or not (in case of direct connection of service line)
- Valves and other appurtenances should be appropriately installed.

8.10.2 Example of Supervision and Inspection of Construction Work

a) General

The following are some of the key elements in inspection of Pipe-work:

i) Trenching to the required depths

ii) Suitable material (e.g., sand or murram) for bedding before pipe laying
iii) Pipe connections (joints), supporting and anchoring
iv) Backfilling and compaction as required in construction works
v) Water pressure test
vi) Record keeping with photographs (for evidence)

As an example, the key elements and extent/level of inspection work in Japan are explained in below.

b) Backfilling

The following should be ensured:

- Pipe depth (top of pipe) is more than 0.3m
- Good quality sand for bedding and, where necessary, backfilling around the pipe.
- Compaction is done in accordance with construction work standards

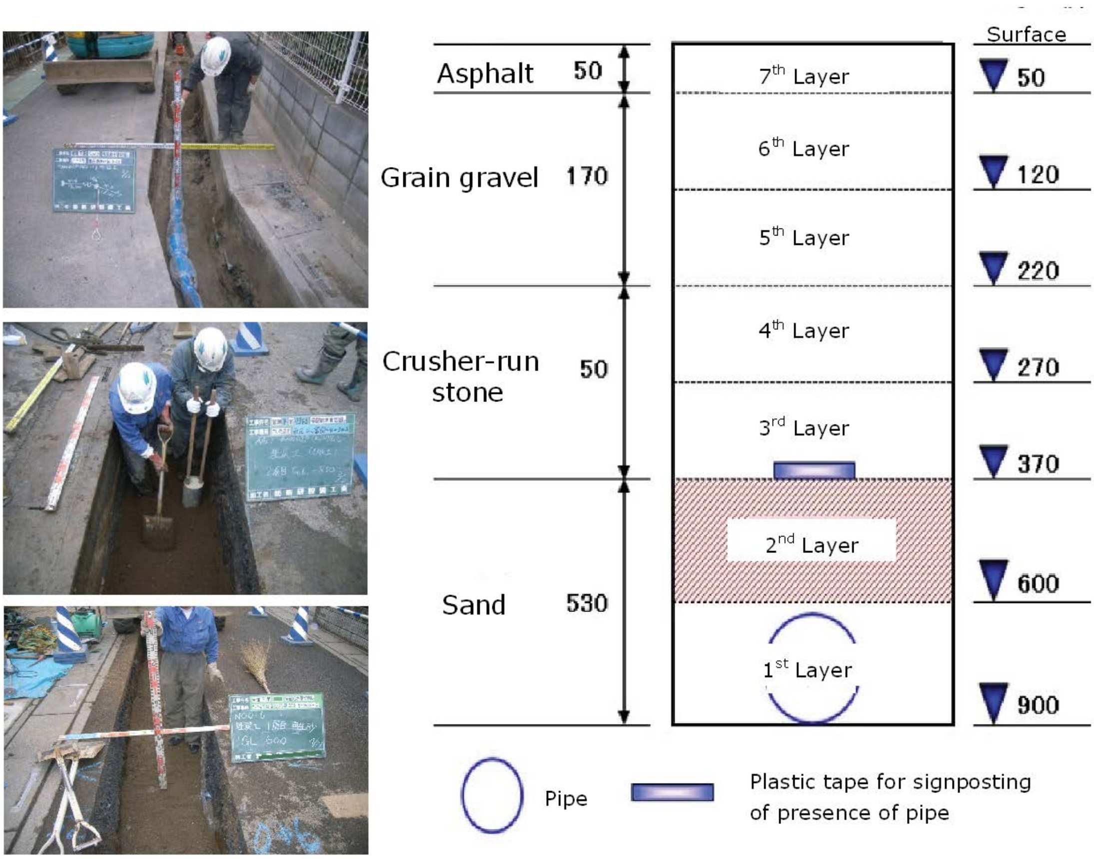


Figure 8.15: Backfilling work of pipe (Japanese Case)

c) Connections (Joints)

Enough length of pipe jointing is necessary for effective jointing.

Figure 8.16: Connection work of Pipe (Japanese Case)

d) Water Pressure Test

Water Pressure Test must always be done after the construction work to confirm that there are no leakages.

During Water Pressure Tests, water pressure in the pipe should be increased up to 1.5 times the normal working pressure of the pipe.

Figure 8.17 Water Pressure Test

e) Record keeping with photograph

Photographs should always be taken at leakage repair site and replacement of service and distribution pipes. Records must be immediately mapped and reflected in a water ledger as below.

Figure 8.18: Water Ledger for Recording after Construction Work (Japan)

Chapter 9

Leak Detection and Pipe Replacement

9.1 Strategic Approach to Underground Leak Detection

1) Priority areas (e.g., DZs and DMAs) of ongoing or future underground leak detection activities should be selected from the entire service area (based on the results of monthly zonal/DMAs NRW monitoring with bulk meters, MNF measurements, tabulated or mapped records of past bursts and leaks, etc).

2) Suitable combination(s) of applicable leak detection methods should be selected for each priority area based on the conditions of the area and WSP's resources (e.g. adaptability of Step Test such as continuity of water supply, security to conduct MNF, availability of functioning gate valves on branch pipelines, cooperation from customers when closing the stop corks on service connections, existence of pavement over buried pipes, availability of leak detection equipment and skilled workers, etc).

3) Door to door survey with listening sticks and other selected method(s) is/are then conducted well in combination with well-established day-to-day activities for underground leak detection.

9.2 Minimum Night Flow Measurement and Step Tests

9.2.1 Introduction

Minimum Night Flow (MNF) is the lowest steady flowrate into a DMA/zone in a 24 hours period. It is therefore a range of flows over a period of time and not one instantaneous flowrate. Figure 9.1 is a typical graph of 24 hours flow in a zone. The lowest flow is 22 lts/hr and occurs between 02:30 am and 04:00 am.

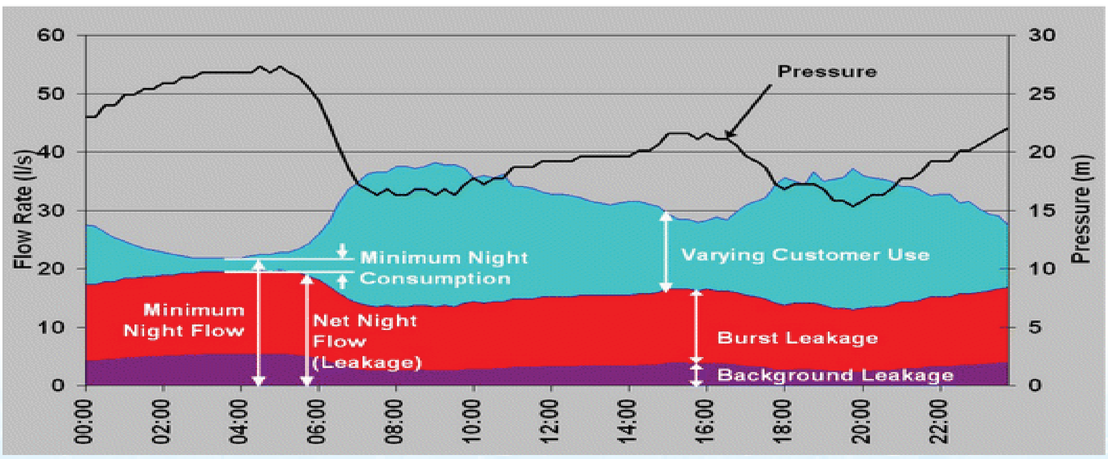


Figure 9.1: Typical Graph of 24 hrs Flow in a Water Supply

Figure 9.1 is a 24 hours graph of Kangaru Zone, Embu Water Co. The lowest steady flowrate was 190m3/hr occurring between 00:00am and 06:00am.

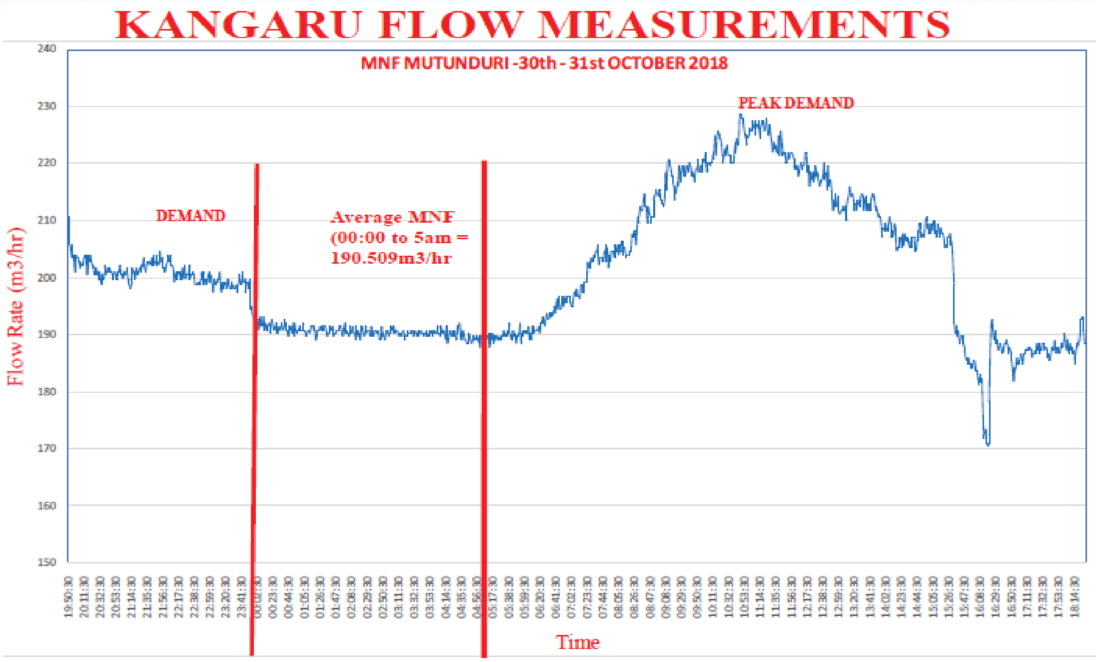


Figure 9.2: Graph of 24 hours Flow in Kangaru Zone, Embu Water Co., Kenya

The period of the lowest flow is unique for each distribution network and depends on the customer types and other factors. Table. 9.1 is a guideline on the recommended time of the night to conduct MNF measurement.

Table. 9.1: Recommended Time to Conduct MNF Measurement

	Customer Category	Time of MNF Measurement	
		Earliest Start Time	Latest Stop Time
1	Rural areas	11:00 pm	04:00 am
2	Peri-urban areas	00:00 am (midnight)	04:00 am
3	Urban areas	02:00 am	04:00 am

MNF comprises the following:

a) water consumed by customers (flushing toilets, washing machines, night clubs, industries, hospitals, prisons) including filling and overflowing storage tanks at customers' premises.

b) illegal use

c) leakage and overflows from WSP tanks downstream of the measurement location.

MNF measures the total of (a) to (c). (a) is normally determined by manually reading customer meters for a sample of domestic customers and the flow estimated for all the customers in the DMA/zone. For large customers, the meters can be read manually; or by automatic meters; or portable meters. This is done simultaneously with the MNF measurement. The total of (b) and (c) is the physical loss.

The purpose of measuring MNF is to determine and understand the level of physical losses occurring in a water supply network. Once this is determined, leak detection and repairs should commence and NRW monitored to achieve as low leakage level as possible.

Note:

a) If the supply system is intermittent make a provision to supply the area continuously for at least 24 hours before starting MNF measurement. The continuous supply may need to be extended to cover at least three nights without any interruption.

b) If the DMA has multiple inflow lines from other areas or outflow lines to other areas, each line should be metered. The readings from all the meters should then be aggregated and the minimum aggregated flow taken as the MNF.

c) It is recommended to measure water pressure in the pipeline simultaneously with the MNF measurement. The pressure gauge should be installed next to the UFM//bulk meter. The purpose of pressure measurement is to ensure that there is adequate pressure in the pipeline during the MNF measurement.

9.2.2 Rough Measurement of Minimum Night Flow using Bulk Meter

Most WSPs have no financial capacity to procure a UFM with their own resources. However, this should not be a hindrance to start leak detection.

MNF measurement can be conducted using any of the following methods:

- Recording bulk meter readings at 5- or 10-minutes intervals.
- Attaching data logger to a bulk meter – it stores the reading for a certain period.
- Attaching data logger and transmission gadget to a bulk meter – continuously transmits the readings to a computer.
- Automatic Meter Reading (AMR) gadget – continuously transmits the readings to the computer.

9.2.3 Case Study: Rough Minimum Night Flow Measurement on Two Inflow Pipes into Kanyoni DMA, Nakuru Town WSP

The NRW staff of Nakuru WSP were conducting MNF measurement using a UFM. However, the UFM did not have the capacity to transfer data to a computer. They therefore had to manually read the data from the UFM and record in the computer.

Figure 9.3 and 9.4 are the graphs of meter readings from the two inlets lines into Kanyoni DMA in September 2018 indicating MNFs of 8.0 and 12.0 m3/hr respectively. The readings were at 15 minutes intervals.

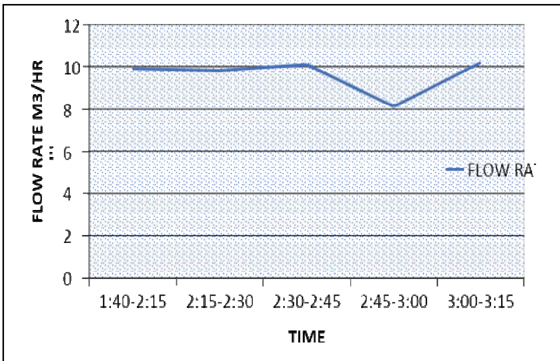


Figure 9.3: City Mission Line: MNF (Sep. 2018) = 8.0 m3/hr

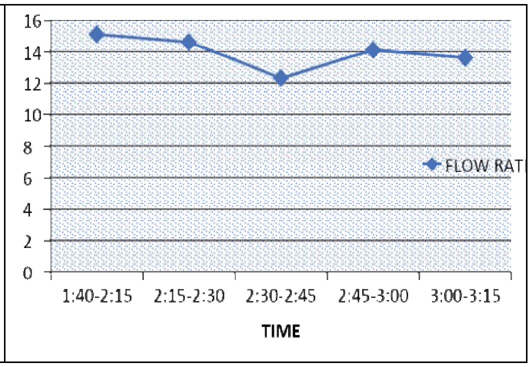


Figure 9.4: Scan Line: MNF (Sep. 2018) = 12.0m3/hr

The staff then conducted leak detection and repaired the leakages in Table 9.2.

Table 9.2: leakages detected and repaired in Kanyoni DMA, Nakuru Town WSP after the MNF measurement September 2018

	Location	Type of Leak Identified	No.
1.	Kanyoni estate	Leaks on meters liners	17
2.	Kanyoni estate	Leakage on 8” dia pipe	2
3.	Kanyoni estate	Leakage on 2” dia pipe	1
4.	Kanyoni estate	Leakage on 1.5” dia pipe	1
6.	Kabachia estate	Leakage from 12” dia sluice valve spindle	1
7.	Kabachia estate	Leakage from 12” pipe	1
8.	Shadrack Kimalel	Leakage from 12” dia sluice valve spindle	**1**

Figure 9.5 and 9.6 are graphs of meter readings from the two inlets lines into Kanyoni DMA in December 2018 indicating MNFs of 2.7 and 3.9 m3/hr respectively. The readings were at 15 minutes intervals.

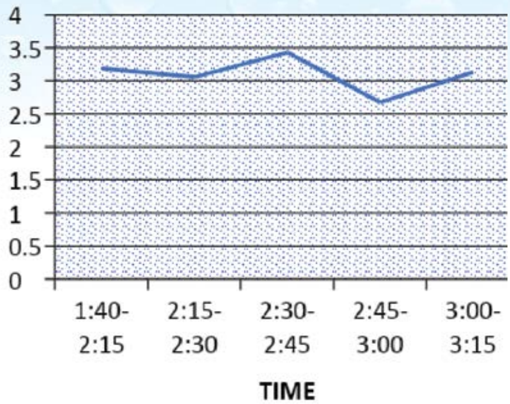


Figure 9.5: City Mission Line: MNF (Dec. 2018) = 2.7m3/hr

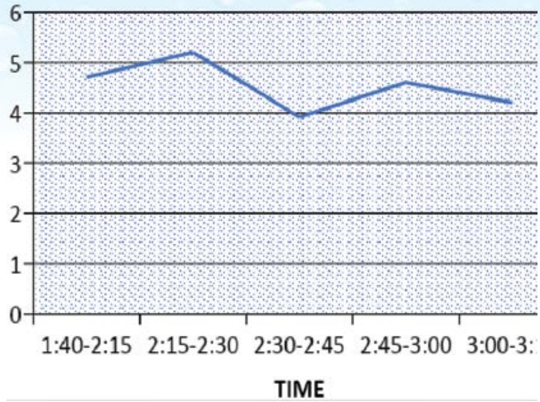


Figure 9.6: Scan Line MNF (Dec. 2018) = 3.9m3/hr

9.2.4 Step Test Measurement

The Step Test allows detection of abnormal flow in an isolated distribution area. By measuring the MNF of a sub-block and comparing the obtained readings to previous MNF records of same sub-blocks any abnormal flow can be detected and can be a pointer to possible leakage.

The procedure for Step-Test Measurement is as follows: -

- The leak survey block should be completely isolated from adjoining blocks, and the survey block must be divided into sub-blocks using sluice valves.
- There should only be one flow meter for the leak survey block, and water should be allowed to flow into each sub-block, one by one, by utilizing sluice valves.

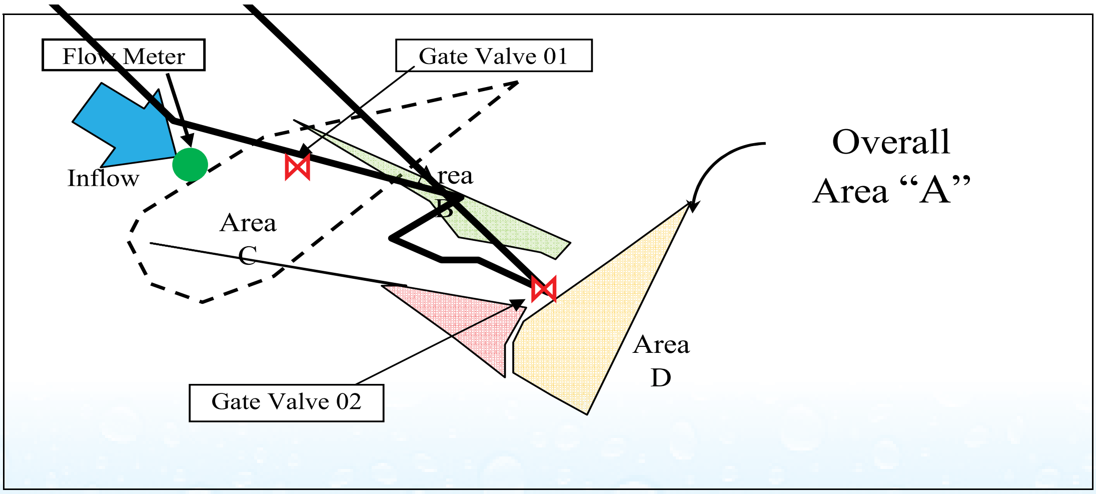


Figure 9.7: Schematic Diagram of Leakage Monitoring Block (Step Test)

The volume of water flow is measured by the flow meter as shown in Figure 9.7.

a) Measure the volume of minimum flow for overall area “A”.

b) Close gate valve 02 and measure the volume of minimum flow for “B+C”.

c) The difference between volume of “A” and “B+C” is minimum flow volume of D, i.e., D= A - (B＋C)

d) Similarly, close valve 01 and measure the volume of minimum flow for “C”.

e) It can be determined that the difference between “B+C” and “C” indicates the volume of minimum flow of “B”, i.e., B = (B＋C) - C.

f) Therefore, the volume of minimum flow for all can be determined.

g) All measurements are recorded and compared to previous volume of minimum flow records.

These comparisons can confirm any abnormal flow and presence of leakage.

Figure 9.8: Flow Meter Reading

Figure 9.9: Closing Gate Valve

Figure 9.10 shows a map of part of Embu WSP distribution network and the result of step test. The network was divided into 7 blocks and Step Tests conducted.

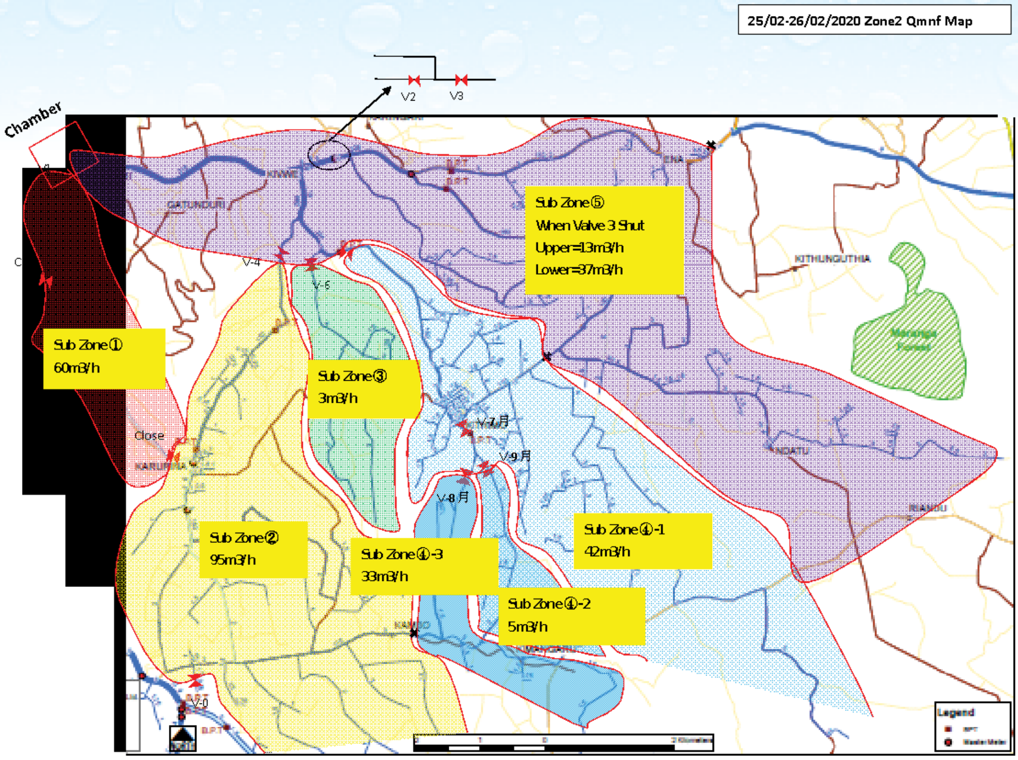


Figure 9.10: Qmnf Volume Map for Step Test(Case of Embu WSP)

Source: Embu WSP

The best step test measurement is normally done with an ultrasonic flow meter.

Figure 9.11 shows the results of the step test in the Embu WSP distribution network on Figure 9.10 above.

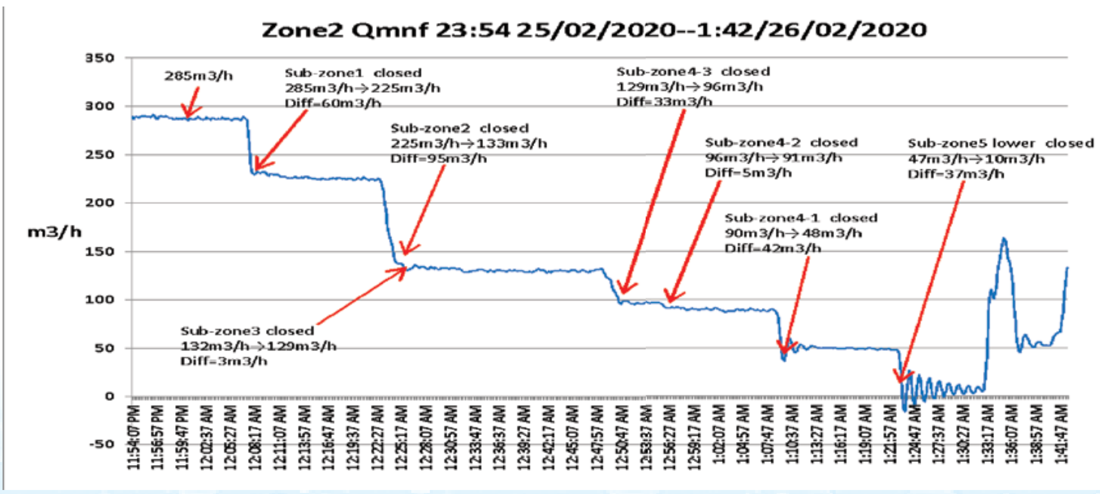


Figure 9.11: Results of Step Test (Case of Embu WSP)

However, step test measurement can also be measured with a bulk meter by taking a video of the bulk meter dial using a Timestamp camera. The camera can add a timestamp watermark (the time the video is taken) on the video in real time. The camera is the only App that can record videos with a time watermark accurate to millisecond (0.001 second). The App can be downloaded from play store (onto smartphone) or the following web link.

https://play.google.com/store/apps/details?id=com.jeyluta.
timestampcamerafree&hl=ja&gl=US

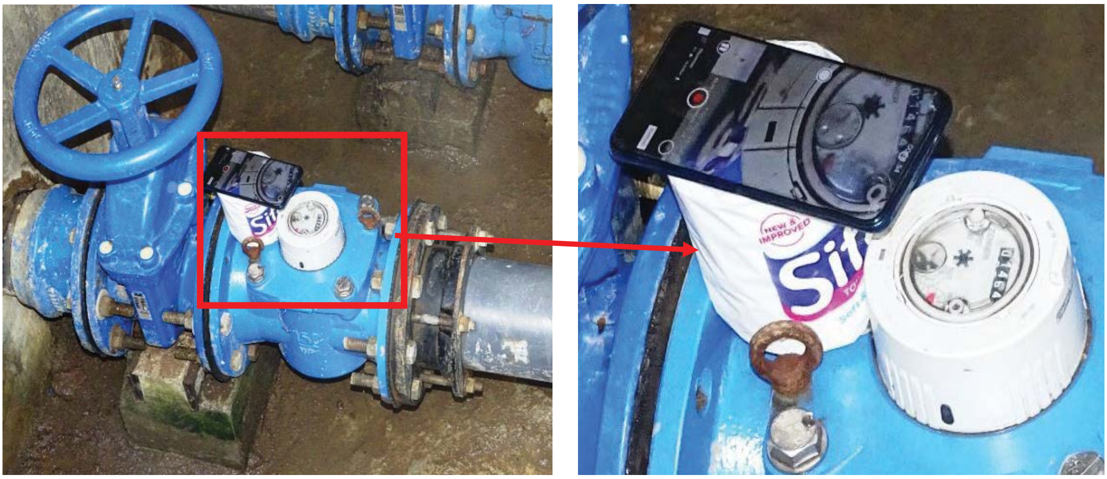


Figure 9.12: Smartphone recording video of bulk meter with timestamp camera

Note: When recording videos or taking photos using a timestamp camera, it is recommended that the current time and location be turn on. Once the video of the bulk meter is taken, the meter readings can then encoded from the video every 30 seconds or 1 minute.

Figure 9.13 is a sample of bulk meter readings recorded with a timestamp camera and the resultant graph of the flowrate at 30 seconds interval.

Video Time	Meter Readings of Bulk Meter 1 (from the Video)	Frow Rate of Bulk Meter 1 (m3/hr)
15:21:18	146461.021	25.68
15:21:48	146461.245	26.88
15:22:18	146461.473	27.36
15:22:48	146461.688	25.80
15:23:18	146461.902	25.68
15:23:48	146462.118	25.92
15:24:18	146462.342	26.88
15:24:48	146462.570	27.36
15:25:18	146462.790	26.40
15:25:48	146463.004	25.68
15:26:18	146463.222	26.16
15:26:48	146463.450	27.36
15:27:18	146463.676	27.12
15:27:48	146463.894	26.16
15:28:18	146464.108	25.68
15:28:48	146464.324	25.92
15:29:18	146464.547	26.76

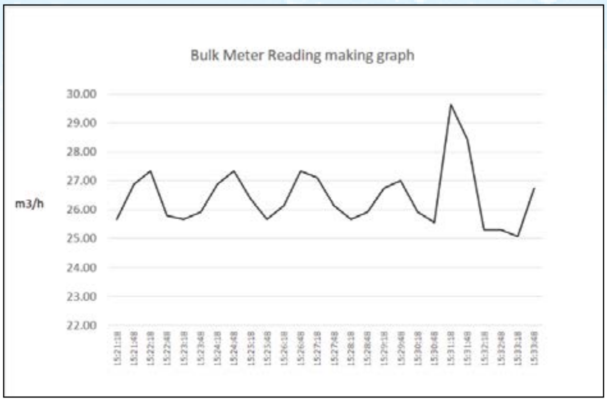


Figure 9.13: Sample timestamp camera data and graph

Abnormal flow cannot be determined solely by flow volume. It is important to understand and take into consideration the seasonal movement of inhabitants, building developments, operation status of big consumers like hospitals and construction works, etc. Characteristics of the area as well as past experiences must also be considered. If abnormal flow is noted in a sub-block, a leakage detection team should be dispatched the following day to determine the cause. If the cause is leakage, repair works should be done immediately.

9.3 Improvements Necessary for Underground Leak Detection

8.3.1 Leak Detection

Non-visible Leakages (Underground Leakages) are often difficult to detect. In order to detect underground leakages, it is necessary to use leak detectors such as listening sticks and electronic leak detectors. Using leak detectors often require specific skill and experience; hence training of staff is important.

Underground leakages are usually detected by using a leak detector, which is placed on the ground surface or on the pipe wall, to detect leak noises. The sound and quality of leak noises vary depending on factors such as soil properties, pipe material, pipe diameter, depth of pipes, magnitude of leakage, water pressures and others. Detecting leak noises in clay soils or pipes with large diameters is not easy and requires experience.

(a) Necessary equipment for Leak Detection work

The following are the minimum requirements for implementation of leakage control work. However, each WSP should prioritize depending on its self-assessment and availability of appropriate resources:

- Listening stick
- Pipe locator (for metallic and non-metallic pipes)
- Hand pump for water tightness test
- Water pressure gauge
- Pipe thickness gauge
- Electronic leak detector
- Electromagnetic flow meter
- Ultrasonic flow meter

The following are typical leak detection equipment and how to operation them: -

(b) Listening Stick

Listening Sticks have been used for many years to detect leaks easily and they are the origin of electronic leak detectors which are presently widely used. Its mechanism is very simple. It consists of a steel rod/bar and a small circular vibration plate connected to the end of the bar at right angle. It is a kind of stethoscope without an electronic amplifier.

Figure 9.14: Listening Stick

Figure 9.15: Leak detection using Listening Stick

Figure 9.16: Leak detection using Listening Stick

The leak noises can be heard by putting the tip of the stick on a meter or a pipe fitting, The ear is the placed on the vibration plate at the top of the stick to listen to leak noise. This method can only confirm the existence or non-existence of leakage near the listening stick but cannot locate the leak point. Listening Stick requires a lot of skill to distinguish the real leak noises from other similar noises. The equipment is still widely used.

(c) Electronic Leak Detector

An electronic leak detector consists of the main unit, a sensor (or pick up), a headphone and a remote-control unit. Leak noises are detected by placing the sensor on the ground surface. An amplifier is used to amplify the noise. The operator wears a headphone to listen to the amplified noise. The leak noise will become clearer and louder as the sensor nears the leak location. Using this device requires skill and experience.

As with the listening stick, this device is used mainly at night when there is less surrounding noise. Electronic Leak Detectors can greatly improve the efficiency of leak detection work.

Figure 9.17: Electronic leak detector

Figure 9.18: Leak detection using electronic leak detector

Figure 9.19: Leak detection using electronic leak detector

(d) Digital Leak Noise Correlator

Leakages occurring in pressurized pipes continuously generate random leak noises, which travel in the pipe in both directions. The device transforms the noise that is detected into electrical signals which is displayed on the monitor of the correlator. This is not only to detect existence of leakages, but also their location by looking at the peaks of wave points. IWA's "Download Leak Detection Technology and Implementation" for detailed explanations and procedures on using a correlator from the following link.

https://library.oapen.org/bitstream/handle/20.500.12657/33035/578133.pdf?sequence=1&isAllowed=y

Figure 9.20: Digital leak noise detector

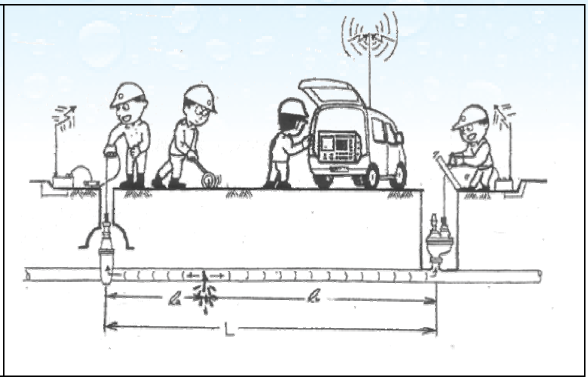


Figure 9.21: Concept diagram of cross- correlation type leak detector

(e) Other Leakage Detection Methods

i) Water quality examination method

Testing water quality at various points can determine whether there is contamination of water and therefore leakages. Generally, this test is conducted on water that flows through construction sites, basement of buildings or simply water flowing out onto the road. The quality of tested water must match that of tap water. The parameters to be examined are residual chlorine, PH, electric conductivity, water temperature, odour, etc. Additional test for trihalomethane may also be conducted.

8.3.2 Buried Pipe Detection Technologies

In the absence of accurate drawings showing the exact location of buried pipes, it is important to be able to identify the exact location of distribution and service pipes to conduct leakage surveys. Some examples of methods of detecting buried pipes are outlined below: -

a) Hammering Method

This method has been used for many years. A hammer is used in a uniform rhythm and strength on the road surface around the area where pipes are estimated to be buried. By using a listening stick or an electronic leak detector, the strength and changes of the sound is followed to identify the exact location of buried pipes.

b) Metallic Pipe Locator

Metallic pipe locator is used to locate metallic pipes. In this method, the pipe locator is placed on the ground above the buried pipes and a magnetic field is generated from a loop antenna with transmission coils. The magnetic current is conducted through the pipes and a secondary magnetic field is generated around the pipe, which can be detected by a separate antenna.

Figure 9.22: Metallic Pipe Locator

(c) Metal Locator

This locator is used to locate buried metal lids or other devices installed on pipes such as sluice valves, fire hydrant chests and customer meter boxes, etc. These may be buried due to construction pavements. The operation principle is the same as the Metallic Pipe Locator, but the metal locator has a capacity to detect metal up to 50cm in depth.

Figure 9.23: Metal Detectors

9.4 Recurrence of Leakage

Recurrence of leakages refers to new leakages that occur near previously repaired leakages of the same pipe. When water distribution pipes are worn out, no matter how many leakages are repaired, there will be a great tendency for new leakages to occur. In order to further lower the leakage ratio, detection of leakages and repair work must outpace leakage occurrence. In cases where leakages still occur in the same pipe, or if the pipe is well past its lifespan, the water pipe must be replaced with newer and stronger pipe.

Figure 9.22 shows the concept of recurrence of leakage.

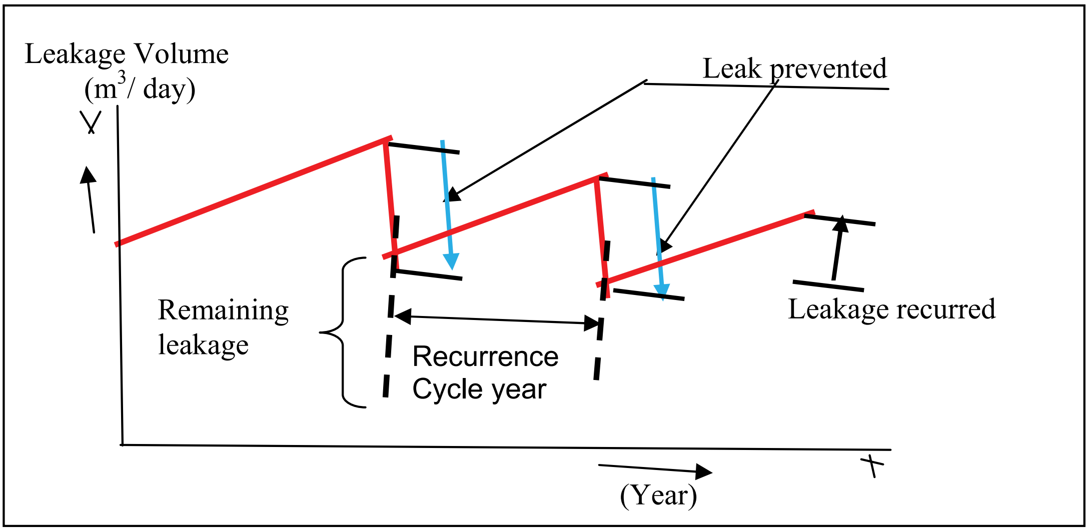


Figure 9.24: Concept of Leakage Recurrence

9.5 Large-scale Replacement of Deteriorated Pipelines

WSPs planning large-scale replacement of deteriorated pipes should following procedure:

1) The types and sizes of problematic pipelines requiring replacement (e.g., asbestos cement, old GI, cast iron and steel pipes having corrosion holes and/or rust incrustation significantly blocking flow; pipes of low-pressure rating (e.g., PN 7.5) in high pressure areas, etc) or rehabilitation (e.g., relining) should be analysed (preferably with GIS) based on available data (e.g., installation year of each pipeline and records of past bursts and leaks).

2) The necessity and priority of large-scale replacement/rehabilitation of transmission, distribution and/or service pipes (and rehabilitation of leaking tanks, etc) should

then be discussed well among relevant staff including managers based on the results from the above analysis before starting the planning process.

3) The large-scale replacement/rehabilitation should be planned (including rough cost estimation) from long-term financial and technical prospects (such as expected reduction in NRW, increase in revenue, and future water demand increase).

4) The planned replacement/rehabilitation should then be incorporated into the latest strategic plan (partly for seeking external funds) and/or into the tariff adjustment application of WASREB with required budgetary provision.

5) The design, bill of quantities and detailed cost estimates should then be prepared for tendering.

6) The replacement/rehabilitation should then be implemented as funds permit.

Chapter 10

Pressure Reduction/Management Including Zoning Using Reservoirs

10.1 Pressure Management to Reduce Physical Losses

10.1.1 Relationship between Excessive Pressure and Water Losses

Low water pressure in a distribution system interferes with adequate water supply to customers and also prevents leaks from being visible on the ground surface. On the other hand, the frequency of pipe bursts and leakage volume are usually high when pressure is high. Therefore, the water pressure in the distribution system should be kept within a suitable range (e.g., 15 to 40m of water head) as much as practical. Reduction of excessive pressure in transmission lines, distribution networks and service connections in relatively low-lying areas is quite important to reduce the number and volume of pipe bursts and leaks.

Figure 10.1 shows the effect of pressure reduction on the number of pipe bursts. If a WSP has many pipes whose pressure rating is not high enough (e.g., PN10) compared to the pressure in those pipes or; has pipes installed without proper fittings, even a limited reduction of pressure (e.g., by 10%) may reduce pipe bursts drastically (e.g., by 25%) like the red trend line in the figure. Leakage volume from leak points can also be reduced by lowering the water pressure as shown in Figure 10.2.

Reduction of water pressure (e.g., by 20%) would reduce leakage drastically (e.g., by 40%) especially if the pipes are mostly plastic as shown in this figure. The value of the exponent N in this figure depends on the nature of the pipes and shape of the leakage opening. For rigid pipes (e.g., thick-walled metal pipes), N is equal to 0.5; but if the pipe is flexible and the leak opening size changes with the change in pressure the value of N increases and reaches up to 2.5.

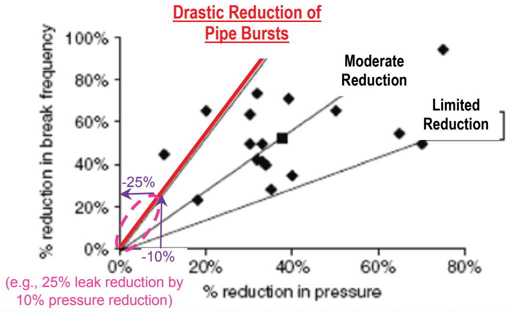


Figure 10.1: Possible Relationship between Pressure Reduction & the Frequency of Bursts

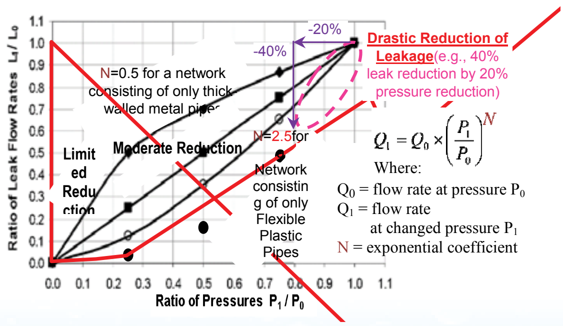


Figure 10.2: Generalized Relationship between Pressure Reduction & Leak Flow

10.1.2 Solving Low-Pressure Problems to Enable Reduction of Excessive Pressure

Managing pressure in low pressure spots is also beneficial for pressure reduction. A WSP may be unable to reduce pressure at all in a high-pressure area just because there is a single under-sized pipe causing a large pressure loss therefore creating a localized low-pressure spot and serious trouble to a few customers. In such a case, a WSP may not dare reduce the overall high pressure of a low-laying area if some of the customers living there suffer from serious low pressure. Figure 10.3 is an example of a large friction pressure loss caused by a small-diameter (e.g., 50mm) distribution pipeline.

Just like a single small pipe causing a large pressure loss, the existence of a single but large hidden leak causing a large pressure loss may also become a serious obstacle in reducing the excessive pressure over a high-pressure area. As shown in Figure 10.4, when the flow rate in a pipe increases due to demand increase or leakage, the friction pressure loss increases.

Therefore, before trying to reduce excessive pressure in order to reduce bursts and leaks in a high-pressure area, small spots of low pressure within the area including those on hills and on small diameter pipes should be resolved first so that the pressure reduction can be applied to the area without resulting into serious complaints from the customers already suffering from low water pressure.

The above is an example of why pressure reduction is complicated and often becomes customer complaints management especially if the system is under intermittent (rationing) water supply conditions.

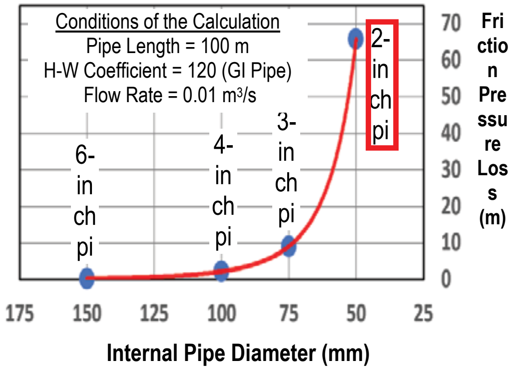


Figure 10.3: Effect of Small Diameter on Pressure Loss calculated with Hazen-Williams Formula

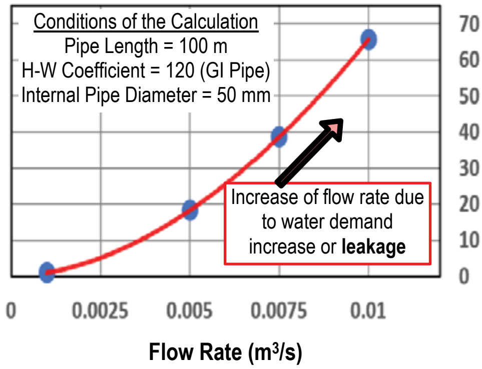


Figure 10.4: Effect of the Increase of Flow Rate on Pressure Loss calculated with Hazen-Williams Formula

10.2 Pressure Measurement to Identify Problematic Areas

10.2.1 Pressure Measurement and Mapping

Water pressure within distribution systems vary relative to the terrain (e.g., elevation difference from upstream tank), pressure losses in upstream pipes, and water supply and demand conditions at a given time (e.g., dry season, night time, etc.). Low-laying areas often get high pressure while high elevation areas and ends of long distribution lines often get low pressure. If a WSP uses pressure regulating facilities and equipment such as pumps and pressure reducing valves (PRVs) the pressure within a distribution system also depends on their specifications and settings.

In order to identify all the high-pressure areas where pressure can be reduced without causing unacceptably low pressure to some customers, a large number of pressure measurements would be required in many areas.

Figure 10.5 is results of pressure measurement mapped on GIS. The daytime pressure should be taken not only at the low-lying locations where high pressure usually occurs but also at the ends of distribution pipes, on hills and upstream and downstream of pressure regulating facilities such as PRVs. This enables to fully understand the existing conditions during high-water-demand hours and the possibility of pressure reduction at different locations.

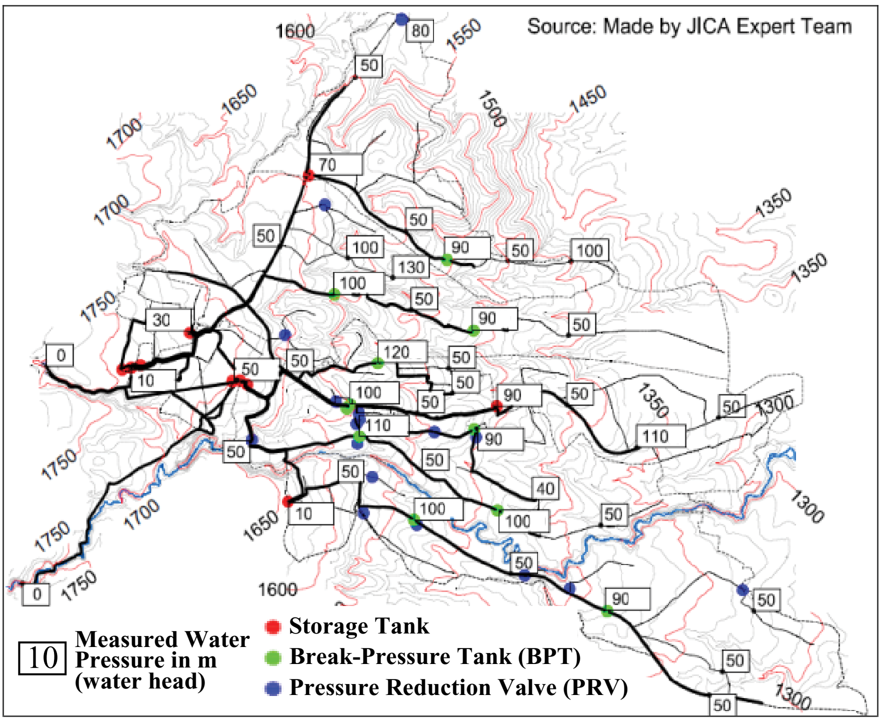


Figure 10.5: Mapped Daytime Pressure Measurements over a Hilly Terrain Area

To cover a large area and/or many pressure measurement points, it is more practical to use pressure gauges than pressure loggers. If pressure gauges with red maximum pressure pointer (Figure 10.6) are available, they can be used to record the hourly maximum pressure that normally occurs overnight to understand the necessity and expected effects of pressure reduction during night-time. From around mid-night to 4.00 am when people use little water, the slowed water flow in distribution pipes cause less friction pressure loss. This results in higher residual pressure in pipes and more pipe bursts and leakage per hour.

After identifying high-pressure areas where pressure reduction may be possible, pressure loggers can be used to understand pressure fluctuations at locations of relatively low pressure within high-pressure areas. This is in order to make sure the planned pressure reduction will not cause unacceptably low pressure at these locations even during peak hours of water demand. As shown in Figure 10.7, pressure loggers used to log flowrate fluctuations while logging pressure changes. This helps to understand the reasons for the measured pressure changes over time.

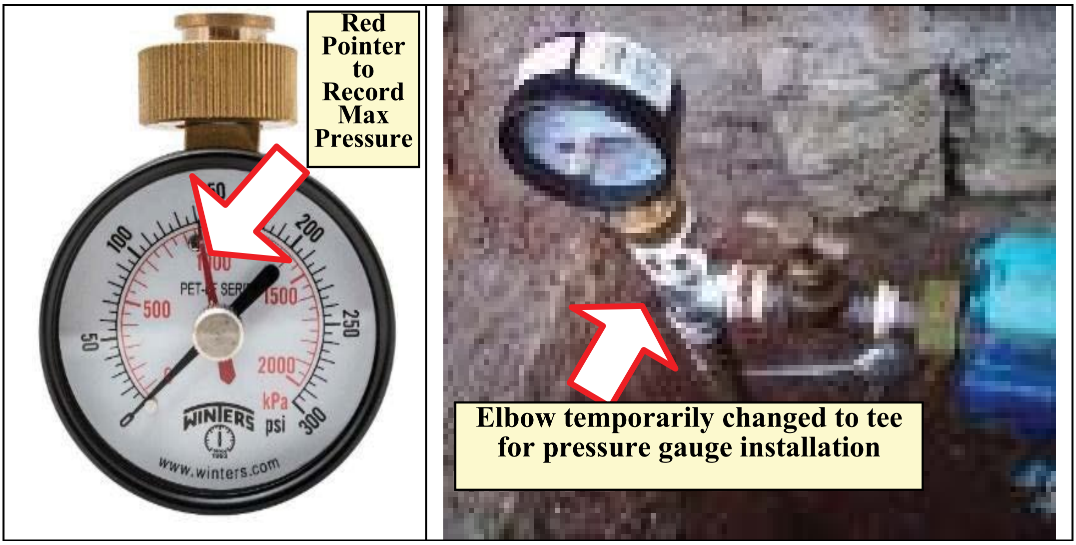


Figure 10.6: Pressure Gauge with a Red Pointer to Record Maximum Pressure over Night and its Installation on the Standpipe of a Domestic Customer Meter

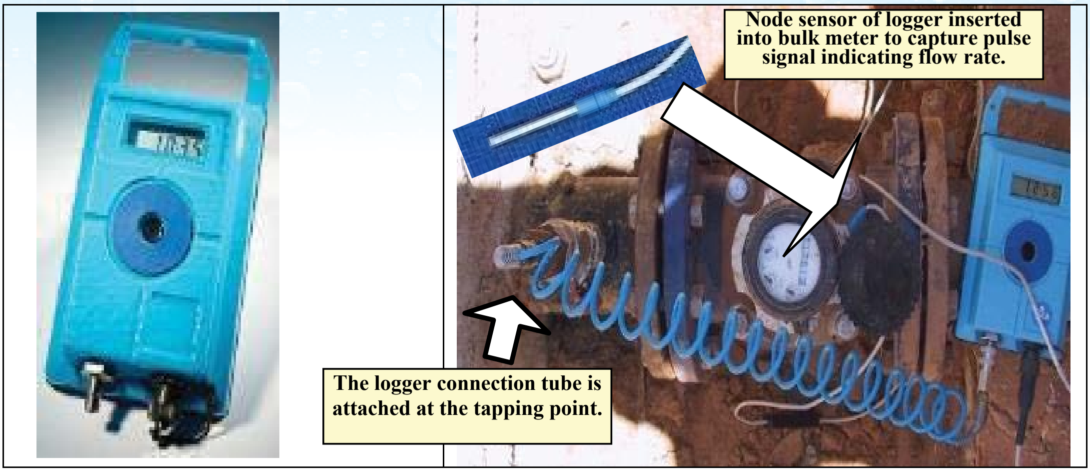


Figure 10.7: Pressure Logger and its Installation inside a Bulk Meter Chamber for the Logging the Fluctuations of Pressure (with the blue spiral tube) and Flow (with the gray colour electric cable)

The mapped pressure measurements should be analysed in relation to the terrain, existing distribution network (e.g., pipe length and diameter, performance of existing pressure regulation facilities, etc.) and hourly water demand changes. This is to identify high-pressure areas where pressure reduction is possible and also understand the reasons behind the high pressure; and to determine the most effective and sustainable interventions to deal with the high pressure.

When a WSP tries to reduce pressure in a relatively small area, the pressure within the area may be measured at many locations with a relatively high density to visualize the measured results as pressure contour maps like those in Figure 10.8 (e.g., before and after the installation of a PRV for pressure reduction).

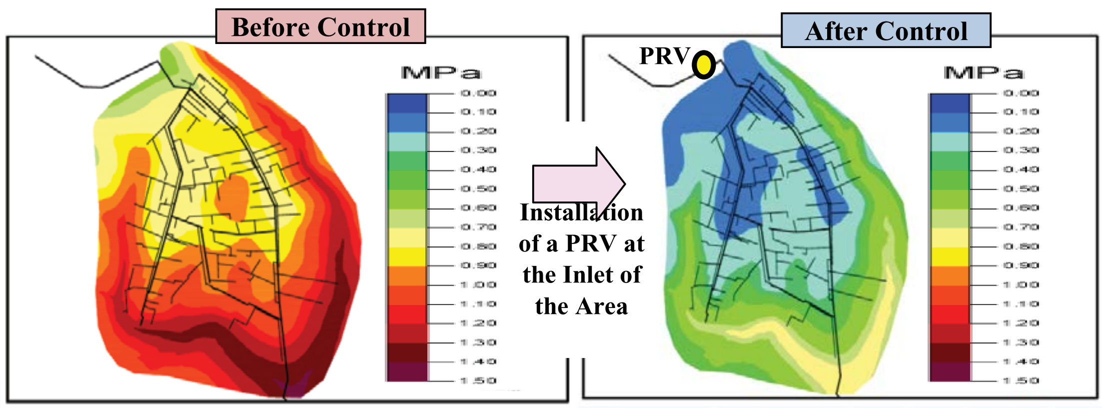


Figure 10.8: Example of Pressure Mapping to Visualize Results of Installing PRV for Pressure Reduction at Embu WSP

10.2.2 *Identification of Problematic Areas Through Pressure Measurement*

Note: The procedure below is only for WSPs that have or may have excessively high pressure causing more bursts and leaks in the distribution systems.

1) Ensure that flow of water from intakes to distribution pipelines is well understood on printed maps and/or GIS map and they are showing boundaries of existing distributing zones (DZs) and smaller pressure zones (possibly DMAs); and intake, production, transmission and distribution facilities (including pipelines, distribution reservoirs/tanks, pump stations; pressure reduction facilities such as break-pressure tanks (BPTs) and pressure reducing valves (PRVs)).

2) Ensure that elevation difference within each DZ and/or pressure zone is well understood (e.g., by overlaying elevation contours, zone boundaries and facilities on GIS; and tabulating elevation of storage facilities, lowest and highest customers, elevation difference between the lowest and highest customers, range of static pressure, etc. in each zone).

3) Ensure that the status (e.g., in use, bypassed), type, capacity and condition (e.g., leaking, overflow) of existing pressure reducing facilities (e.g., distribution reservoirs/tanks, BPTs, PRVs) are identified through visual observation, maintenance, etc.

4) Ensure that priority zones for pressure reduction are selected (based on static water pressure range calculated from elevation differences, occurrences of bursts and leaks, types and age of existing distribution pipelines and service pipes, conditions of existing pressure reducing facilities, MNF measurements (if possible). in each zone).

5) Ensure that adequate pressure measurement points (e.g. at fittings around customer meters to where pressure gauges can be easily installed) are planned for the selected prioritized zone(s) on map (preferably with GIS), especially in the areas where high and low residual pressure are expected (e.g. around ground distribution reservoirs, ends of branch distribution pipes going up or down hills, ends of long small-diameter pipelines including long service pipes, etc.) and upstream and downstream of existing PRVs/BPTs, for measuring maximum pressure (which usually happens after midnight when water demand become lowest) and running pressure (during day time when the gauges are installed or removed). (Note: minimum pressure during highest-water-demand hours may also be measured to avoid pressure reduction resulting in unacceptably low pressure on existing low-pressure lines).

6) Ensure that a map showing the planned pressure measurement points for prioritized zones are shared with surveyors who measure pressure. (If measurement is planned using GIS, this can be done using free online GIS (e.g., QGIS Cloud) or free mobile GIS on smartphone (e.g., QField, MAPinr and Google Earth)).

7) Ensure the maximum and running pressure (at the planned pressure measurement points) are measured with pressure gauges having red maximum pressure pointer and/or pressure loggers. (Note: free data collection software such as Kobo Toolbox/Collect can be used for the pressure measurement).

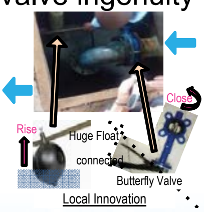
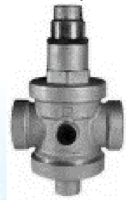
8) Ensure pressure data measured in priority zones are mapped (e.g. over zone boundaries, distribution facilities and elevation contours) and analysed spatially (preferably on GIS) to confirm the necessity for pressure reduction in the prioritized zones and identify especially problematic high-pressure areas and/or pipelines which can be improved with relatively small investments (e.g. replacing a limited span of pipeline with high pressure rating pipes, installation of PRV and/or BPT) as opposed to large investments (e.g. zoning with reservoirs, replacement of pumps).

10.3 Pressure Reduction Measures

10.3.1 Selection of Suitable Pressure Reduction Measures

There are different ways of reducing excessive pressure in distribution networks. Table 10.1 shows a range of measures for pressure reduction seen in Kenya.

Table 10.1: Measures for Pressure Reduction in Water Supply Systems

Category	Large-scale Impact & Sustainable	Medium-scale Impact with low Sustainability		Small-scale Impact with Demerits
Facility / Equipment	Ground distribution reservoir 	Common Pressure Reducing Valve (PRV) capable of keeping outlet pressure constant 	Break-Pressure Tank (BPT) with a local float valve ingenuity 	Low-cost PRV usually used for tertiary Pipes, Boiler, etc. (its outlet pressure cannot be kept constant) 

Category	Large-scale Impact & Sustainable	Medium-scale Impact with low Sustainability		Small-scale Impact with Demerits
Advantage (Pro) and Disadvantage (Con)	Pro: (1) can cover a large area (2) easy to maintain Con: needs a large capital investment	Pro: its downstream pressure can be adjusted. Con: (1) can be expensive or low quality depending on manufacturer. (2) high-maintenance.	Pro: relatively inexpensive and low-maintenance Con: (1) its downstream pressure cannot be adjusted. (2) cannot supply water to surrounding households at same elevation. (3) may cause overflow.	Pro: low cost Con: (1) cannot reduce pressure very much at night (e.g., only 10m/1bar). (2) cannot be modelled in hydraulic analysis.

If a WSP has a heavily interconnected distribution network with large elevation differences, the network should be clearly separated into zones with ground reservoir(s), elevated tank(s) or distribution pump(s) dedicated for each zone. As shown in Table 10.1, using ground reservoirs would be the most effective and sustainable way to reduce excessive pressure over large areas although it requires a large capital investment.

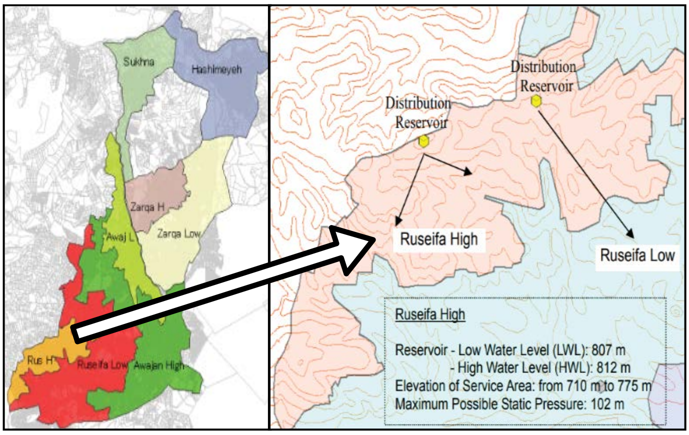
If a WSP has some high-pressure areas within separated zones, pressure reducing valves (PRVs) and/or break-pressure tanks (BPTs) can be used to reduce the high-pressure areas inside the zones.

If there are groups of customers who continuously draw water from high pressure branch distribution pipelines, low-cost PRVs incapable of keeping the downstream pressure at a constant level (see Table 10.1) may be installed on those distribution pipes or on their common service pipes for small-scale pressure reduction. However, the low-cost PRVs installed on branch distribution pipes may cause disruptively large pressure loss during high water demand hours and would probably reduce only 1 to 2 bar (10 to 20m) during late-night hours when pressure in distribution pipes is usually at its peak due to the limited water use at night.

10.3.2 Construction of Reservoirs/Elevated Tanks

Well planned water distribution from ground reservoirs is the best solution for large-scale pressure reduction. Pumping should only be used to distribute water to areas where gravity flow cannot reach, to transmit water into ground distribution reservoirs from which water is distributed by gravity or pumped; and to lift water to elevated tanks for gravity distribution. The main advantages of gravity flow distribution systems are that the pressure in distribution pipes remain relatively stable, water distribution is continuous even during power failures and; complicated operation of multiple distribution pumps (to follow hourly water demand changes) can be avoided.

Figure 10.9 and Table 10.2 is an example of how to zone distribution systems in a way that each DZ will supply to a limited elevation difference for pressure reduction using a ground reservoir for gravity distribution. When planning a gravity flow distribution from a ground reservoir or elevated tank, the boundary of DZ should be carefully considered with reference to elevation contours in order to keep water pressure within acceptable range. Selection of adequate pressure rating (e.g., PN16) for distribution and service pipes is also important to withstand the expected pressure and reduce pipe bursts and leaks, especially in areas where it's difficult to avoid high pressure. This is the example in Jordan as shown below.



Source: WAJ & JICA (2011) Guidelines on Distribution Network Management for NRW Reduction

Figure 10.9: Zoning of Distribution Systems conducted in Zarqa Governorate, Jordan

Table 10.2: Elevation Variation of Each Created DZ in Zarqa Governorate, Jordan

S.N.	Zone	Reservoir		Elevation variation in service area (m)	Static pressure Min ~ Max (m)
		Elevation (LWL–HWL) (m)	Capacity (m^3)		
1	Ruseifa High	807 – 812	1800	710 ~ 775	32 ~ 102
2	Ruseifa Low	750 – 756	6300	650 ~ 715	35 ~ 106
3	Awajan High	694 - 700	6300+ 4500	600 ~ 660	34 ~ 100

S.N.	Zone	Reservoir		Elevation variation in service area (m)	Static pressure Min ~ Max (m)
		Elevation (LWL–HWL) (m)	Capacity (m^3)		
4	Awajan Low	638 - 643	1800	550 ~ 600	38 ~ 97
5	Zarqa High	710 - 714	2500	615 ~ 708	2 ~ 99
6	Zarqa Low	645 - 654	14000+ 4000	530 ~ 625	20 ~ 124
7	Hashemeyeh	625 - 629	1500	530 ~ 610	15 ~ 99
8	Sukhna	585 - 589	1000	480 ~ 560	25 ~ 109
9	Hettein	786 - 790	3000 + 500	770 ~ 650	16 ~ 140

Source: WAJ & JICA (2011) Guidelines on Distribution Network Management for NRW Reduction

10.3.3 Pressure Reducing Valves and Break-Pressure Tanks

Pressure Reducing Valves (PRVs) and Break-Pressure Tanks (BPTs) can be used to reduce excessive pressure in relatively small areas compared to ground reservoirs. Figure 10.10 is an example of the effect of installing PRVs at the inlets of low-lying areas where the water pressure is highest in a DZ. Areas having PRVs or BPTs can be considered as DMAs if they have operating bulk meters at their inlets.

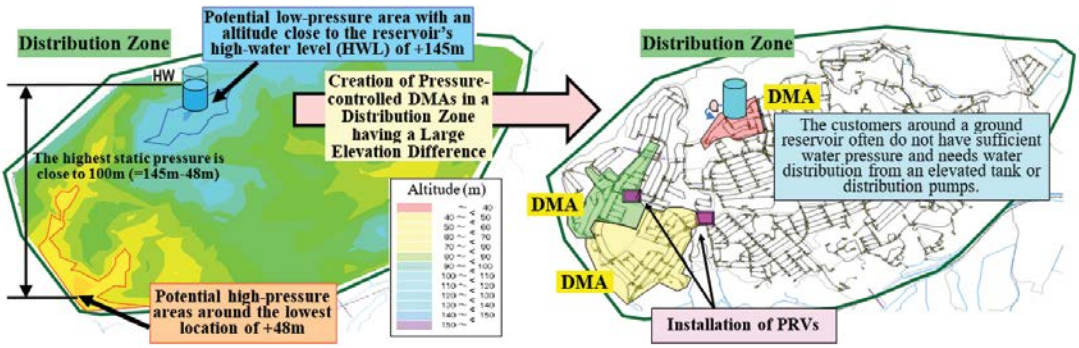


Figure 10.10: Establishing Pressure-controlled DMAs for Pressure Reduction within a Distribution Zone with a Large Elevation Difference

Low cost PRVs are more suitable than BPTs in built-up areas for the following reasons.

1) The outlet pressure of a PRV can be adjusted after installation and as the area develops over time and increase in the number of high-rise buildings.

2) The pressure at the outlet is not zero unlike for BPTs. Therefore, a PRV can be used to supply water to its nearby customers who are at a ground elevation similar to that of the PRV.

3) The site selection is easier for a PRV because the chamber of a PRV can be constructed on the roadside where the pipe is usually laid; unlike for BPT which requires larger spaces.

Use of PRVs is therefore recommended in urban areas. Unlike low-cost PRVs shown in Table 10.1, common PRVs for water distribution can keep the outlet pressure constant regardless of flow rate and upstream water pressure.

Advanced models of PRVs can automatically lower the downstream water pressure setting during late-night hours when water pressure is usually high due to low water demand. However, the maintenance cost of low-cost PRVs high especially where supplied water is silty and/or intermittent.

The PRV diameter need to always match the pipe diameter. Smaller diameter PRVs than the pipe should be provided with calming sections (10D and 5D lengths of the same diameter upstream and downstream respectively) to avoid cavitation which may occur causing damage to the PRV, hence the need for care in size selection.

Especially, when the range of pressure reduction is large, cavitation causes serious vibrations and noise, thereby wearing-off the valve seat.

Installation of isolation valves, strainer, air valve and bypass pipe inside the PRV chamber should also be considered to make the troublesome maintenance work of PRVs easier and sustainable.

On the other hand, BPTs that are simple structures with relatively fewer possibilities of breakdown can be recommended mainly for rural areas.

As shown in Table 10.1, local innovation using butterfly valve can be used to make more effective and sustainable float valves.

BPTs are sometimes vandalized to create overflow for irrigation purposes. The BPT should therefore have a tamper-proof locking mechanism to enable easy detection of overflow (e.g., by discharging overflow water onto the road surface instead of into a grass covered side ditch) to reduce water wastage.

10.3.4 Proper Use of Pumps for Direct Water Distribution and Water Hammer Prevention

Direct water distribution to customers by pumping instead of by gravity flow from storage tanks is currently not common in Kenya. However, with continuous improvement of distribution systems, such options will no doubt become available.

In a direct pumped distribution system, the flow rate of the distributed water varies greatly with time due to hourly water demand fluctuations. The maximum hourly flow rate of a distribution system can be ten times higher than the minimum hourly flow rate. This difference in flow rate may cause a larger pressure difference in pump-distributed areas than in gravity-distributed areas basically due to the pump characteristics (i.e., Pump-Head Curve). When the water demand reduces at late night, the friction pressure loss in pipes reduces and residual pressure rises. In addition to this, the discharge pressure of a distribution pump may also rise when its discharge flow rate reduces at night (as illustrated in Figure 10.11).

In order to prevent build-up of excessive pressure at late-night, it is necessary to carefully adjust the pump discharge pressure at a distribution pump station. One method of controlling the discharge pressure of pump is to adjust the number and combination of large and small capacity pumps that are operating at a given time in accordance with the hourly water demand fluctuations.

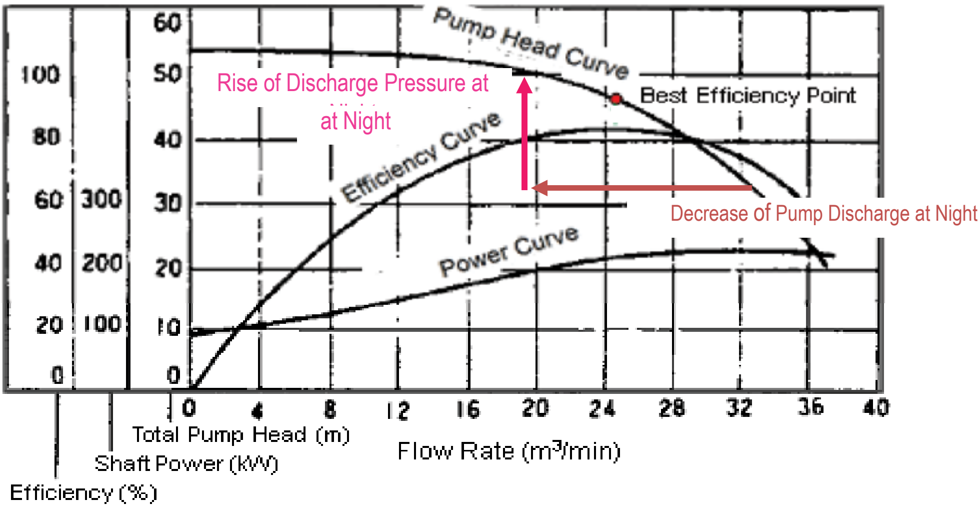


Figure 10.11: Typical Pump Characteristics showing Increase in Discharge Pressure due to Decreased Flow Rate

As illustrated in Figure 10.12, in a hilly area where water can only reach by pumping, limiting the extent of pump-distributed areas as much as practically possible is quite important to reduce the bursts and leaks caused by pressurized water as well as to reduce the number and size of the required pumps and power consumption.

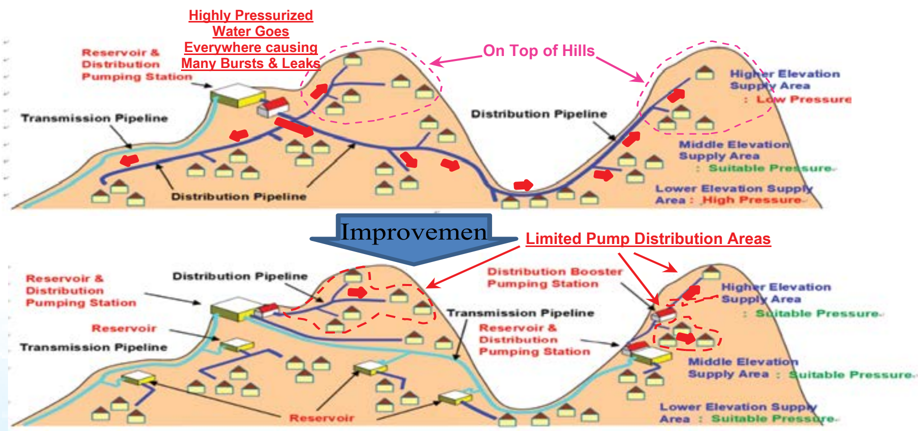


Figure 10.12: Suitable Use of Distribution Pumps & Booster Pumps for Limited Areas Only

Water hammer is a surge of pressure caused by a sudden stop of water flow in pipes. The sudden changes in water velocity due to pump-stop, for example, generates pressure waves which are rapidly transmitted through the pipeline system to the other end(s) where they bounce back. These pressure waves drastically increase and decrease pressure in the pipe network and damage facilities including causing pipe bursts. Water hammer increases when the pipeline is long and straight and has high flow velocity and fewer branches.

Figure 10.13 shows a typical distribution pumping station layout and installation points for common protection devices against water hammer. These devices (in order of increasing price and O&M cost) are check valve, flywheel on pump, air inlet valve, and air chamber (or one-way surge tank, surge tower, etc.).

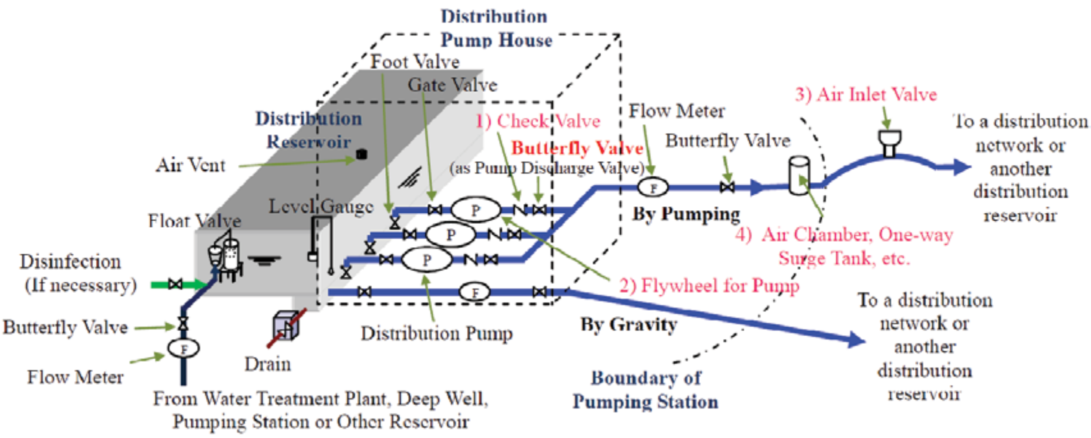


Figure 10.13: Common Water Hammer Protection Devices at a Distribution Pump Station

10.3.5 Different Levels of Hydraulic Analysis for Pressure Reduction

Hydraulic calculation is important to manage pressure throughout the water supply systems. Lengthy distribution pipes or service pipes of adequate diameter for the respective water demand often results in low pressure in certain areas. These low-pressure spots make pressure reduction over larger areas quite difficult. This is because serious water shortages would likely occur at the low-pressure spots if pressure is reduced without first resolving the low-pressure spots. The water shortage would also cause many customer complaints and eventual abandonment of the pressure reduction initiative. WSP staff should therefore routinely conduct hydraulic calculations to ensure suitability of new pipe sizes before installation to prevent any troublesome low-pressure spots.

Figure 10.14 shows the different hydraulic calculations for water pipes.

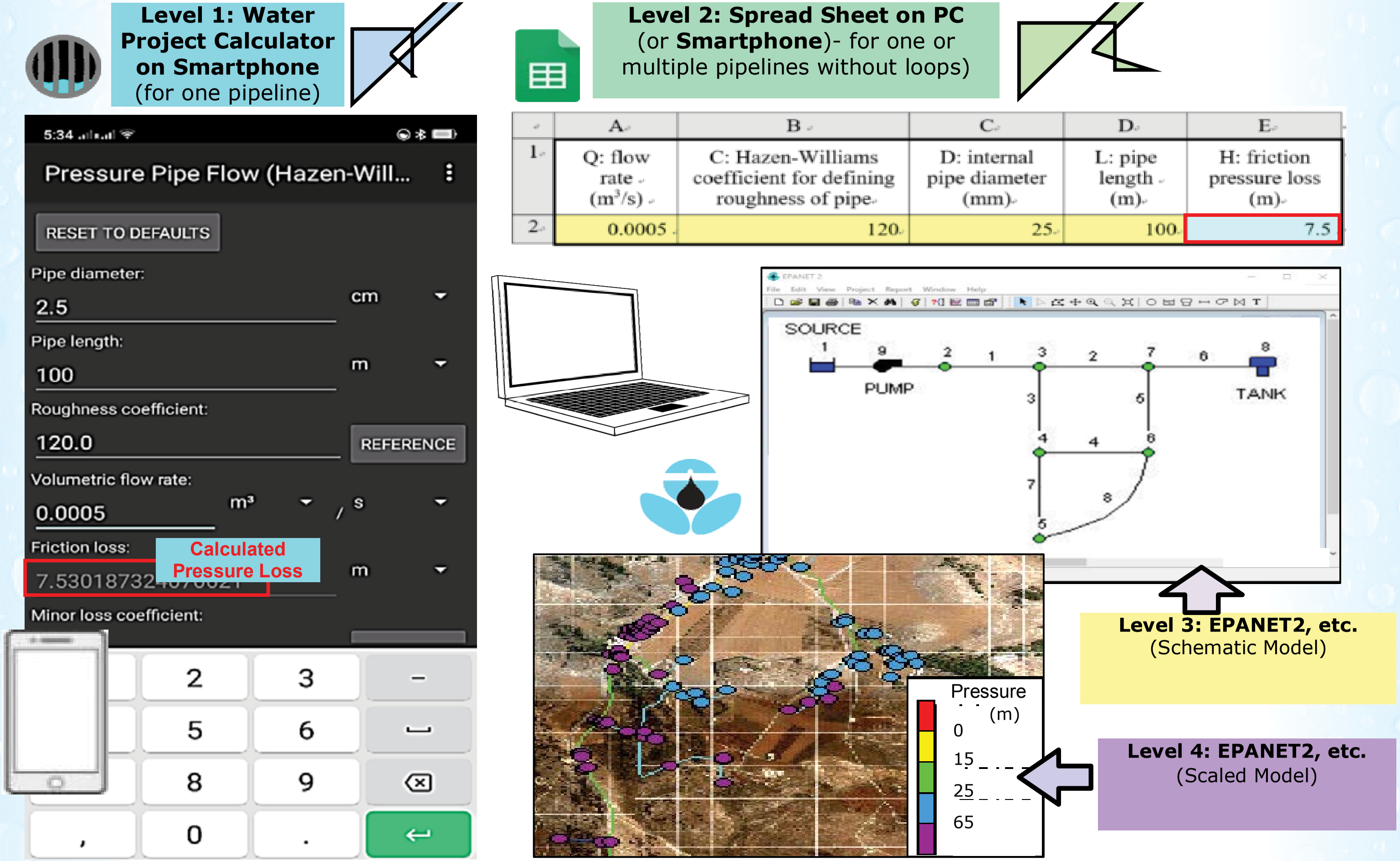


Figure 10.14: Selection of the Proper Level of Hydraulic Analysis and Appropriate Free Software

- If the target of hydraulic calculation is a single pipeline, a free software program called Water Project Calculator can be used (see Level 1 of Figure 10.14) to check the expected friction pressure loss in the pipe.
- If the target is multiple pipelines (different in sizes and/or material) connected in series, a spread sheet program like MS Excel on a PC may be used to calculate the total pressure loss in the pipelines (see Level 2).
- If the target is a distribution network having loops of pipelines, a free hydraulic analysis software program called EPANET 2 can be used. A transmission system or a rural distribution system can easily be modelled as a schematic model using EPANET 2 (see Level 3),
- However, a distribution network in populated areas probably requires a scaled model, which can be created on a scaled background map (e.g., satellite imagery with elevation contour lines) imported onto EPANET 2 (see Level 4).

Figure 10.15 explains how to calculate the friction pressure loss of a single pipeline using Hazen-Williams Formula on MS Excel.

< Hazen-Williams Formula in SI Units >

$$H = 10.666 * Q^{1.85} / C^{1.85} /(D/1000)^{4.87} * L$$

Wherein, H: frictional pressure loss (m), Q: flow rate (m^3/s), C: Hazen-Williams coefficient for defining roughness of pipes, D: internal pipe diameter (mm), L: pip length (m)

Calculation of Friction Pressure Loss using MS Excel

The below table (in an Excel Spreadsheet) shows an example of calculated friction pressure loss at one of the conditions shown in the figure above.

	A	B	C	D	E
1	Q: flow rate (m^3/s)	C: Hazen-Williams coefficient for defining roughness of pipe	D: internal pipe diameter (mm)	L: pipe length (m)	H: friction pressure loss (m)
2	0.0005	120	25	100	7.5

Enter this equation of the Hazen-Williams formula!

E2=10.666*A2^1.85* B2^-1.85*(C2/1000)^-4.87* D2

Figure 10.15: Calculation of Friction Head Loss in a Pipeline using Hazen-Williams Formula in MS Excel

10.3.6 *Pressure Reduction/Management with Relatively Small Investments* (e.g., PRV, BPT, etc.)

(**Note:** The procedure below is only for WSPs considering implementation of pressure management with relatively small investments)

1) Ensure that pressure reduction/management measures with relatively small investments listed in Table 10.3 below, such as sub-zoning with PRV and/or BPT, removal of bottleneck pipes, etc. (excluding large investments such as construction of distribution reservoirs and/or pump stations for large-scale zoning of distributing networks) are considered, planned and implemented for the identified problematic areas and pipelines having high pressure and/or many bursts (within zones prioritized for pressure measurement and reduction).

Table 10.3: Pressure reduction/management measures with relatively small investments

a) Replacement of pipelines experiencing high pressure with high-pressure rating (e.g., PN16) pipes effective for leak reduction (e.g., long rolled HDPE pipes)	
Better Pressure Control	b-1) Pressure reduction by installing PRVs (which are adjustable and capable of distributing water to the customers around them due to the residual downstream pressure but of high maintenance) and/or constructing BPTs (which are neither adjustable nor capable of distributing water to the surrounding customers due to zero residual downstream pressure but of relatively easy maintenance)
	b-2) Installation of a booster pump for a limited high area instead of using a high-head distribution pump for a large area encompassing the high area
	b-3) Prevention of water hammer in long pumped pipelines (e.g., installation of non-return and butterfly valves on the discharge pipe of pump, flywheel to the pump shaft, air inlet valve, air chamber, on-way surge tank on the pipeline, etc.)
c) Inclusion of high-pressure pipelines into a neighbouring zone having relatively low pressure by shifting the zone boundary with minor network modifications	

2) To reduce pressure without causing serious complaints of excessively low pressure in certain areas, ensure the following supporting measures are well considered (and implemented if necessary):

   (i) Removal of bottleneck or long pipes causing high pressure losses (especially pipelines going up hills) by replacing with larger pipes or augmenting capacity with additional pipes.

(ii) Removal of air trapped at high locations of pipelines (i.e., air lock) using additional air valves, etc.

(iii) Detection and repair of hidden large leaks causing localized large pressure drops.

3) Ensure that facilities improvement for pressure reduction are planned based on the following hydraulic considerations (in addition to pressure measurements and analysis of terrain around target pipelines using elevation contours):

(i) hydraulic calculation for pipeline with free software on smartphone (e.g., Water Project Calculator).

(ii) hydraulic analysis for multiple pipelines without loops using spread sheet (e.g., MS Excel).

(iii) schematic or scaled hydraulic modelling of pipe network with free software (e.g., EPANET 2).

4) Ensure that pressure measurements, identification of problematic areas, planning and implementation of pressure reduction measures are also carried out in other zones (that were not initially prioritized).

10.3.7 Pressure Reduction/Management with Relatively Large Investments

(e.g., Zoning with Reservoirs, Pump Replacement, etc.)

Note: This procedure is only for WSPs considering implementation of pressure management using relatively large investments

1) Ensure that the necessity of taking the following pressure reduction/management measures that require relatively large investments (that probably cannot be budgeted from the operational revenue of the WSP) are considered.

(i) Large-scale zoning of distribution pipes with additional reservoirs, elevated tanks and pump stations to limit elevation difference of each DZ.

(ii) Separation of distribution pipes from transmission pipelines to control pressure in distribution pipes or keep sufficient pressure in transmission pipelines even when a large amount of water is extracted directly from the transmission lines for distribution.

(iii) Replacement of existing pumps having excessive pressure head with pumps with suitable head.

2) Ensure that application of pressure reduction/management measures (using relatively large investments) deemed necessary through the above consideration are planned (including future water demand projection and rough cost estimates).

(**Note:** these relatively large investments should not be planned only for pressure reduction but also for improving zonal NRW monitoring, equalizing water distribution and resilience against risks such as power cuts, service areas expansion, etc).

3) Ensure that the planned improvements with relatively large investments are incorporated into the latest WSP's strategic plan (partly for seeking external funds) and/or into the tariff adjustment application of WASREB with required budgetary provision.

4) Ensure that the design, bill of quantities, detailed engineer's cost estimates and tender documents for the planned improvements are prepared for bidding.

5) Ensure that the planned improvements are implemented soonest or as funds permit.

Chapter 11

Cost-Benefit Analysis

11.1 Outline of Cost-Benefit Analysis

Cost-Benefit Analysis is the comparison of the change (increment or decrement) of the benefit from the current status.

It is probably fair to say that most utilities would benefit from an NRW management programme. However, the big question is usually the extent of the potential benefits. Therefore, it is important for water utilities to consider conducting Cost-Benefit Analysis when they are trying to determine the scope of the NRW reduction measures that should be implemented. Cost-Benefit Analysis will show the effects of the invested cost by comparing the benefit obtained with the cost invested.

Normally cost and benefit are correlative. Therefore, when more cost is invested, more benefit can be expected. In the application of NRW reduction measures however, when a certain level of low NRW ratio is achieved, the correlative benefit cannot be expected, no matter how much more cost is invested. This is usually observed around the NRW ratio of 15% although it depends on the conditions of the water utility.

In Kenya where the average NRW ratio is at 41% or above, the priority should be placed on bringing down the NRW ratio to the sector benchmark of 20%. Once a low NRW ratio of below 20% is achieved, then a detailed Cost-Benefit Analysis can be performed to assess whether injecting cost to NRW reduction measures is advantageous or not.

11.2 Cost of NRW Reduction Measures

For this purpose, the actual cost spent during the implementation of Pilot Project NRW reduction measures should be used. The following items and the costs associated with the items should be used as reference when extending the NRW activities to adjacent areas.

- Organizational maintenance cost: personnel cost, office maintenance cost
- Purchase of equipment and material and maintenance cost for equipment
- Cost of establishing DMAs/LMBs
- Cost for installing measuring devices
- Cost of servicing and testing/replacing all customer meters
- Cost of leakage / water theft control
- Cost of pipe replacement

Attention must be paid to the extent to which costs for renewal of facilities such as pipes and/or water meters are included, especially if regular or periodic facility replacement plan is not in place.

It is absolutely imperative to have a proper sustainable O&M guideline for any water utility to function well. Sustainable O&M measures should be obviously included in the ordinary facility replacement plans.

Adequate budget for the implementation of NRW reduction plan should be provided in accordance with the strategic objectives and prioritization of activities of the WSP.

Planning for facility replacement according to the ages of the facilities is the more suitable planning method, rather than including it as part of NRW reduction measures.

Facility replacement should therefore be considered as the duty of waterworks utilities, and not be included as part of NRW reduction activity. Cost-benefit analysis for NRW reduction measures should only include cost of those pipes requiring urgent replacement as a result of frequent numerous leaks.

Existence of pipes with frequent numerous leaks may be a reflection of the status of the utility.

11.3 Benefits of NRW Reduction Measures

The calculation of “benefit” for NRW reduction measures takes into consideration the volume of NRW reduction before and after the implementation of the reduction measures. Once the figures are obtained, either:

a) Profit from increase in volume of revenue water: - in utilities where water demand is much higher than distributed water, the volume of water saved as a result of implementation of the NRW reduction measures can be considered as increase in volume of revenue water. In other words, the water that is “saved” as a result of NRW reduction measures can now be tariffed water and considered as “benefit”.

b) Raw water/treated water/profit from reduced cost of water distributed: - in utilities where volume of water distributed meets the water demand, the cost of producing the volume of water “saved” can be considered to be profit. Reduction in operational cost such as chemical cost and/or electricity costs associated with reduced production of water can be considered as “profit”.

11.4 NRW Management Considering Cost-Benefit Performance

When estimating the economic value or cost/benefit of NRW projects, consider the following:

i) The additional revenue that will be generated owing to higher volume of water
ii) The reduction in operating costs that may occur
iii) Improvement in service delivery
iv) The cost of implementing the projects

It is strongly recommended that cost-benefit analysis should be conducted based on the results obtained from the Pilot Project. The results should then be extended to other adjacent areas. The purpose of conducting a cost-benefit analysis to obtain maximum effects and benefits. Through the cost-benefit analysis, the profit-loss break-even point is determined (Figure 11.1).

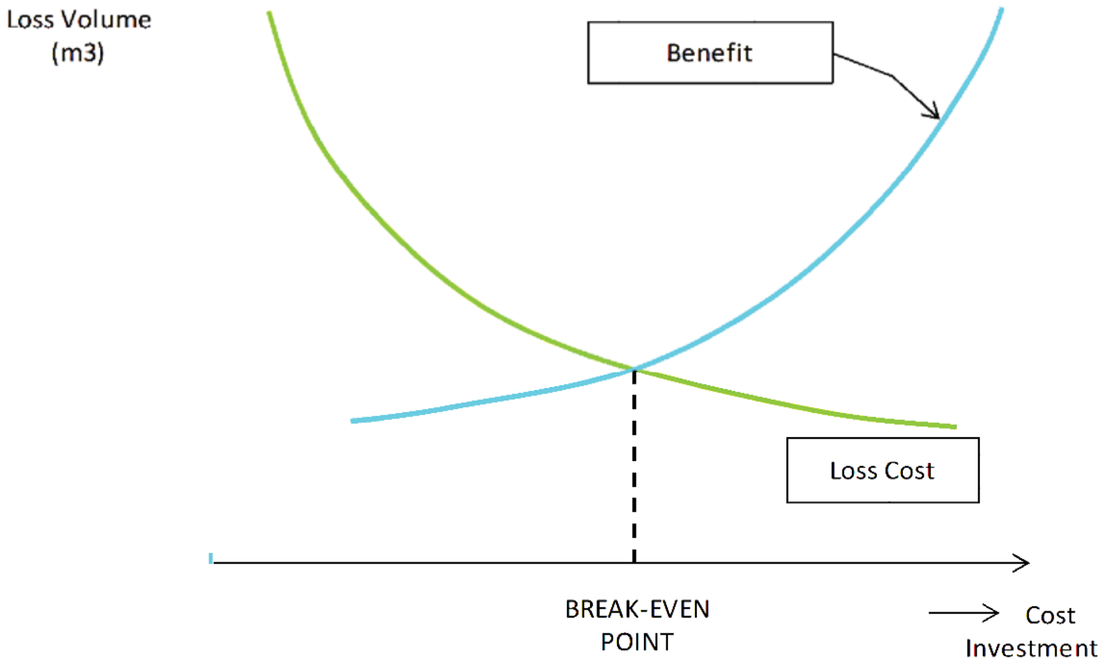


Figure 11.1: Graph of Cost-Benefit Analysis

The Graph depicts the cost-benefit analysis with the assumption that funds invested into NRW reduction measures are most effectively used when the funds are injected at the profit-loss break-even point.

In regard to the cost-benefit calculation, the figures may greatly change depending on the level of consideration that is placed on the cost and the benefit.

The most difficult point regarding calculation of cost-benefit is determining the extent to which the cost of leakage repairs and pipes replacement can be considered as NRW reduction costs. Decisions of this nature may highly depend on the policies and/or strategies of the water utility, because leakage repairs and pipes replacement are considered as part of the fundamental and mandatory operations of water utilities. For this reason, therefore, it is normal that only those costs associated with replacement of pipes that have numerous/frequent leakage occurrence are considered as part of the NRW reduction costs but costs associated with planned pipe replacement should not be considered as part of NRW reduction costs.

"Cost" for the cost-benefit analysis of the pilot project should reflect the amount of funds spent. In regard to the "benefit", the amount of benefit that was achieved by the implementation of NRW reduction measures must be calculated. Cost must then be compared to the benefit and the disparity must be checked. In most cases, the final decision on what NRW reduction measures to be implemented will be conducted based on the results obtained by cost-benefit analysis. In addition to the results obtained, there will be policy and/or strategy including political factors to be considered.

Such considerations are necessary because implementing the ideal NRW reduction measures require tremendous amount of funds and labour. It will be difficult for the majority of the water utilities in the developing countries to implement the full-scale activities. Often, items such as full-scale construction of DMAs are omitted from the activities to be implemented.

11.5 Example of Cost-Benefit Analysis

The following is an example of cost-benefit calculation of Embu WSP from the results of an implemented pilot project.

The real costs of implementing the project and real results (benefit) achieved are used in the example. The results should be used as a basis for preparing NRW reduction plans for adjacent areas within the supply area.

The performance data of the Embu WSP Pilot Project was:

- NRW ratio : 48%
- Total length of distribution pipe : Approx. 700 km to 1000 km
- Total number of connections : 5000 to 6000 connections
- Population served: 15,000 to 20,000 people
- The structure of Embu WSP NRW Reduction Measures Team was composed of: Supervising Engineer : 1 person
- Technicians : 4 people
- Skilled staff : 10 people
- Administration staff : 2 people

Table 11.1 to 11.3 provide an example of Cost-Benefit Analysis from a pilot project in Embu WSP.

Table 11.1: Cost Items (costs from NRW reduction measures)

Cost Item		Formula
1	Labour cost	Average salary x number of persons
2	Purchasing cost of materials and equipment	Unit price of leak detector, MNF measuring car, etc. x respective quantity
3	Construction cost of DMA and LMBs	Purchasing expenses of flow meters, pressure gauges and valves + construction expenses
4	Installation cost of trunk measuring equipment	Purchasing expenses of flow meters and pressure gauges
5	Replacement cost of malfunctioning customer meters	Purchasing expenses of customer meters
6	Office maintenance cost	Annual office maintenance expenses
7	Repair cost of leaks and illegal connections	Unit repair expenses of leaks and illegal connections x respective quantity
8	Pipe replacement cost	Unit replacement expenses of mains and service pipes x respective quantity

Note: Usually, most costs of No. 2, 3, 4, 5, 7 and 8 are considered as mandatory costs.

Table 11.2: Benefit Items (benefit from effects of NRW reduction measures)

Benefit Item		Formula
1	Profit from increase in revenue water	Unit sales price x Annual volume of increased water x no. of years accrued
2	Profit from reduced operating cost	Unit production cost x Annual volume of reduced leakage x no. of years accrued
3	Profit from postponement of development cost of new water resources	Unit cost of developing new water resources x Annual volume of reduced leakage
4	Profit from postponement of construction cost of new waterworks facilities	Unit facilities construction cost x Annual volume of reduced leakage

Table 11.3: Calculation (Cost-Benefit Analysis)

Cost (for 3 (three) years)	
Cost of staff related with NRW reduction	14,490,000
Cost of pipe replacement (including construction cost)	1,750,000
Cost of meter replacement	949,000
Sub-total of Costs	**17,189,000**
Benefit	
Reduced volume	434,472
Unit price of water tariff	65
Sub-total of Benefits = KShs (434,472x65)	28,240,680
Profit over 3 yrs (= 28,240,680 - 17,189,000)	**1,105,680**

Chapter 12

Example of Workflow in a Pilot Project

⇔ WASPA's NRW Roadmap

12.1 Basic and Pilot Activities

The proposed roadmap includes 4 main components

1) Raise company-wide awareness and support (aimed at capturing the attention of the management on the magnitude of the Water lost both as % and volumes and appoint a task team with duties and responsibilities to carry-out the defined duties).

2) Obtain a clear picture of the NRW problem for the entire company (This activity is meant to showcase insights of underlying issues and the proposed response strategies).

3) Divide the NRW problem into manageable pieces and conduct pilot NRW reduction measures. The step-by-step implementation of activities should be tracked, starting with selection and isolation of prioritized area. Implementation of activities and daily monitoring on the focus area should be sequenced to ensure reduction and sustainability are clarified well.

4) Prioritize response measures in a Performance Improvement Plan. (The pilot serves to make a business case for scaling up the demonstrated approach to the entire supply area. A Performance Improvement Plan (PIP) that is well aligned to the corporate goals should highlight priorities on the basis of their contribution to the achievement of corporate objectives and anticipated results) refer to WASPA Roadmap to NRW Reduction athttps://rb.gy/rdwmlo

12.2 Preparation (Basic) Activities

12.2.1 Selection of Priority Areas (DZ or DMA)

Selecting a pilot DMA

The general characteristics of a supply system are important aspects to be considered for the selection of a pilot DMA. The understanding of the water source, means of supply/distribution (gravity/pumping) as well as the system characteristic (continuous/ intermittent) should inform the selection.

Important criteria for selecting a pilot area include:

- "High NRW' area (suspected commercial and/or physical losses)
- Manageable number of connections (about 500 connections)
- Relative ease of isolating the DMA with as few district meters as possible (i.e., clear out-skirts of distribution network and if possible, with minimum number of bulk meters)
- 24/7 water availability (since lack of water/low pressure levels undermine reliability of meter readings and the subsequent water balance calculations and night flow measurements)

12.2.2 Isolation of the Pilot Area

Zoning of the supply area

Since acting in the entire supply area at the same time is impossible, the area should be divided into manageable pieces. The most important criteria for zoning are:

- topography and water pressure
- pipeline network layout (i.e., natural DMA catchments and NOT administrative boundaries)
- number of customers (500 to 1,500 connections per DMA)
- water availability

Isolate the pilot DMA (while developing the block map)

At the start of the pilot project, the NRW team requires to:

a) Install meters and valves in tamper-proof chambers on all incoming lines (into DMA) and outgoing lines (from DMA) and,

b) Verify which consumers are (and are not) supplied by the incoming lines (by closing valves and verifying whether or not they still receive water) and deliberately including (or excluding) them in the DMA water balance calculations.

12.2.3 Customer Identification and Visual Meter Inspection

Door-to-door consumer and meter survey

This survey serves to:

a) confirm/link consumer data in the field with billing data and update consumer details (name, telephone number, email) and meter details (brand, type, size, material, date installed, serial number, GPS coordinates7), and

b) identify and address potential meter by-passes and illegal connections.

12.2.4 Monthly Bulk Meter Reading & Initial NRW %

Zero reading of all district and consumer meters followed by a second reading two weeks later to establish the NRW baseline value

a) To optimize the accuracy of the water balance calculation, it is recommended that all valves on incoming and outgoing lines be closed before reading all district and consumer meters (on day 1 and day 16), before resuming the supply

b) Subject to the reduced NRW levels in a given month, two-weekly or monthly readings will suffice depending on the scope of the NRW reduction measures taken or planned – the impact of which can be evaluated on the basis of the next two-weekly or monthly water balance calculation.

c) Daily monitoring of DMA consumption levels (e.g., done in Meru & Nyeri) serves as an early (leakage) warning tool, while monthly monitoring of consumer specific consumption levels serves to identify outliers requiring in-field inspection of potential meter inaccuracies or illegal consumption.

12.2.5 Customer Identification and Visual Meter Inspection

Door-to-door consumer and meter survey

This survey serves to:

a) confirm/link consumer data in the field with billing data and update consumer details (name, telephone number, email) and meter details (brand, type, size, material, date installed, serial number, GPS coordinates7), and

b) identify and address potential meter by-passes and illegal connections.

The result: new billing system entries and/or cleaned-up double or ‘ghost’ entries.

12.2.6 Mapping of Customer Meters & Distribution Facilities

Initiate the mapping and collection of attribute data for all assets

Required for:

a) the system as a whole to demarcate DMAs), and

b) the pilot area i.e., showing incoming/outgoing DMA meters, valves, service connections/meters, etc.

Basic steps in reducing and sustaining NRW levels in the pilot DMA

This involves implementing activities pertaining in all 4 categories of commercial and physical losses (Figure 12.1).

The sequence of the proposed steps naturally speaking focusses on addressing 'quick wins' first i.e., meter inaccuracies, meter reading data collection and entry reliability, unauthorized consumption (commercial losses) and visible leakages (physical losses).

Key activities in the (pilot) DMA(s) include: -

a. Zero reading of all district and consumer meters followed by a second reading two weeks later to establish the NRW baseline value.

b. Repair all visible leakages and pressure level measurement/management

c. Door-to-door consumer and meter survey

d. Testing and calibration of production and district meters

e. Testing and servicing/replacement of all faulty and under-registering consumer meters

f. Reduce the number of gate-locked cases

g. Inspect all 'disconnected' consumers and 'dormant' connections

h. Minimum Night Flow (MNF) measurements (entire DMA) and step testing (DMA branches) to quantify and localize invisible leakages

i. Improve the speed and quality of repairs

j. Improve the quality of materials

k. Daily monitoring of DMA consumption levels monthly monitoring of customer specific consumption levels.

Implement the 'full-scale' NRW reduction/management activities in a pilot DMA

The main purpose of this activity is to demonstrate how the piloted NRW reduction/ management approach can be scaled up to other District Metering Areas.

The four internationally (IWA) recognized categories (and related response strategies) for both commercial and physical losses are presented below: -

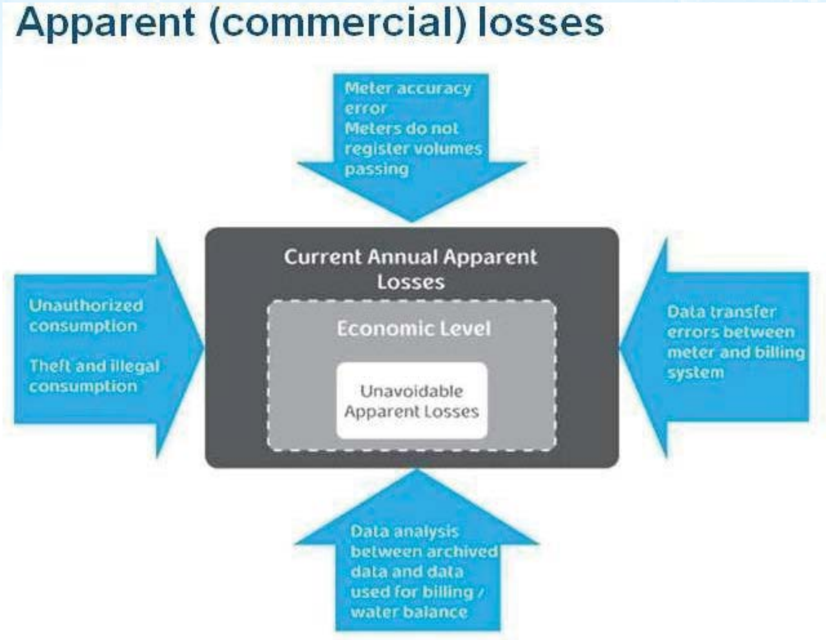


Figure 12.1: Components of apparent (commercial) losses

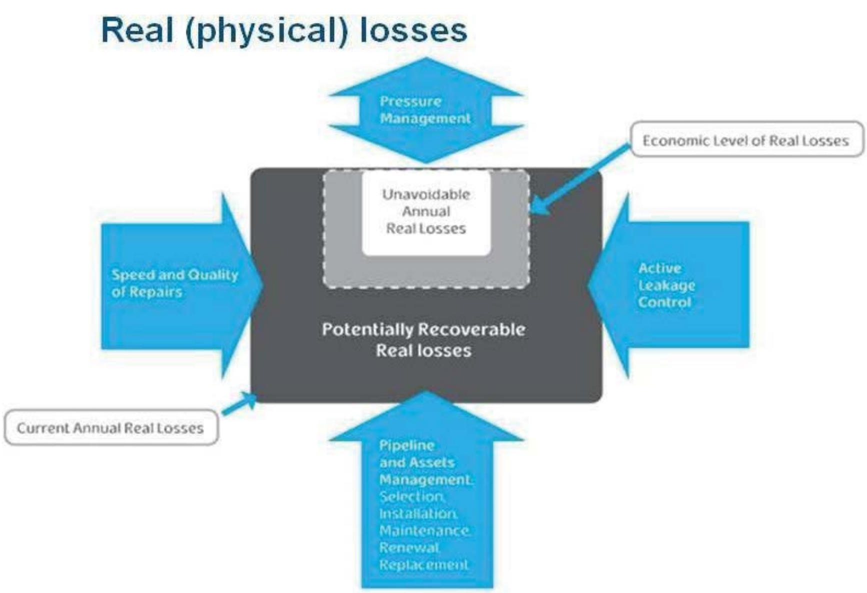


Figure 12.2: Components of real (physical) losses

12.3 Relatively Low-cost and/or Easy (Basic) Activities

12.3.1 Repair of Surface Leakage

a) Visible leakages repair and pressure measurement/management

As part of the longer-term objective to develop a comprehensive asset management strategy, this activity involves the development (or refinement of existing) line patrolling and/or leak identification and reporting procedures. The assessment and management of pressure should be included as part of this activity.

b) Improve the speed and quality of repairs

While most WSPs have established leak reporting procedures, very few actually analyse the leakage trends (number in time, number per zone, number per pipe size, number per cause), locations (so as to identify recurrent leaks that point to dilapidated infrastructure, poor quality material and/or poor-quality repairs) and accurately record the time of leak discovery and repair (the basis for evaluating the speed of repairs)

c) Improve the quality of materials

Most WSPs have taken deliberate steps to improve the quality of materials, e.g., by using:

- Class D or even Class E PVC for transmission mains - an improvement from the lower PVC Classes used by the Municipal Councils in earlier years and,
- PPR (6m pipes e.g., Nakuru WSP) or HDPE (100+ meter rolls e.g., Nyeri WSP) materials for service connections.

Nonetheless, (recurrent) leaks are often caused by a combination of the following factors:

- Quality of repair: classic examples include poor quality PVC connections glued under wet conditions in the absence of upstream control valves and/or the absence of appropriate fittings between pipes of different materials and sizes,
- Quality of materials: Class C (or lower) PVC pipes that are vulnerable to high pressure
- Other factors: exposed lines due to shallow depth of installation/erosion/poor backfilling and, direct & ‘spaghetti’ connections to transmission mains.

12.3.2 Improvement of Customer Meter Registration and Reading

Meter Reading

Improvement of customer meter registration and reading needs to consider the following:

- Optimization of meter reading routes and workload (e.g., meters/day) for teams and individuals by, e.g., using Google Earth.
- Use of 'rotational' meter reading method or 'motivational' (caretaker) meter reading method
- Combination of meter reading, consumer contact information validation, scanning for (potential) illegal connections etc. in one data collection sheet.
- Sample-based verification of meter reading accuracy by independent staff; e.g., the NRW coordinator.
- Retroactive billing of gate-locked consumers based on meter testing variance with the reading.

Note: validation of samples of reported consumer meter readings, meter reading entries in the billing system, 'gate-locks' (12.3.5 (a), disconnected consumers and dormant connections (12.3.5 (b) by the NRW Coordinator or other (independent) technical staff can serve to keep meter readers on their toes and minimize (potential) consumer-staff collusion.

Transfer of Meter Reading data

- Use of data loggers to minimize transfer (wrong accounts) and consumption (volume) errors.
- Verification of a sample of meter reading data entries in the billing system by independent staff e.g., the NRW coordinator.

12.3.3 100% Metering & Replacement of Obvious Faulty Meters

100% metering of all consumers is essential in determining the actual NRW level and calculate the percentage commercial loss.

Testing and servicing/replacement of all faulty and under-registering consumer meters. The analysis of the causes of faulty and under/over-registering meters (dirt, sub-standard specifications, sub-standard quality, age) and locations of leakages are important for a comprehensive asset management strategy.

Note 1: meter testing can be combined with the door-to-door consumer/meter survey.

Note 2: by monitoring the consumption patterns of individual customers (zero and/ or low consumption connections) (e.g., based on DMA averages), specific customer meters can be identified for inspection.

12.3.4 Meter Accuracy Test and Replacement of Inaccurate Meters

Meter accuracy

- 'Quality assurance' through rigorous technical specifications (e.g., accuracy of low flow measurement) in the procurement process and validation of compliance upon delivery.
- Use of strainers to minimize damage to mechanical meters as result of poor water quality (e.g., little stones damaging impellers).
- Testing of small diameter meters with portable meter testing kits, test-meter in series or meter testing benches e.g., every 3 years and/or triggered by client specific consumption monitoring after installation/servicing/replacement.
- Testing of large diameter (production and district) meters with Ultrasonic 'clamp-on' Flow Meters e.g., every 3 months.
- Sealing of tested meters to prevent future tampering.
- Backdated billing of over/under-registering meters based on the testing variance.

12.3.5 Identification and Prevention of Illegal Uses

a) Reduce the number of gate-locked cases

This activity requires the team to pro-actively engage 'gate-locked' consumers through phone/SMS/email and (subsequently) disconnect non-compliant consumers. In doing so, the number of bills based on estimates and (potential) water theft can be reduced. This serves to improve water balance accuracy and revenue collection.

b) Inspect all 'disconnected' consumers and 'dormant' connections

This activity aims to minimize (potential) water theft by verifying that disconnected customers are not consuming water illegally and dormant connections are not receiving water (again).

c) Provide rewards for information that lead to discovery of illegal connections.

Many companies reward consumers and/or staff for providing information leading to identification of illegal connections e.g., Kshs 10,000 (Nyeri). Examples of disincentives to consumers include Kshs 15,000 fines for illegal connections/by-passes and back-dating of bills by 24 months (Nakuru).

12.4 Relatively High-cost and/or Difficult (Pilot) Activities

12.4.1 Use of specialized equipment

Some utilities have the Specialized NRW equipment.

WASPA acquired some equipment under PEWAK program. The equipments are availed to WSPs on hire. WASPA also provides training on their use for effectiveness.

KEWI, being a member of the JICA program, formulated a training course on use of NRW equipment for interested WSPs using the equipment procured under the program. WSPs with practical experience in daily use of the equipment should ensure that the acquired skills are utilized for RW reduction/management activities.

12.4.2 Detection and Repair of Underground Leakage

(a) Minimum Night Flow (MNF) measurements (entire DMA) and step testing (DMA branches) to quantify and localize invisible leakages

MNF measurements serve to quantify the invisible leakages by measuring the flow into a DMA branch when consumers are asleep (i.e., between 12.00am and 4am) and consumption has dropped to a bare minimum, The prevalence of premises storage tanks and their filling time (if at all at night) should be taken into account.

The lost volume due to invisible leakages can be detected by conducting MNF measurements on DMA branches, thus enabling trained staff to locate the leak with specialized equipment (listening sticks, ground microphones, leak noise correlators, etc.).

Note: the location of distribution lines, valves and other assets must be known (mapped) for planning and implementation of MNF and step-test measurements.

12.4.3 Water Pressure Control

Pressure management

- Measuring and monitoring high pressure in suspected areas.
- Use of PRVs/BPTs to lower pressure and minimize water losses (Nyeri, Meru, Embu).

12.4.4 Replacement of Distribution & Service Pipes Aspects (26) & (27)

a) Improve the speed and quality of repairs

While activity 12.3.1(a) focuses on the repair of earlier unnoticed/unreported visible leaks and activity 12.4.2(a) focuses on the identification and repair of invisible leaks within the (pilot) DMA. This activity aims to assess, evaluate and improve the speed and quality of repairs for the supply area as a whole.

While most WSPs have established leak reporting procedures, very few actually analyse the leakage trends (number in time, number per zone, number per size, number per cause and locations to identify recurrent leaks that point to dilapidated infrastructure, poor quality material and/or poor-quality repairs) and accurately record the time of identification and repair (the basis for evaluating the repairs speed).

b) Improve the quality of materials

Most WSPs have taken deliberate steps to improve the quality of materials, for example by using:

- Class D or even Class E PVC for transmission mains - an improvement from the lower PVC Classes used by the Municipal Councils in earlier years, and PPR (6meter pipes e.g., Nakuru) or HDPE materials (100-meter rolls e.g., Nyeri) for service connections.

12.4.5 Introduction of Smart Customer Meters

Smart meters or Automatic Meter Reading (AMR) gadgets continuously transmits the readings to a receiver such as a computer. The data can then be used for billing, customer consumption pattern analysis, etc.

Some WSP's have adopted the technology, which has its Pros & Cons.

WSPs are advised to try on pilot basis before going full scale which would be a substantial investment.

12.5 Evaluation for Expansion of Activities

12.5.1 Confirmation of Reduced NRW (%) & MNF

By conducting MNF measurements on the incoming line(s) after identifying/repairing all visible leakages (assuming there is no authorized unbilled consumption), the remaining commercial losses can be estimated by subtracting the MNF volume from the total NRW volume.

12.5.2 Analysis of Effective Measures

To monitor and evaluate the extent to which activities have contributed to the achievement of the corporate objective of NRW reduction, (among others), regular reporting on prioritized Performance Indicators (PI's) is a must:

a) Current status: progress vis-à-vis the PI baseline value and target.

b) Time frame: Progress vis-à-vis set timelines.

c) Strategy and actions: Evaluation of the effectiveness of the adopted strategy and actions to achieve the set PI target(s).

d) Budgets: Budget utilization and refinement.

e) Other needs: Supplementary requirements pertaining to staff (e.g., NRW team capacity, training), equipment (e.g., leak detection) etc.

f) Risks: Foreseen and emerging risks of pursuing individual/parallel NRW reduction measures.

g) Partner WSP(s): to contact/visit for benchmarking and learning.

12.5.3 Expansion of Activities to Reduce Overall NRW Ratio

a) Documentation of the action-learning process and results is crucial.

- Increase the understanding of the main causes and contributions of commercial and physical losses to the total 'volume of water and money lost',
- Refine the response strategy based on emerging evidence as to what works and what does not, and
- Future up-scaling efforts.

b) Develop a business case for scaling-up the demonstrated approach to other supply zones

The business case must be preceded by an up-scaling strategy that spells out the sequence of activities to:

- Quantify and localize (the highest) NRW losses through zoning of the entire supply area (as was done for the pilot DMA),
- Replicate the piloted approach to: (a) DMAs with the highest NRW losses - NRW baseline volumes established through water balance calculations, or (b) DMAs identified on the basis of other criteria (if the entire network has NOT yet been divided into DMAs)

- Gradually develop and implement a comprehensive asset management strategy that considers all aspects of asset selection (e.g., choice of material), installation (e.g., depth of distribution lines, quality of connections), maintenance, renewal and replacement.

Informed by the results from the pilot and 'up-scaling' DMAs, the business case serves to project the additional costs and anticipated revenues of the NRW reduction/ management activities for endorsement by the Management Team and Board of Directors.

c) Organizational measures

Organizational measures that positively contribute to the achievement of any overall objective, including NRW, are presented below:

- **Agreeing on roles and responsibilities**

It is important to clearly define the roles and responsibilities of all stakeholders in the process. This creates a common understanding of each person's envisaged contribution and underpins the collaborative effort towards achievement of a common goal.

- **Organizing planning and review meetings**

While weekly team meetings help to keep staff focused, emerging issues should be discussed on a day-to-day basis as they arise. An open-door policy by top and mid-level managers further allows lower cadre staff to voice their (possibly divergent) opinions and provide suggestions based on experience on the ground.

- **User to be part of Inspection and Acceptance Committee**

The integrity of the Inspection and Acceptance Committee (I&AC) must be held high. Deterrent measures for corrupt (I&AC) members, including surcharge and loss of job. Maintain transparency in all procurements.

- **'Caretaker approach'**

Experience in supporting water utilities to reduce NRW levels world-wide has led M/S Vitens Evides International (VEI), a Dutch company, to develop and promote a 'caretaker approach' in which a dedicated area manager, referred to as a 'caretaker', is given the responsibility to lead a joint (commercial/technical team) effort to reduce and sustain NRW achievements within a designated DMA. This arrangement ensures that NRW reduction/management activities are embedded in the organizational setup.

Competitions between zonal and/or DMA teams should be encouraged.

Documentation of the action-learning process and results is crucial to:

a. Increase the understanding of the main causes and contributions of commercial and physical losses to the total ‘volume of water and money lost’,

b. Refine the response strategy based on emerging evidence as to what works and what does not, and

c. Future up-scaling efforts while focusing on quick wins, medium and longer-term objectives requiring action now must also be considered. A comprehensive asset management and development strategy, for example, requires unknown distribution lines and valves to be identified and mapped, attributes (e.g., size, material, depth, date of installation) to be registered etc.

Chapter 13

The Project for Strengthening Capacity in NRW Reduction in Kenya (JICA, 2016-2021)

A Summary of Experience from Output 4 of the Project

13.1 Introduction

Non-Revenue Water reduction is one of the fields in which many water utilities have been struggling to improve in low-income countries. It is also the field in which international aid agencies are struggling to find effective support because the methods of NRW reduction used in high-income countries are often incompatible with or inadequate for the conditions in developing countries.

Unlike water utilities in advanced countries, water utilities in developing countries are likely to face:

- scarce budgets for NRW reduction,
- intermittent water supply conditions,
- disorderly distribution networks,
- recurrent and chronic water theft, etc.

These situations often make adoption of the technical skills from advanced countries ineffective or unsustainable. Moreover, the number of water utilities which an aid agency can directly support in each target country is limited. In addition, the water utilities targeted for assistance by the aid agencies on NRW reduction have more serious immediate concerns, which is - “performance over the entire service area”; and not only small areas like a pilot DMA that is often created during the projects.

Even though the ultimate goal of these projects is to create a nation-wide impact for effective NRW reduction, the available resources for NRW reduction are of course inadequate on both sides (i.e., the aid agency’s’ project period and human resource are limited; while the water utilities in low-income countries often lack adequate budget and other resources).

The main question is: “How is it possible, with the limited resources, to achieve a nation-wide NRW reduction under the difficult conditions in developing countries?”

This chapter intends to provide some potential answers to this question based on recent experiences of the project in Kenya. The alternative strategy presented here is to target the entire distribution service areas of each water utilities from the beginning instead of investing heavily in one or a few pilot areas first.

JICA started implementing the “Project for Strengthening Capacity in Non-Revenue Water Management” (the Project) in Kenya from October 2016. The project aimed to support Kenya to reduce the national NRW ratio from 42% in 2015 to 30% by 2030.

This was through provision of technical assistance to nine large and medium size water utilities in Eldoret, Kisumu, Nakuru, Nyahururu, Mavoko, Ruiru-Juja, Embu, Meru and Kilifi-Mariakani. Targeting nine water utilities as pilot utilities was quite ambitious for JICA's NRW reduction technical cooperation projects, which usually target one to three utilities.

The alternative strategy adopted in this project on handling the nine utilities may provide some possible answers to the question above.

In addition, this Project had the aim of establishing a NRW reduction support mechanism at the national level, thereby which would strengthen the roles and capacity of the relevant national agencies. The supporting mechanism included the long-term NRW public sensitization in the form of water education, which is related to the alternative strategy and is discussed at the end of this introduction.

First, we shall explain the conventional strategy often adopted by international aid agencies in NRW reduction in developing countries. We shall then discuss the alternative strategy adopted with the nine water utilities.

Aid agencies often promote NRW reduction activities isolating small areas as pilot projects as an initial step to figure out which NRW reduction activities are effective, while at the same time providing various OJTs for underground leak detection, meter accuracy tests, etc, before expanding the effective activities over other areas of a utility. However, the activities tried in the pilot area are very often never expand to other areas because of several reasons:

- Largely, the activities conducted in the pilot area are often too expensive and/or too complicated to be expand to other areas without additional budget by the utility or support from the aid agencies.
- Efficient expansion of activities from the limited pilot area to larger areas usually require other or additional skills which are often not taught in pilot activities.
- Difficulties in detecting underground leakage and, especially, in evaluating leaks under intermittent water supply conditions are also major reasons for the failure to expand. These difficulties are never taken into consideration.
- Difficulties in isolating DMAs especially when the distribution network is complicated and/or not properly documented.
- Difficulties in sustaining the accuracy of the bulk meters and in factoring the seasonal fluctuation of NRW ratio (noted mainly under intermittent water supply conditions, which makes evaluation of activities in pilot areas very difficult).

Since it was realised that the chances of effectively expanding and evaluating the various activities often tried out in pilot areas is low, the Project limited the activities in the pilot areas to underground leak detection only (only if the water supply was continuous) on trial basis and; pressure reduction (only if high pressure was a priority) as a way of efficiently utilizing the available resources.

To implement the two activities as well as evaluate their effects, hydraulic isolation of the target areas is necessary. By taking this approach of implementing limited activities in the pilot areas, the Project was able to allocate resources, mainly the consultants' time, to the alternative strategy of targeting the entire service area from the beginning.

Various methods were developed under this strategy to reduce both commercial and physical water losses; and tried out in the nine water utilities. Some of the methods failed while others worked very well. As a result, five out of the nine utilities had significantly reduced their overall monthly NRW ratio by between 10 and 15% over a period of 12 to 24 months before the time of the Project interim report in 2019.

One of the most effective methods of this strategy was the analysis of the monthly meter readings and billing data for all the customers over a period of 12 or more months in each pilot water utility. The results revealed that a huge portion of their customers were billed based on estimated water consumption even though almost all the customers had meters installed. The findings were presented to the managers as well as the staff of the technical and commercial departments of each utility. As a result, everybody in the utilities realized that many meters, even of large water consumers, had stalled or stopped for a long time, thus creating a huge and continuing revenue loss.

After extensive discussions on the malpractices in meter readings and billing that were exposed through the analysis, the pilot WSPs were strongly urged to use their limited resources to prioritize on large customers regardless of their location.

The other successful method used in the Project was the introduction of innovative templates for capacity assessment, annual and medium-term planning, performance monitoring and review.

Several methods were also developed using smartphones, mobile and cloud GIS and also data collection and video software to efficiently expand the various activities over the entire distribution service area.

In addition to assisting the nine WSPs, the Project also aimed at establishing a NRW reduction support mechanism for water utilities at the national level. The NRW Unit of the MWS&I was encouraging water utilities to engage in systematic and long-term sensitization activities to the public on NRW.

One of the activities was water education for schools within WSPs' service areas. This is where pupils are invited to learn about water treatment and the cost of water production. Embu WSP has been inviting grade 6 or 7 pupils to their water treatment plant for some time. The objectives of inviting students are: to enhance their knowledge on water production and the role of the water company and to sensitize their parents and relatives on the importance of water conservation and NRW reduction through the pupils. After the visit, the pupils were encouraged to discuss about what they learned during the visits with their family and practise water conservation at home. The gradual education of customers through their children can enhance the nation-wide reduction of NRW in Kenya where water theft, meter theft, visible leaks, etc. are still common though the effect may not show quickly. Many people still believe that provision of safe water does not cost money and therefore water should be free. Thus, investing in children (living in WSPs' service areas) by offering water education can be a complimentary method to the alternative approach for immediate expansion of the various activities to the entire service area.

Other effective approaches for NRW reduction that were developed under the project are discussed in details in the following sections.

13.2 Strategies to Solve Problems

Problems related to NRW reduction were identified at each Pilot WSP through baseline survey and specific strategies used to deal with the problems while conducting NRW reduction activities. The following strategies, which are only part of a large number of NRW reduction activities, were confirmed as effective through the project activities conducted so far.

13.2.1 Expansion of Activities targeting the Entire Service Area

In order to realize a quick large-scale reduction of NRW, NRW reduction activities that are relatively easy to expand (e.g., identification of unbilled customers, ensuring and sustaining meter accuracy for large customers, patrolling for visible leaks, standardization of service connections, etc.) were prioritized for expansion over the entire service area. As a result, 5 Pilot WSPs (Kisumu, Nakuru, Nyahururu, Ruiru-Juja, and Eldoret) managed to reduce their NRW significantly. Meanwhile, the effectiveness of leak detection and pressure reduction in the distribution network, which are more effectively if implemented in hydraulically isolated areas, were confirmed at DZs (or DMAs) selected as pilot areas before expanding to other areas.

13.2.2 Support for Voluntary Restructuring and Strengthening of the Organization

Each Pilot WSP was encouraged to strengthen their organization (e.g., by engaging the commercial department in NRW reduction activities and/or increasing the NRW Unit staffing) through the activities (e.g., frequency analysis [by customer category] of estimated billed consumption [due to faculty meters, etc] and planning of activities based on capacity self-assessment) by involving the entire WSP or its multiple departments. As a result, organizational strengthening was implemented by 4 WSPs (Embu, Kisumu, Nakuru and Eldoret) while similar efforts were going on at another 2 WSPs (Ruiru-Juja and Kilifi-Mariakani).

13.2.3 Ensuring Credibility of Universal NRW Ratio

Abnormal fluctuations of NRW ratio caused by faculty bulk meters can be checked by analysing the changes in monthly NRW ratio and other main performance indicators over the previous few years. Problems with production bulk meters or those used to calculate the total supply volume should be resolved as early as possible. The accuracy of the most important bulk meters in Embu WSP was improved while similar improvement was going on in Meru and Kilifi-Mariakani WSPs.

On the other hand, one strategy failed to work as initially expected.

Initially, an interactive electronic form was created to guide the Pilot WSPs through some activities related to problems around customer meters (e.g., faulty meters, water theft, leaks on service connections). However, although the form was being continuously improved to accommodate as flexibly as possible the differences in WSPs' organizational setup, work flows and prioritizations, it reached a point where these improvements could not accommodate all the requirements. Therefore, instead of using the same form for all WSPs, each Pilot WSP started developing its own electronic form for each activity to suit its needs.

Moreover, NRW reduction activities such as those that take place around customer meters were, at the beginning, grouped based on their location to enable handling of multiple activities together. However, these activities were later regrouped based on their technical fields. Other problems and strategies are explained in the subsequent sub-sub-sections based on the categories used to regroup NRW reduction activities.

13.2.4 Capacity Assessment for NRW Reduction Plan Preparation

Pilot WSPs had managed to prepare their medium-term and annual NRW reduction plans for the previous 3 years. However, the assessment of the current conditions, which is necessary before planning, was initially not adequate. Therefore, for the third year, a list of about 250 points, which can display the assessment results automatically on a graph, was developed as a template for capacity self-assessment (with a checkbox function and MS Excel formulas). The template was developing with checkboxes because it seemed that not many WSPs in Kenya can adequately assess their capacity on the basis of the existing guidelines and report its findings without assistance.

13.2.5 GIS Development and Zoning

The development of GIS database for three Pilot WSPs was started from scratch while the project supported improvement of the existing GIS database for the remaining six Pilot WSPs. Two out of the three WSPs continued using their newly developed GIS databases on a continuous basis for NRW reduction activities.

Planning for Zoning of distribution systems (the entire service area) into separate DZs (and DMAs when required) was carried out for seven of the Pilot WSPs. At each of these WSPs, it was planned that separation of the distribution zones would be implemented gradually.

Meanwhile, the Pilot WSPs were facing difficulties in expanding their leak detection activities over the entire service area, which is often a mixture of areas of continuous and intermittent supply. Since the methods suitable for leak detection depend on the water supply condition, the current or near-future water supply condition of each DZ and DMA were mapped on GIS at three Pilot WSPs. Thereafter, the areas where different leak detection methods are applicable were discussed with the help of the GIS map to gradually expand leak detection activities.

The sustainability and expandability of the leak detection methods taught by the JICA Experts during OJTs were expected to improve through this type of support.

13.2.6 Monitoring of NRW Reduction Progress

Monthly meetings between the various departments on NRW reduction have become more common in Pilot WSPs following the start of this project. However, the effects of their NRW reduction activities can be quite difficult to distinguish especially when the data used in the meetings is limited and shows changes in NRW ratio over just a few months. This is because NRW ratio often fluctuates a lot on seasonal basis. Therefore, in order to distinguish between the effects of NRW reduction activities from seasonal fluctuations, it is recommended that WSPs should analyse the following 3 types of monthly data over at least the last 3 years:

- Supplied volume,
- Billed consumption,
- Revenue from billed water (Kshs)

4 indicators should be calculated from this monthly data and displayed on a single graph with the graph being updated every month. These are:

- NRW ratio, Volume of NRW = Supplied Water - Billed Consumption
- NRW ratio (%) = volume of NRW x 100 / Supplied Water volume
- Average Tariff of water billed = Billing for Water / Total Billed Consumption
- Potential Revenue Loss due to NRW = Average tariff x [Supplied Water - Billed Consumption])

13.2.7 Measures against Commercial Water Losses

The monthly meter readings and billing data of all the customers for at least 1 year were analysed at each Pilot WSP to determine the frequency of using estimated consumption for billing. The results were that Ruiru-Juja WSP had the highest frequency of using estimated consumption for billing. After the WSP increased the number of meter readers and replaced many faulty customer meters, a large increase in t revenue from billed water was realised.

To a large extent, Kisumu and Nakuru WSP also successfully reduced their NRW ratio by strengthening their strategy against large customers. Eldoret WSP, which had many large customers, also targeted large customers in an effort to improve customer meters accuracy and deter illegal connections with substantial support from the managers.

Meanwhile, requests for support in evaluating the recent improvement in meter readings and billing through repeat analysis were made by some WSPs. However, analysis on data spanning 12 months or more is quite tedious and time consuming for WSPs. Therefore, a simplified analysis method that uses only two-month data (one data before and another after the improvement) developed and applied for 3 WSPs.

13.2.8 Measures against Physical Water Losses

Minimum night flow (MNF) measurements and step tests were applied in one or more pilot areas selected at each Pilot WSP to determine the level of the existing leakage and the areas having large amounts of leakage. Leak detection was conducted in these areas based on the results of the two measures. However, it is difficult to conduct accurate MNF measurements and understand the level of leakage under intermittent supply conditions.

Meanwhile, leakage once reduced in the pilot areas often increases again over time. Therefore, data on hourly fluctuation of water flow under intermittent supply and the trend of recurring leaks after leak detection were collected and analysed at a few Pilot WSPs to assess how to improve leak detection activities.

13.3 Results of Implementing the Strategies

[Planning and Implementing Realistic NRW Reduction Activities for Each WSP]

13.3.1 Preparation of NRW Reduction Plans and Self-Capacity Assessment

Assessment of a WSP's current capacity is necessary for preparation of a NRW reduction plan. In order to improve the assessment, a list of about 250 points on a template was developed. The template was simplified by providing checkboxes to be used for the capacity self-assessment. The template groups all the activities and attributes of NRW reduction into 4 large categories, 14 sub-categories and 33 sub-sub-categories. By clicking the checkboxes, the achievement level in NRW reduction at a WSP can be calculated and displayed on a graph.

Moreover, each WSP can set its NRW target levels for the next 1 to 5 years and the improvement priorities on each sub-sub category of the assessment. The target levels and the achievement levels are displayed on the same graph to ease the next planning process. Trials on using the template are now complete. Use of the template to formulate NRW reduction plans and to share the plans within each WSP has become more efficient.

This template enabled all the Pilot WSPs to update their medium-term plans and to prepare the annual plans for NRW reduction for the year 2019 based on the results of a comprehensive capacity self-assessment.

Figure 13.1 shows the results of Nyahururu WSP's self-assessment of its current situation.

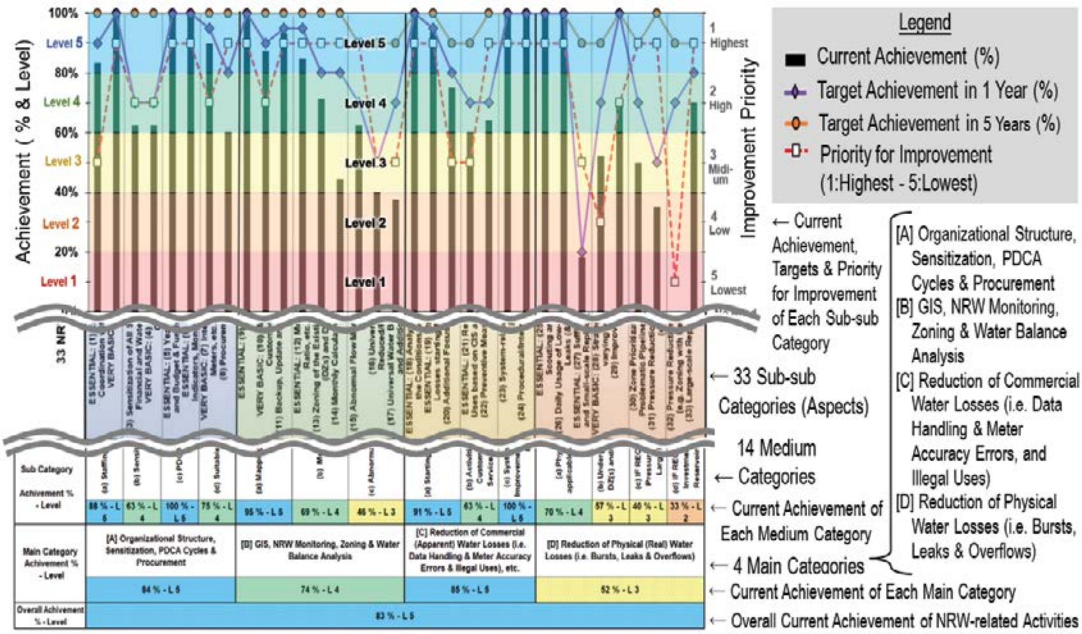


Figure 13.1: Results, Targets & Improvement Priority of the Self-Capacity Assessment at Nyahururu WSP

13.3.2 GIS Development and Zoning of Distribution Systems

The mix of continuous and intermittent water supply areas at each Pilot WSP makes it difficult for them to visualize how to expand leak detection activities over the entire service area. It is therefore important for WSPs to discuss and determine the current and near-future water supply conditions in the current and planned DZs and DMAs on GIS.

Figure 13.2 shows Ruiru-Juja WSP's expansion plan of leak detection activities for areas with a mix of continuous and intermittent supply. The plan was developed based on their DZs and DMAs plan of the entire service area. Areas of continuous supply where step tests can be used for leak detection are shown in red while areas of intermittent supply, which are a high priority for leak detection are shown in blue. Previously, the WSP had difficulties in selecting the pilot areas suitable for leak detection methods taught in OJTs. This hampered the efficiency of their capacity development and leak detection activities. Higher perspective use of GIS based on their zoning plan improved selection of the pilot areas, thereby making the OJT more meaningful and expansion of leak detection activities more sustainable.

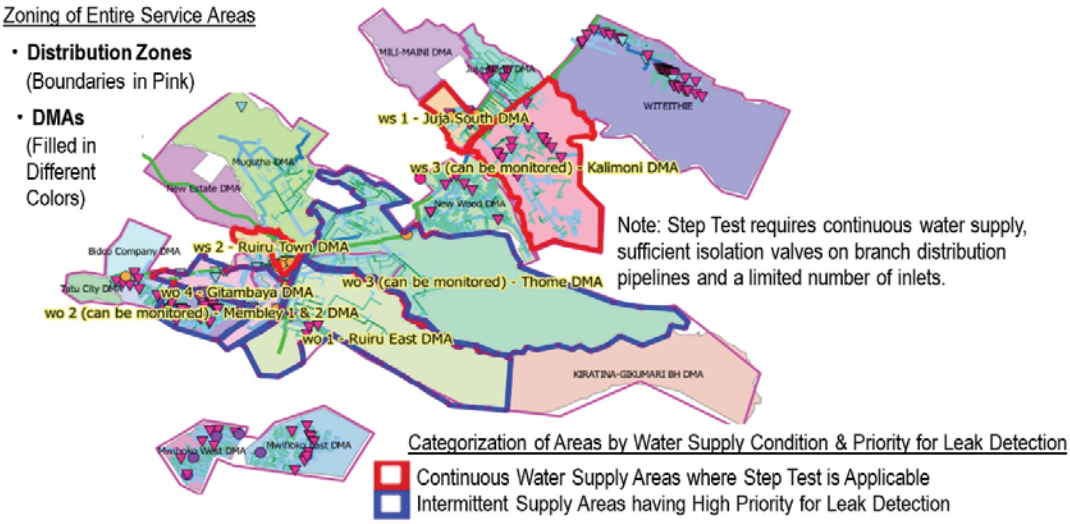


Figure 13.2: Zoning of the Entire Service Area at Ruiru-Juja WSP and Selection of Priority Areas and Leak Detection Methods

13.3.3 Monitoring of Progress in NRW Reduction

Figure 13.3 shows a 3-year data graph with 3 types of raw monthly data and 4 indicators calculated from the raw data for Nyahururu WSP. The data and indicators are plotted on one graph so as to understand the seasonal fluctuations of NRW ratio and the effect of the NRW reduction activities.

The 3 types of raw monthly data are:

- Total Supplied water [Orange ○]
- Total Billed consumption [Purple ○]
- Revenue from billed water (Kshs)

While the 4 types of indicators calculated from the raw data are:

- Volume of NRW [Red ○] (= Supplied Water - Billed Consumption)
- NRW ratio [Red ○] (= volume of NRW x 100 / Supplied Water volume)
- Average Tariff of water billed [Blue○] (= Billing for Water [Green □] / Total Billed Consumption)
- Potential Revenue Loss due to NRW [Pink □] (= Average tariff x [Supplied Water - Billed Consumption])

In this graph, the NRW ratio decreased by about 10% over the last two years with seasonal fluctuation every few months. The seasonal fluctuations are due to the shallow wells used by the small customers as alternative water sources. When the wells dry up in the dry seasons, this results to a corresponding increase in both the total Supplied Water and total Billed Consumption. Consequently, while the volume of NRW did not change much, the NRW Ratio decreased for a few months in each dry season.

The decrease in average tariff in each dry season can be attributed to the increase in piped-water consumption among the small customers whose average water charge per 1m3 is relatively low due to their lower tariff block.

At WSPs in Kenya, shortage of water sources and intermittent water supply conditions often substantially affect the total amount of supplied water while the fluctuations in water demand again substantially affect the total billed consumption. These values therefore fluctuate repeatedly due to seasonal changes in temperature and precipitation.

This trend whereby the NRW ratio rises and falls every few months was found to be common in Kenya.

From Figure 13.3 the following information can be obtained:

- The variations in the monthly amount of Supplied Water [Orange ○] is a useful indicator to presume the progress of physical water loss reduction.
- The total Billed Consumption [Purple ○] and the total amount of Billing for Water [Green □] are effective indicators for understanding the progress in reducing commercial losses caused by low meter accuracy and water theft.
- Moreover, the Average Tariff [Blue ◇], which usually increases when billing of large customers is improved, can be an indicator of how well large customers are targeted in commercial loss reduction.
- The volume and ratio of NRW for the entire service area [Red ○ and Red ○], and the potential revenue loss due to NRW [Pink □] are useful indicators for quantitative evaluation of the overall effect of NRW reduction activities.

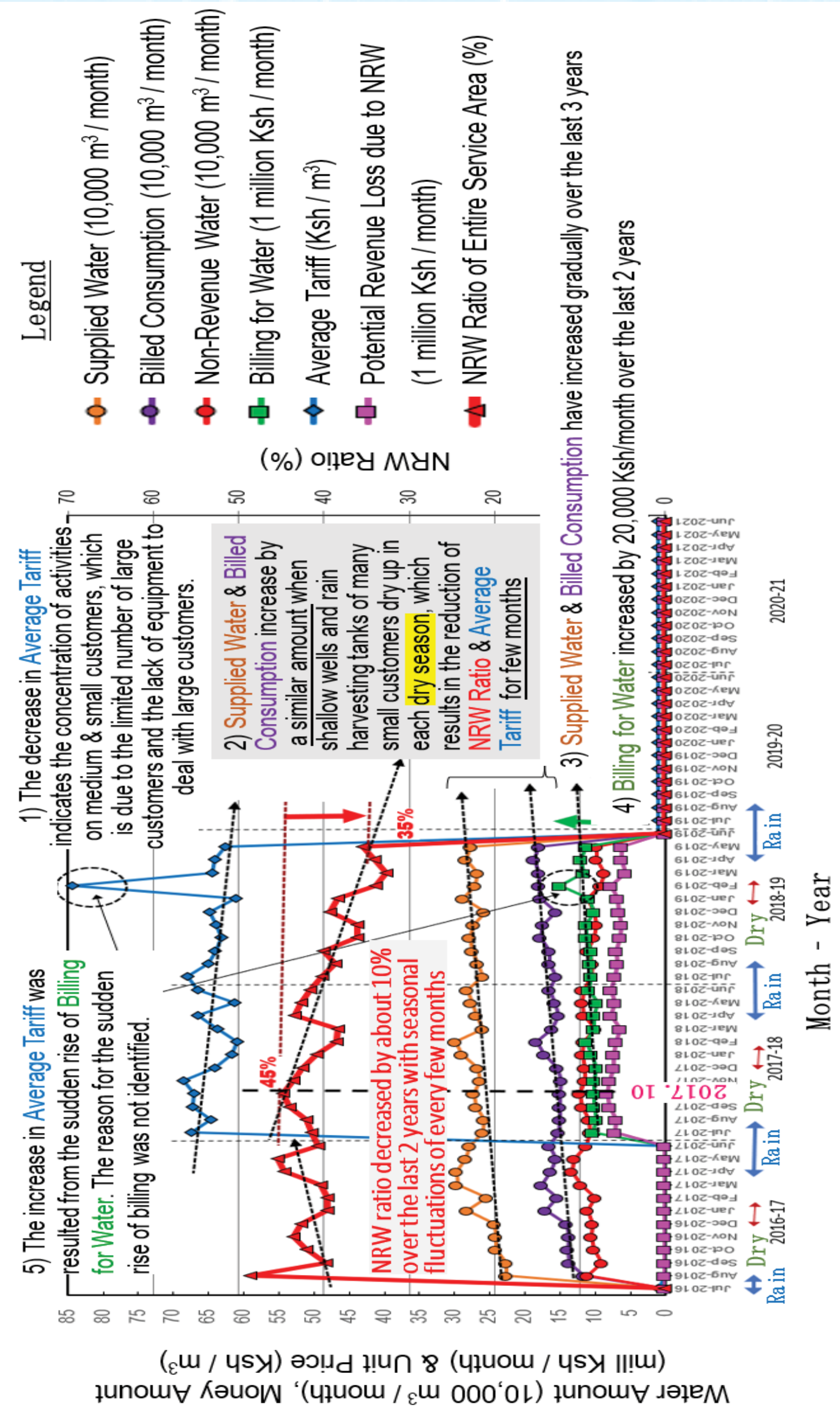


Figure 13.3: Seasonal Fluctuation of NRW Ratio & Effect of NRW Activities in Nyahururu WSP

This method of using a line graph is much easier and often more effective than filling a complicated water balance table for the entire service area once a year.

Kisumu WSP carried out the rigorous monitoring of large customers' consumption using ultrasonic flow meters to reduce meter errors and water theft; and replacing faulty meters after conducting meter accuracy tests targeting large and medium customers.

Figure 13.4 shows the variations and relationship between several additional monthly indicators and the amount or results of certain NRW reduction activities. These are used to identify factors substantially affecting NRW reduction. The following were the findings:

- Replacement of faulty customer meters to reduce estimated billed consumption [Green line △] was quite effective in reducing NRW ratio [Red line △],
- Increasing the budget for pipeline maintenance such as selective replacement of aged pipes [Yellow line □] may reduce the number of leaks and bursts found and repaired per month [Pink line □].

13.3.4 Reduction of Commercial Water Loss

Table 13.1 shows a comparison of data before and after the improvement of meter reading and billing (e.g., reduction of meter accuracy errors) at Nakuru WSP. This is an alternative to analysing meter reading and billing data for one year.

This analysis shows that active reduction of estimated billed consumption for large customers results in a large increase in the total billed consumption and total billing.

13.4 Lessons and Innovations of Project Implementation

The following lessons were learnt from the project activities.

13.4.1 Importance of Selecting Target Areas

Expansion of NRW reduction activities from the pilot areas to other areas is often not successful.

In order to realize a quick large-scale reduction in NRW, it is more effective to first prioritize the improvement of meter readings and billing (e.g., meter accuracy starting with large and medium customers) and expanding over the entire service area. By using this approach, 5 of the Pilot WSPs reduced their NRW significantly.

Meanwhile, it is more effective to try leak detection and pressure reduction in pilot areas to confirm their effectiveness before expanding to other areas.

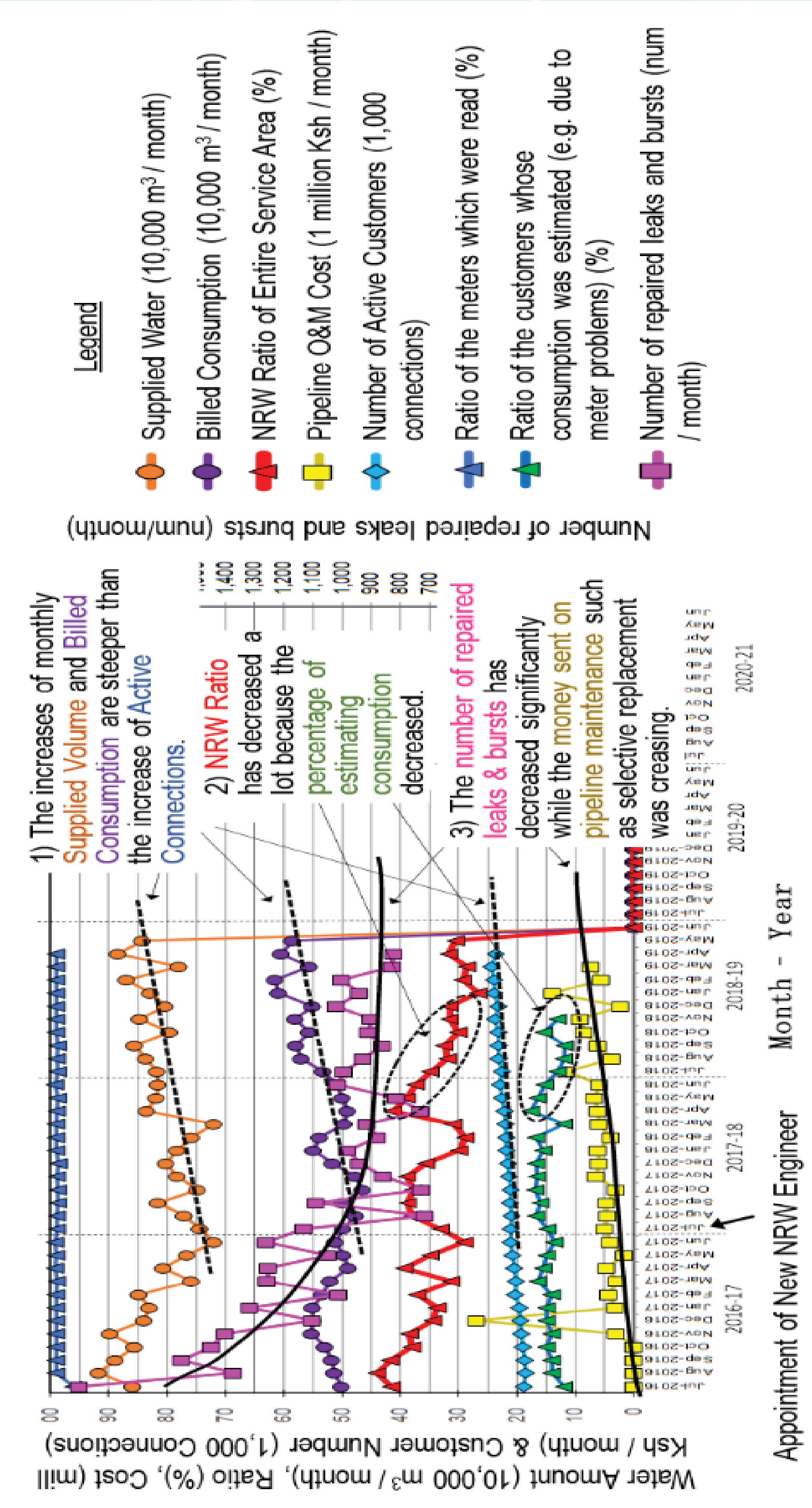


Figure 13.4: Factor Analysis of NRW Reduction based on Additional Monthly Indicators at Kisumu WSP

Table 13.1: Analysis on the Reduced Frequency of Estimating Billed Consumption by Customer Category at Nakuru WSP

Customer Category by Average Billed Consumption	Year - Month	Number of Connection [1] Num	Number of Connection Distribution %	Billed Consumption [2] Total Volume (m³/month)	Billed Consumption Distribution %	Billed Consumption [3](=[2]/[1]) Average (m³/month/customer)	Customers whose Consumption is Estimated [4] Num	Customers whose Consumption is Estimated Distribution %	Customers whose Consumption is Estimated [5] (=[4]/[1]) Frequency %	Increase from no consumption 0↑X	Increase from other than no consumption +X	Change to no consumption X↓0	Decrease to other than no consumption -X
C1: > 300 m3/month	2017 - October	130	0.3%	115,732	18.1%	890.2	17	0.2%	13.1%	15	1	0	1
C2: 101-300 m3/month		465	1.2%	74,839	11.7%	160.9	64	0.8%	13.8%	36	18	0	10
C3: 51-100 m3/month		1,077	2.7%	73,597	11.5%	68.3	155	1.9%	14.4%	110	27	0	18
C4: 21-50 m3/month		4,664	11.6%	144,864	22.6%	31.1	891	10.9%	19.1%	[illegible]			
C5: 7-20 m3/month		15,330	38.0%	181,004	28.3%	11.8	4,800	58.6%	31.3%	[illegible]			
C6: 0-6 m3/month		18,630	46.2%	49,882	7.8%	2.7	2,267	27.7%	12.2%	1989			
Total		40,296	100.0%	639,919	100.0%	15.9	8,194	100.0%	20.3%	7,464	437	9	284
C1: > 300 m3/month	2019 - May	114	0.3%	130,787	18.9%	1,147.3	4	0.1%	3.5%	2	0	0	2
C2: 101-300 m3/month		601	1.4%	94,577	13.7%	157.4	43	0.6%	7.2%	23	11	0	9
C3: 51-100 m3/month		1,375	3.3%	93,946	13.6%	68.3	127	[illegible]	9.2%	95	14	0	18
C4: 21-50 m3/month		5,769	13.7%	177,675	25.7%	30.8	[illegible]	11.1%	14.0%	726	44	0	35
C5: 7-20 m3/month		16,971	40.4%	199,200	28.8%	11.7	3,959	54.7%	23.3%	3702	192	0	65
C6: 0-6 m3/month		19,437	46.2%	50,480	7.3%	2.6	2,058	28.4%	10.6%	1767	163	14	114
Total		44,267	100.0%	746,666	100.0%	16.9	6,996	100.0%	15.8%	6,315	424	14	243

Effective focus on large & medium custo
(reduction of about 10% to 5%)

Increase of customers by around 4,000 (10%)

Large increase of billed consumption by more than 100,000 m³/month (17%)

Reduction of the number of customers whose consumption is estimated by around 1,200

Reduction of the estimated consumption for billing by 4.5% on average

Mainly by replacing the faulty meters which are completely stalled.

13.4.2 Encouraging Organization-wide NRW Reduction Activities

In order to get the full involvement of the commercial staff in NRW reduction efforts and get commercial loss reduction into full swing, the meter readings and billing data of all customers for the last 1 to 2 years should be analysed, the problems identified (e.g., many faulty meters, and frequent and continuous under-estimation of billed consumption even for large customers) and shared with all staff including managers.

This analysis made an impact on all Pilot WSPs and encouraged them to hold more joint meetings between the technical and commercial staff for NRW reduction. Moreover, through the activities that involved many staff (e.g., those related to customer meters, capacity assessment, and planning), the Pilot WSPs became encouraged to implement self-motivated organizational strengthening. As a result, 4 of the Pilot WSP strengthened their organizational setups for NRW reduction, while Ruiru-Juja and Kilifi-Mariakani WSPs commenced the same.

13.4.3 Sustainable and Extensive Utilization of ICT

Applications of ICT including smartphones for data collection and mapping were tried out to find more efficient ways to carry out NRW reduction activities. In the early stage of this project, a free software program called Open Data Kit (ODK) was used to create a versatile interactive electronic form for guiding different WSPs in collecting relevant data related to NRW reduction activities around customer meters. However, the electronic form had limitations mainly because different WSPs have different organizational structures and priority activities.

A shift was therefore made to another free software called Kobo Toolbox/Collect which is easier to use. By using this software, WSPs can now setup their own cloud space for data sharing, create an original electronic form for each activity and automatically map the collected data. This will make it possible to expand the use of ICT applications to more staff and to cover the entire service area in a more sustainable way.

13.4.4 Flexible Training for Each WSP

There were challenges in providing uniform and intensive trainings because of delays in procuring the necessary NRW equipment. Flexible OJTs based on the available equipment at each WSP and those procured by WSBs were therefore conducted by training on the operation of the equipment.

Meanwhile, due to delay in procuring potable ultrasonic flow meters, which are developed specifically for the water supply field and essential for NRW reduction, certain low-cost industrial ultrasonic flow meters were tried as potential alternatives. However, they were found to be difficult in setting up and ensuring accuracy.

Another alternative, video recording functions of smartphone was used for logging the ever-varying flow rate as a trial. Figure 13.5 shows the process of a taking video of a mechanical bulk meter counter with a smartphone and later extracting the flow rates from the video file at a certain time interval. This method can make minimum night flow measurements and step tests easier without using a potable ultrasonic flow meter and may help many WSPs in their leak detection.

Various trials were carried out in liaison with the Pilot WSPs in this project. Continuous trials to challenging problems without placing a large financial burden on WSPs and sharing the information and experiences with other parties are important especially now that the capabilities of smartphones and free software available in the market continue to increase.

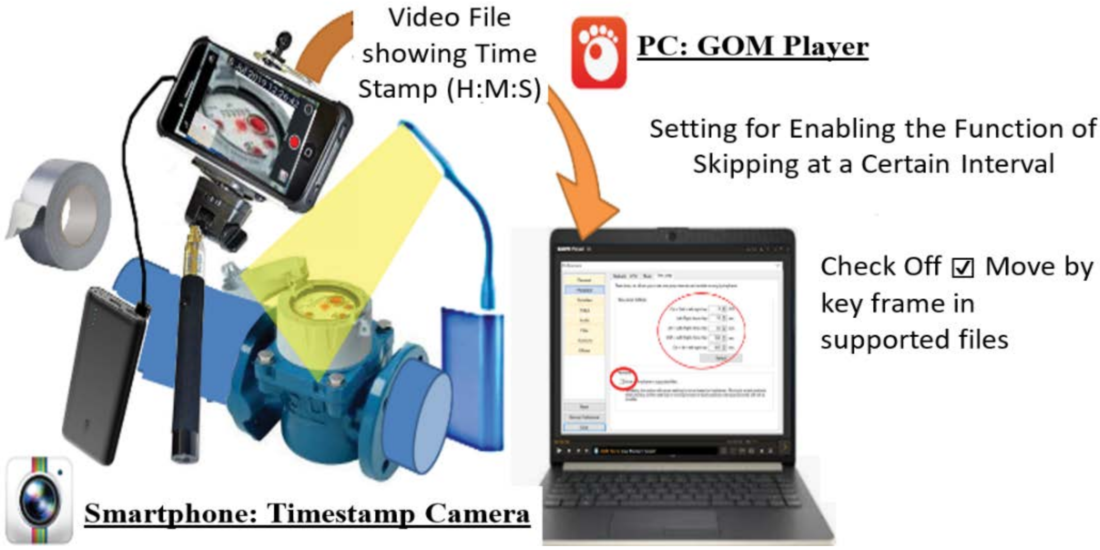


Figure 13.5: Measurement of Hourly Water Flow with Smartphone and Free Software

Figure 13.6: Meter Accuracy Test on Site Using Bucket and Meter Tester

Figure 13.7: Flow Measurement at Mavoko WSP

APPENDIX 1

Appendix-1 - Revised Templates for Annual Review, Assessment, Planning & Monitoring (WASREB website)

APPENDIX 2

Appendix-2 - Customer Meter Analysis of 2017 Data - Embu WSP (WASREB website)

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