The Manager's Non-Revenue Water Handbook

A Guide to Understanding Water Losses

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FOREWORD

Most developed countries have a solid infrastructure and established operational practices for managing and controlling non-revenue water (NRW). This is not always the case in developing countries; many are struggling to ensure that customers receive a reasonable supply of safe drinking water, often via a pipe network that is inadequate, with poor record systems and a low level of technical skills and technology. Tariff systems and revenue collection policies often do not reflect the true value of water supplied, which limits the utility's cost recovery and encourages customers to undervalue the service.

Developing countries in Asia face similar challenges in reducing NRW, including aging infrastructure, financial constraints, poor governance, and poor project design. Many utilities in the region, however, can draw on motivated and industrious staff to implement solutions once the challenges of reducing NRW have been identified.

Using some key messages, *The Manager's Non-Revenue Water Handbook* leads the utility manager through the stages of addressing NRW—first, understanding and quantifying NRW, and then developing a strategy to address it.

Chapter 1: examines the scale of NRW, and emphasises the challenges to Asian water utilities. Utility managers and operational staff should be committed to managing NRW as a long-term process that incorporates numerous aspects of water operations. Addressing NRW is the responsibility of managers across the water utility, including finance and administration, production, distribution, customer service, and other departments. Utilities must end a cycle, known as the 'Vicious Circle', where companies face increased NRW, financial losses, limited investment, and poor service. Instead, utilities should follow the 'Virtuous Circle' that enables them to decrease NRW, improve efficiency, preserve financial resources, and promote strong customer satisfaction and willingness to invest.

Chapter 2: highlights the need to understand and accurately quantify NRW as an indicator of a water utility's operating efficiency. The International Water Association (IWA) water balance is an excellent method for utility managers to break down and identify the key components of NRW. Ensuring the accuracy of data used to calculate the level of NRW is also essential in understanding the full problem. Collecting accurate data from production meters and customer meters helps to measure the true NRW level. In addition, the customer billing cycle must be factored into NRW calculations to ensure that the time period used for the consumption volume measurement matches the production meter volume measurement.

Chapter 3: considers the requirements to develop an NRW reduction strategy. Utilities need to consider establishing an NRW management team to develop a strategy, ensure that all components of NRW are addressed, and verify that the proposed strategy is feasible and practicable in terms of the workload and budget. Choosing the right team members promotes ownership among the various utility departments involved in the strategy's implementation, and also facilitates consensus at the senior management level. As a first step in developing the strategy, the team should set an initial utility-wide target for NRW reduction based on the economic level of NRW. The team can balance the financial and water supply objectives of the strategy using the water balance results, while aiming to shorten the awareness, location, and repair (ALR) times in addressing water

losses. The NRW strategy may cover a period of four to seven years. As a result, pilot projects can help utility managers understand the full budget and resources required to implement the entire strategy.

Chapter 4: emphasises the level of awareness required at all levels—from top decision-makers to the end consumer—that is critical for a successful NRW reduction programme. Support from the programme's top-level management, and the budget required, promotes the financial sustainability of the strategy. Middle management and staff must understand their roles and responsibilities in reducing NRW, since it requires a long-term combined effort from all departments in the utility. Also, reaching out to customers helps increase their awareness of NRW and how reducing water losses results in improved water supply and quality.

Chapter 5: addresses commercial losses. Commercial losses represent lost revenue, and even a small volume will have a large financial impact. They occur mostly through tampered meters, aging and improperly maintained meters, unauthorised connections, and administrative errors or even corrupt practices during the meter reading and billing process. Utilities should invest in training for meter readers, staff, and crews, as well as in accurate meters and a robust billing system, which can directly result in higher returns. In addition, collaboration from the public and certain government departments is required to overcome theft and illegal use of water.

Chapter 6: examines physical losses. These include leakage on transmission and distribution mains, leakage and overflows from storage tanks, and leakage on service connections up to the customer meter. Leakages from transmission and distribution mains are usually large events that can cause serious damage, but the public typically reports them rapidly, followed by the utility repair on an emergency basis. Other types of leakage are more difficult to detect and repair. A successful leakage management strategy requires pressure management, active leakage control, pipeline and asset management, and speedy and high-quality repairs.

Chapter 7: deals with zoning. Dividing an open water supply network into smaller, more manageable zones or district meter areas (DMAs) is now internationally accepted best practice. It enables the utility to better understand the network, and to more easily analyse pressure and flows in problem areas. The criteria for establishing DMAs include the size (or number of connections), number of valves that must be closed, number of flow meters, ground-level variations and visible topographic features that can serve as DMA boundaries. Utility managers use the minimum night flow (MNF) and legitimate night flow (LNF) to calculate the net night flow (NNF), along with commercial losses, to determine NRW in a DMA. Establishing DMAs helps to manage pressure, improve water quality, and enable continuous water supply.

Chapter 8: gives an indication of the range of performance indicators (PIs) available to utility managers. PIs are an aid to measuring progress in reducing NRW, developing standards, and prioritising investments. The IWA recommends the Infrastructure Leakage Index (ILI) as the best performance indicator for physical losses. Currently, the best PI for commercial losses is to express them as a percentage of authorised consumption. The IWA is developing another indicator for commercial losses called the Apparent Loss Index (ALI). Utility managers should develop and implement monitoring programs to ensure their NRW targets are being met.

Chapter 9: discusses some options for building capacities for managing NRW through 'twinning' arrangements, or utility-to-utility partnerships, facilitated through the Environmental Cooperation–Asia (ECO-Asia) Programme of the United States Agency for International Development (USAID). Water service providers worldwide have demonstrated the value of twinning, or focused and sustained exchange between practitioners, in promoting the adoption of improved policies and best practices, and in building human and institutional capacity. Twinning partnerships rely on counterpart exchange to help strengthen the capacity of a utility to improve services delivery (such as NRW reduction), expand services or convert to continuous water supply. Effective twinning partnerships are demand driven, address the interests and priorities of partners, results-oriented, and aim at the adoption and replication of best practices and solutions from one partner to another. The ECO-Asia twinning model demonstrates how regional collaboration and sharing of best practices among peers benefit all parties involved, although the benefits vary in form and results.

I am pleased to have been associated with developing *The Manager's Non-Revenue Water Handbook*. NRW is a global problem requiring a management strategy that can be globally applied. Developing such a strategy requires a diagnostic approach to identify the problem, and then to use the available tools to reduce or remove it. Following a step-wise process—asking some basic questions about the utility policies and practices, then undertaking the appropriate tasks to answer them—is the basis of successful strategy development.

As an international consultant, I have worked with many utilities in both developed and developing countries to introduce and implement NRW reduction strategies. I believe that the philosophies, concepts, and recommendations contained in this handbook closely reflect international best practice, particularly those recommended by the IWA and the World Bank Institute. I am pleased to endorse it. If Asian utilities apply the approach recommended in the handbook, they will rapidly benefit from a greater understanding of their networks' performance, and will have an increased knowledge of the tools available to identify and reduce their levels of NRW.

Malcolm Farley
International Water Loss Management Consultant
23 June 2008

1. INTRODUCTION

1.1 BACKGROUND

The global volume of non-revenue water (NRW) or water losses is staggering. Each year more than 32 billion m^3 of treated water are lost through leakage from distribution networks. An additional 16 billion m^3 per year are delivered to customers but not invoiced because of theft, poor metering, or corruption. A conservative estimate of the total annual cost to water utilities worldwide is US$14 billion. In some low-income countries this loss represents 50-60% of water supplied, with a global average estimated at 35%. Saving just half of this amount would supply water to an additional 100 million people without further investment.[1]

Other benefits from reducing NRW include the following:
- Water utilities gain access to a further US$3 billion in self-generated cash flow
- Water utilities reduce illegal connections, thereby creating greater fairness between users
- More efficient and sustainable utilities improves customer service
- New business opportunities creates thousands more jobs

In Asia, many water utilities operate under the jurisdiction of municipal, provincial, or central governments. These utilities often rotate or appoint senior managers and directors with various backgrounds outside the water sector. As a result, senior managers entering these positions have limited knowledge of water supply operations, especially on the vital technical and institutional requirements for effectively managing NRW and water losses. This handbook serves to assist

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1   Source: World Bank Discussion Paper No. 8, December 2006

senior water utility managers in better understanding the definition, causes, and practical solutions to address NRW, a key performance indicator for a utility's operations. It provides the information that managers need when discussing NRW-related issues with their staff. By design, it is not a hands-on technical guide for engineers to manage NRW, but rather is a reference for senior managers.

By reducing water losses, water utilities have additional supply to expand services to underserved areas.

The United States Agency for International Development (USAID), under the Environmental Cooperation–Asia (ECO-Asia) programme, demonstrates how "twinning" arrangements can help water utilities meet the challenges of NRW management and adjust their operational efficiencies to improve service delivery in urban areas. ECO-Asia is working with a number of successful urban water utilities to develop and implement twinning partnerships with other utilities seeking to enhance their services provision. In 2006-2007, ECO-Asia facilitated twinning partnerships between Ranhill Utilities Berhad (Ranhill), a Malaysian utility recognized for effectively reducing and managing NRW, with the Provincial Waterworks Authority (PWA) of Thailand and the Bac Ninh Water Supply and Sewerage Company (WSSC) in Vietnam. The objective of these partnerships was to strengthen the capacities of PWA and Bac Ninh WSSC to better understand and address NRW. Lessons from Ranhill's experiences and these twinning arrangements have contributed to the development of *The Manager's Non-Revenue Water Handbook*.

1.2 CHALLENGES IN ASIAN WATER UTILITIES

There are areas of plentiful water across Asia, just as there are water-scarce areas, as a result of both regional geography and a country's ability to pay for water. The photos below illustrate the inequity of water availability between countries. Although reducing NRW cannot solve such global contrasts, it can help to improve the quantity and quality of water available in water-scarce areas.

Not all countries or regions—particularly those in parts of Asia—have the infrastructure and established operational procedures to begin tackling NRW. Many are struggling to ensure that customers receive a reasonable water supply to sustain health and life. Water utility managers in Asia will invariably face

Water abundance improves quality of life

Customers queuing to collect water in water-scarce regions

greater challenges including the following:

- Rapid urbanization
- Diminishing water supply
- Environmental pollution
- Outdated infrastructure
- Poor operations and maintenance policy, including ineffective record-keeping systems
- Inadequate technical skills and technology
- Greater financial constraints, including an unsuitable tariff structure and/or revenue collection policy
- Political, cultural, and social influences
- A higher incidence of commercial losses, particularly illegal connections

However, Asian utility managers also have a number of strengths they can build on:

- A high work ethic and level of industriousness
- Ability to make do with available resources and materials
- Motivated staff with the potential for developing high technical capacity

These factors all influence the scope for managing losses and demand, and affect the pace of change. At the same time, continued NRW limits the financial resources available to tackle these challenges facing water utilities in Asia. This handbook enables water utility managers in the region to address the limitations, acknowledge the challenges, and make gradual improvements to current policies and practices.

Box 1.1: Why Do Utilities Struggle with NRW Reduction?

- Not understanding the problem (magnitude, sources, costs)
- Lack of capacity (insufficient trained staff)
- Inadequate funding to replace infrastructure (pipes; meters)
- Lack of management commitment
- Weak enabling environment and performance incentives

Bill Kingdom, Roland Liemberger, Philippe Marin, "The Challenge of Reducing Non-Revenue Water in Developing Countries--How the Private Sector Can Help: A Look at Performance-Based Service Contracting", World Bank, Paper No. 8, Dec 06

1.3 IMPACTS OF NRW: THE VICIOUS AND VIRTUOUS CIRCLES

The 'Vicious Circle' of NRW (Figure 1.1) is one of the key reasons for poor company performance and results in both physical and commercial losses (see Chapters 5 and 6). Physical losses, or leakages, divert precious water from reaching customers and increase operating costs. They also result in larger investments than necessary to augment network capacity. Commercial losses, caused by customer meter inaccuracies, poor data handling, and illegal connections, reduce income and thereby financial resource generation.

Figure 1.1: The Vicious NRW Circle

Expenditure is concentrated on meeting increasing customer demands

Operational budgets are reduced especially in areas of network maintenance

NRW Increases

Revenues decrease and operational costs increase
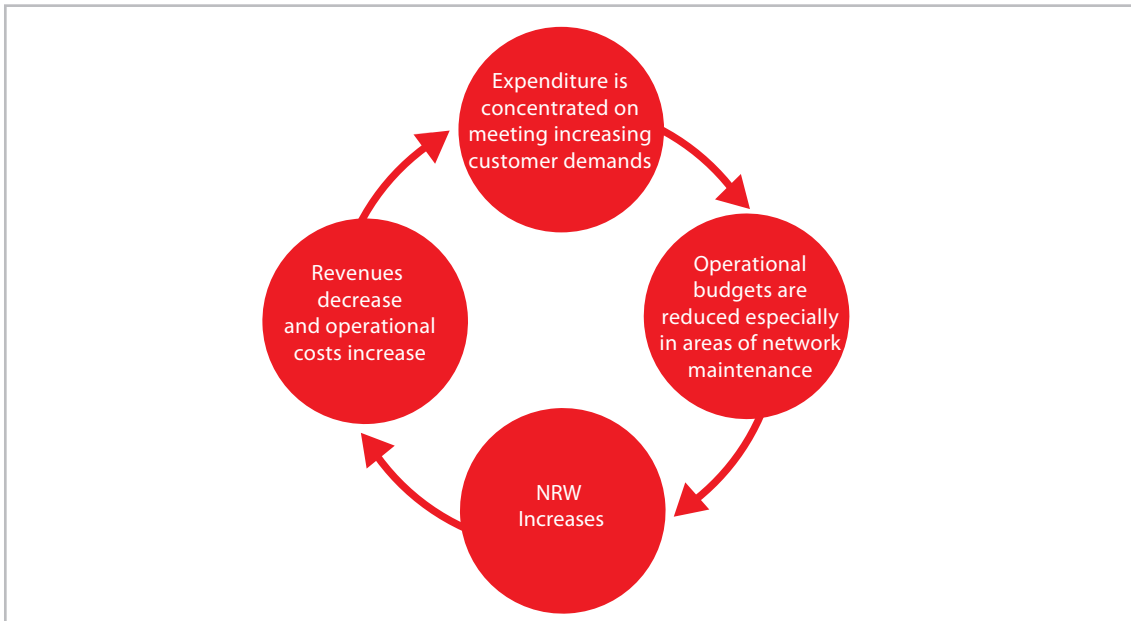
The challenge for water utility managers is to transform the Vicious Circle into the 'Virtuous Circle' (Figure 1.2). In effect, reducing NRW releases new sources of both water and finances. Reducing excessive physical losses results in a greater amount of water available for consumption and postpones the need for investing in new sources. It also lowers operating costs. Similarly, reducing commercial losses generates more revenues.

Figure 1.2: The Virtuous NRW Circle

Expenditure is increased to include operational improvements

Revenues increase and operational costs decrease

NRW Decreases

Investments are made in further NRW reduction programmes

Replacing aging infrastructure requires financial capacity, which can be gained through NRW reduction
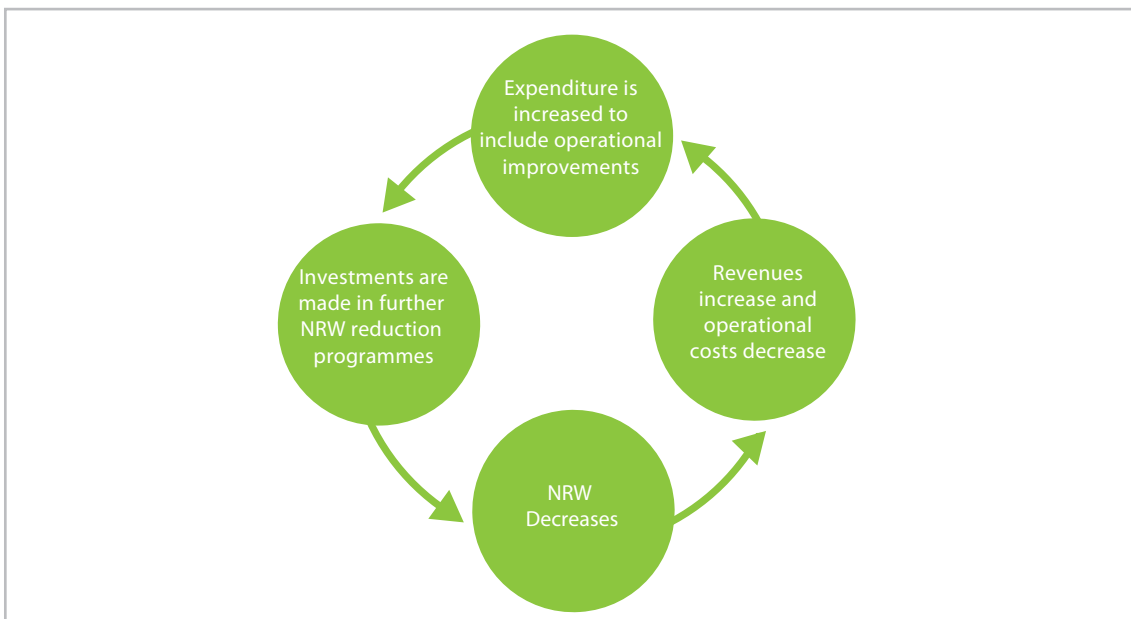
1.4 ADDRESSING NRW

Water utilities anywhere in the world should use a diagnostic approach, followed by the implementation of solutions that are practicable and achievable to reduce NRW. The first step is to learn about the network and operating practices. Typical questions during this process include:

- How much water is being lost?
- Where are losses occurring?
- Why are losses occurring?
- What strategies can be introduced to reduce losses and improve performance?
- How can we maintain the strategy and sustain the achievements gained?[2]

1.4.1 Reasons for failure—and the road to success

Although minimising non-revenue water should be a priority for water utilities, many still struggle to achieve acceptable NRW levels. The reasons NRW strategies fail range from not understanding the magnitude of the problem to a lack of financial or human resource capacity. In addition, utility managers often do not pay enough attention to NRW because of weak internal policies and procedures, which contributes to rising NRW levels.

NRW management is not a one-off activity, but one requiring a long-term commitment and involvement of all water utility departments. Many utility managers do not have access to information on the entire network, which would enable them to fully understand the nature of NRW and its impact on utility operations, its financial health, and customer satisfaction. Underestimating NRW's complexity, and the potential benefits of reducing NRW, often lead to reduction programmes' failure. Successful NRW reduction is not about solving an isolated technical problem, but is instead tied to overall asset management, operations, customer support, financial allocations, and other factors (Figure 1.3).

2   Kingdom, B., R. Liemberger, and P. Marin, 2006. "The Challenge of Reducing Non-Revenue Water in Developing Countries—How the Private Sector Can Help: A Look at Performance-Based Service Contracting", World Bank, Paper No. 8, Dec 2006

Figure 1.3: Reducing NRW is everyone's responsibility
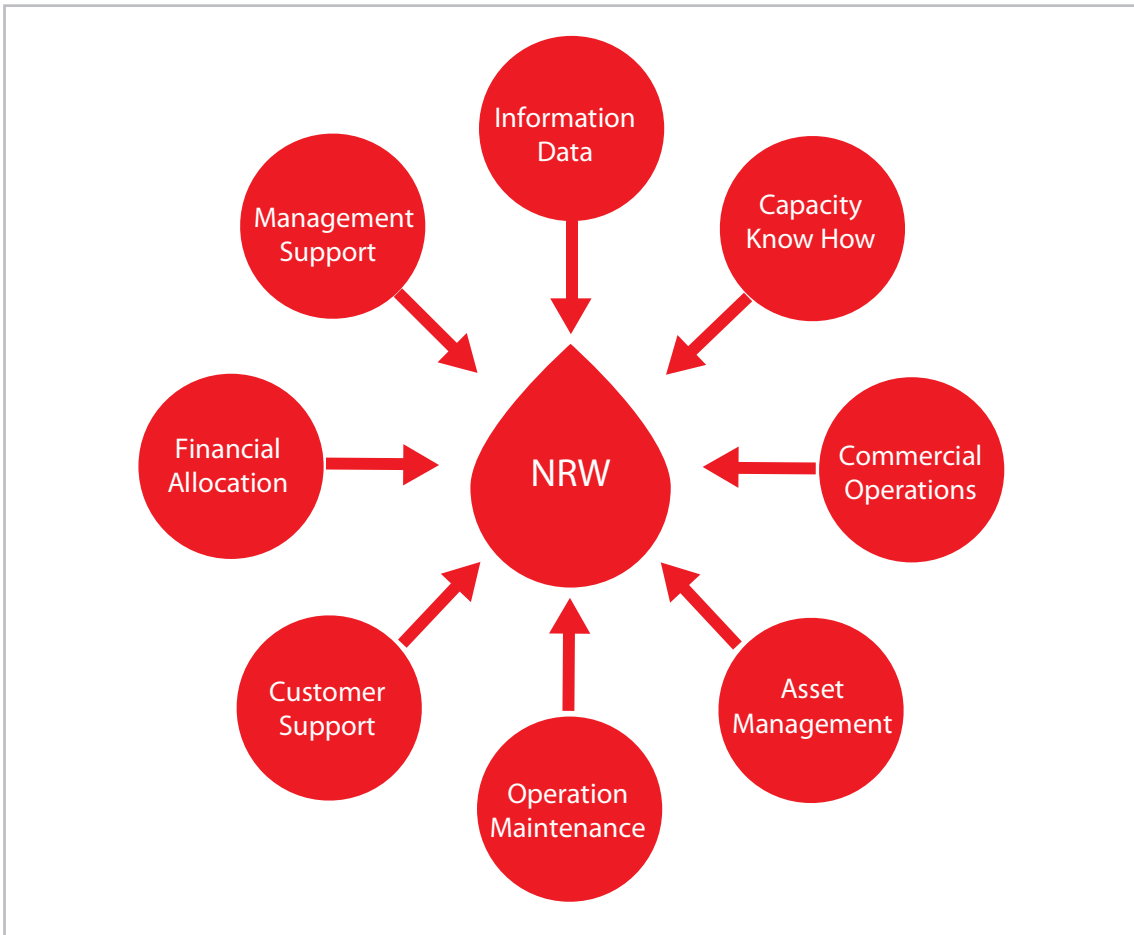
Poor governance also affects NRW reduction. Utility managers often lack the autonomy, accountability, and technical and managerial skills necessary to provide reliable service. The utility's management should also tackle organisational challenges, such as policy barriers, inadequate technical capacity, and aging infrastructure. Finally, poor project design hinders efforts to reduce NRW, particularly underestimating the required budget.

However, utility managers' understanding of the institutional dimension of NRW is growing. In addition, a number of tools are emerging to support sustainable NRW reduction:

- New methodologies that quantify physical and commercial losses more accurately
- More effective technical approaches to manage leakage and reduce system pressure
- New instruments for engaging the private sector, such as performance-based contracts

1.4.2 The Manager's NRW Handbook

The Manager's NRW Handbook is a guide to implementing NRW reduction strategies by addressing each of these issues and designing solutions tailored to the water utility's specific needs. Its approach enables water utility managers to take a fresh look at the NRW problem and the factors influencing it. The handbook provides a starting point for a utility manager to assess NRW, modify operations and infrastructure to address such factors, and implement the required policies and practices. The handbook covers the following issues:

- Calculating the water balance, or how much water enters the network, and the amount that contributes to the utility's revenue water and non-revenue water (Chapter 2)

- Prioritising target NRW components and developing a reduction strategy (Chapter 3)

- Involving stakeholders, including management, operations staff, and the public, to implement the reduction strategy (Chapter 4)

- Addressing commercial losses (Chapter 5)

- Addressing physical losses (Chapter 6)

- Establishing District Meter Areas (DMAs) and using them to manage NRW (Chapter 7)

- Monitoring the utility's NRW management performance (Chapter 8)

- Highlighting a case study where utilities increased capacity and addressed NRW challenges through a twinning partnership arrangement (Chapter 9)

KEY MESSAGES

- Reducing NRW increases both financial resources and the water available to utilities.

- Developing countries in Asia face challenges in reducing NRW, such as aging infrastructure, financial constraints, and poor governance; however water utilities can draw on their motivated and industrious staff as a key strategy to improve NRW.

- The Vicious Circle leads to increasing NRW and financial losses, while the Virtuous Circle leads to decreasing NRW and financial resources.

- Managing NRW is a long-term process that must incorporate numerous aspects of water operations.

- Addressing NRW is the responsibility of managers across the water utility, including finance and administration, production, distribution, customer service, and other departments. *The Manager's NRW Handbook* can help utility managers identify sources of NRW and develop a strategy for reducing them.

2. KNOWING YOUR WATER LOSSES: THE WATER BALANCE

To most water utilities, the level of NRW is a key performance indicator of efficiency. However, most utilities tend to underestimate NRW because of institutional and political pressures, as well as a lack of knowledge to properly determine the NRW level. Reports of low levels of NRW are eagerly accepted by senior managers. However, reported low levels of NRW, whether due to deliberate misinformation or, more likely, a lack of accurate information, will not help the water utility to reduce its costs or increase revenue. Instead, it will mask the real problems affecting the water utility's operating efficiency.

Only by quantifying NRW and its components, calculating appropriate performance indicators, and turning volumes of lost water into monetary values, can the NRW situation be properly understood and the required actions taken. The utility manager now has a powerful tool to support this first step—the water balance calculation. In this chapter we will introduce the water balance concept and also an example of water balance software, WB-EasyCalc. This software assists managers in developing the water balance while also indicating the level of accuracy of the NRW calculation.

2.1   HOW MUCH WATER IS BEING LOST?

The first step in reducing NRW is to develop an understanding of the 'big picture' of the water system, which involves establishing a water balance (also called a 'water audit' in the United States). This process helps utility managers to understand the magnitude, sources, and cost of NRW. The International Water Association (IWA) has developed a standard international water balance structure and terminology that has been adopted by national associations in many countries across the world (Figure 2.1).

Figure 2.1: Water balance showing NRW components

System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Commercial Losses	Unauthorised Consumption	
			Customer Meter Inaccuracies and Data Handling Erros	
		Physical Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows from the Utilities Storage Tanks	
			Leakage on Service Connections up to the Customer Meter	

Non-revenue water (NRW) is equal to the total amount of water flowing into the water supply network from a water treatment plant (the 'System Input Volume') minus the total amount of water that industrial and domestic consumers are authorised to use (the 'Authorised Consumption').

NRW = System Input Volume - Billed Authorised Consumption

This equation assumes that:

- System input volume has been corrected for any known errors
- The billed metered consumption period for customer billing records are consistent with the System Input Volume period

Utility managers should use the water balance to calculate each component and determine where water losses are occurring, as described in the next sections. They will then prioritise and implement the required policy changes and operational practices.

NRW components cover the entire water utility supply system from the water treatment plant outlet meters to the customer meters, which means that managing NRW is the responsibility of the entire operations department. Water utilities often set up a dedicated 'NRW team', with disappointing results as everyone else in the company leaves NRW management to this team. As discussed in Chapters 3 and 4, an NRW reduction strategy should encompass all staff with each department's responsibilities outlined in detail.

2.2 WATER BALANCE COMPONENTS: WHERE ARE YOUR LOSSES OCCURRING?

Abbreviated definitions of the principal IWA water balance components are outlined in this section (see Annex 1: Glossary for other definitions)[3]:

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3 See more detailed descriptions of each component and their measurement in the IWA reference manual by Farley, M. and S. Trow, 2003. *Losses in Water Distribution Networks—A Practitioner's Guide to Assessment, Monitoring, and Control.* IWA Publishing: ISBN 1 900222 11 6. http://www.iwapublishing.com/template.cfm?name=isbn1900222116

- **System Input Volume** is the annual volume input to that part of the water supply system.

- **Authorised Consumption** is the annual volume of metered and non-metered water taken by registered customers, the water supplier, and others who are implicitly or explicitly authorised to do so (e.g. water used in government offices or fire hydrants). It includes exported water and the leaks and overflows after the point of customer metering.

- **Non-Revenue Water (NRW)** is the difference between System Input Volume and Billed Authorised Consumption. NRW consists of Unbilled Authorised Consumption (usually a minor component of the water balance) and Water Losses.

- **Water Losses** is the difference between System Input Volume and Authorised Consumption. It consists of Commercial Losses and Physical Losses

- **Commercial Losses**, sometimes referred to as 'apparent losses', consist of Unauthorised Consumption and all types of metering inaccuracies

- **Physical Losses**, sometimes referred to as 'real losses', are the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

Sometimes even the most basic information, such as system input volume, average pressure, supply time, length of mains, and the number of service connections, is not initially available. The process of calculating each of the water balance components and performance indicators will reveal such deficiencies. The utility management should then take corrective action to close these data gaps and improve data quality. Using incomplete or inaccurate data for the water balance calculation will not produce useful result.

When the entire system input is metered, determining the annual system input volume is a straightforward task. Utility managers must collect meter records regularly and calculate the annual quantities of the individual system inputs. This includes a utility's own sources as well as imported water from bulk suppliers. Ideally the accuracy of the input meters is verified using portable flow measuring devices.

Billed metered consumption includes all of the water consumption that is measured and charged to domestic, commercial, industrial, or institutional customers. It also includes exported water that is measured and charged. The billed metered consumption period used in the calculation should be consistent with the audit period by processing it for time lags (see Section 2.4.3 on 'Customer billing cycles' below). There is generally a lag of up to 30 days between the time when water is consumed and when the meter is read. In addition, NRW managers should determine the general accuracy of various domestic

Water utility managers need to accurately measure water produced from the treatment facility. Total water produced is a key input for the water balance.

and non-domestic consumption meters for a possible 95% confidence limit by taking a sample of existing working meters from various locations and testing them on a standard meter test rig. Independent companies provide testing services if the water utility does not own a meter test rig. If several different customer meter brands are in operation, then the sample selection should include meters from each brand.

Determining the annual billed metered consumption goes hand in hand with detecting billing and data handling errors, information that utilities also require for estimating commercial losses. The volume of unbilled metered consumption should be established using a similar approach to that for billed metered consumption.

Unbilled unmetered consumption is any kind of authorised consumption that is neither billed nor metered. This component typically includes items such as fire fighting, flushing of mains and sewers, street cleaning, frost protection, etc. In a well-run utility, it is a small component that is very often substantially overestimated. Unbilled unmetered consumption, traditionally including water the utility uses for operational purposes, is often seriously overestimated. This is sometimes caused by simplification (e.g. using a percentage of total system input), or by deliberate overestimates to 'reduce' the amount of NRW.

2.3 KEY STEPS FOR CONDUCTING A WATER BALANCE

The utility manager needs to have certain information about the network to conduct a water balance:

- System input volume
- Billed consumption
- Unbilled consumption
- Unauthorised consumption
- Customer metering inaccuracies and data handling errors
- Network data
- Length of transmission mains, distribution mains and service connections
- Number of registered connections
- Estimated number of illegal connections
- Average pressure
- Historic burst data
- Level of supply service (24-hour, intermittent, etc)

The four basic steps to conduct a water balance are summarised below (see a detailed description in Annex 3: Steps for Calculating NRW Using the IWA Water Balance):

- Step 1. Determine system input volume
- Step 2. Determine authorised consumption
  - Billed—total volume of water billed by the water utility
  - Unbilled—total volume of water provided at no charge

Box 2.1: WB-EasyCalc

WB-EasyCalc is one example of a tool to support water balance calculations in addressing NRW. Utility managers can use this spreadsheet-based software, developed by Liemberger and partners and supported by the World Bank Institute (WBI). The picture below shows the homepage of the software for 'getting started'.
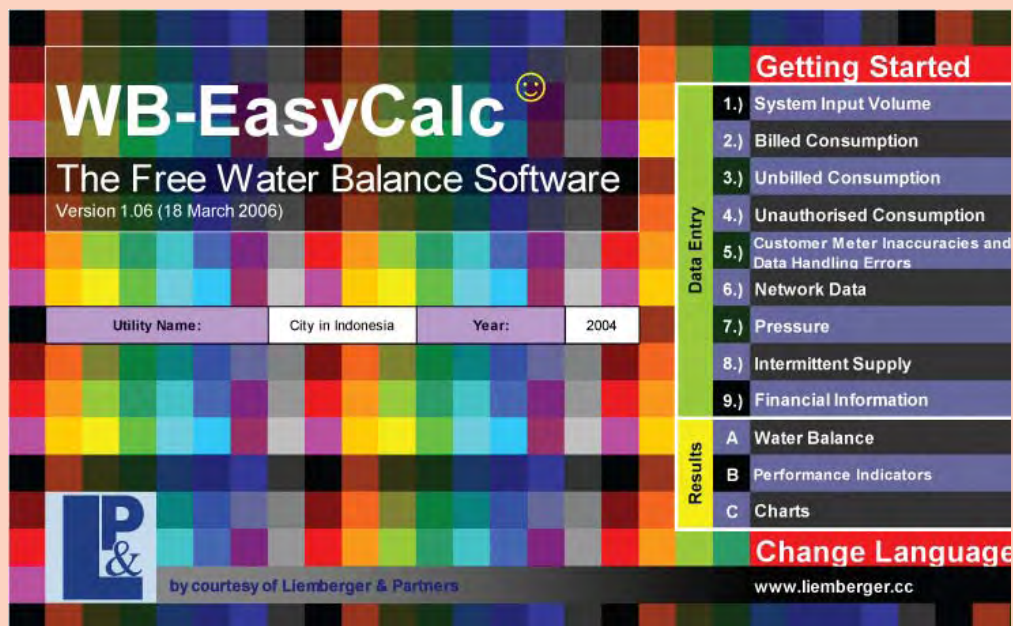
One advantage of EasyCalc is that the software not only asks for physical data, but also for an assessment of the accuracy of that data. For example, when entering the production volume, the user must also estimate the accuracy of this data based on the type and age of production flow meters, if any, and the amount of maintenance carried out on the meter. Using these estimates, the software calculates NRW volume and its various components, in addition to the accuracy of these volumes. For example, EasyCalc may determine that NRW is 21% with an accuracy of +/- 66%— meaning that the actual NRW ranges between 7% and 35%.

WB-EasyCalc is available as a free download at http://www.liemberger.cc/diverse_uploads/WBEasyCalc.xls.

- Step 3. Estimate commercial losses
    - Theft of water and fraud
    - Meter under-registration
    - Data handling errors

- Step 4. Calculate physical losses
    - Leakage on transmission mains
    - Leakage on distribution mains
    - Leakage from reservoirs and overflows
    - Leakage on customer service connections

Confidence limits of 95% should be applied to all water balance data. These define the boundaries within which utility managers can be 95% sure that the true value for that particular component lies. Although the water balance is an important tool for understanding inflows, consumption, and losses, the general lack of data leads to problems. Data gaps make it difficult to quantify commercial losses and to pinpoint the nature and location of physical losses. However, the water balance can be improved using two other methodologies[4]:

- Component analysis of physical losses (see Chapter 6), using the network information required listed in Table 2.1
- Measurement of leakage, using analyses of night flows into District Meter Areas (DMAs) (see Chapter 7)

2.4 IMPROVING THE ACCURACY OF WATER BALANCE RESULTS

The accuracy of production meters, customer meter reading, and billing are the main factors affecting the NRW volume calculation.

2.4.1 Production meter accuracy

The accuracy of production flow meters is critical to calculating system NRW. Generally, the number of production flow meters is relatively small, meaning that a greater proportion of the flow is measured by each meter. This means that an error on one of these meters has a great impact on the total production measurement. Different meter types have different accuracies, as shown in Table 2.3.

Table 2.1: Indicative examples 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%
Note: Actual meter accuracy will depend on many factors (like flow profile, calibration, meter installation, maintenance) and has to be verified case by case	

Source: World Bank Institute, 2007

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4   These methodologies are briefly outlined Chapters 6 and 7, and explained in more detail in Losses in Water Distribution Networks.

All meter types detailed above must be regularly maintained to ensure their continuing accuracy. Over time these meters can be affected by a number of factors, including water quality, pipe vibration, dirt entering the meter, and electronic malfunction. Utility managers should regularly check the accuracy of both the electronic functionality of the meter, if electronic, and the volumetric accuracy. The electronic functionality can be checked onsite using the meter manufacturer's test equipment. The volumetric accuracy can be checked using a second meter, which is generally a portable meter installed just for the test period. Some water utilities opt to install a second meter permanently as a backup in case the first meter fails.

Ranhill Experience: Production volume measurement

Independent water suppliers operating several water treatment plants in Johor, Malaysia, receive payments depending on the volume of water supplied. Because this volume requires accurate measurement, Ranhill has installed two production meters in series at all independent water supplier outlets to ensure continued accuracy.

2.4.2 Customer meter accuracy

The accuracy of customer meters is equally important, with the main difference being that there are many more customer meters in operation—and each measures a relatively smaller flow—than production meters. The accuracy of customer metering depends on several factors, including meter type, brand, replacement policy, maintenance, and water quality. The water utility should establish guidelines for all of these factors to ensure accuracy of customer consumption data.

Faulty meters require immediate replacement.

2.4.3 Customer billing cycle

When calculating the NRW value, many water utilities simply subtract customer consumption data from the production meter volume, and then are satisfied with the low result. However, this is often a false measurement of NRW because, unlike with the production meters, which are usually read on the same day of every month, customer meters are read over the full month. Information on the average billing cycle, or the time in days between meter reads, is critical. Utility managers should then factor the total consumption down

Field verification of network system data is crucial to understanding where water losses originate and setting NRW baseline level.

to get the true consumption volume for the exact time period as the production meter volume measurement.

Addressing the above issues greatly improves the accuracy of the NRW calculation, which utilities will use as the baseline in developing an NRW reduction strategy.

Ranhill Experience: Accurate NRW baselines

When the water utility in Johor was first privatised in 2000, the initial NRW level was reported as 33%. To verify this baseline level, Ranhill spent two years installing new production meters and replacing 150,000 customer meters. In addition, Ranhill implemented a new customer reading and billing system. These activities improved the data accuracy, resulting in a baseline NRW level of 45%. Although this new reported NRW level was higher, Ranhill now had confidence in its accuracy and could start to develop an NRW reduction strategy.

KEY MESSAGES

- NRW is an indicator of water utilities' operating efficiency.

- Ensuring the accuracy of the NRW calculation is essential in understanding the full problem.

- The IWA standard water balance is an excellent method of breaking down the components of NRW, and tools are available to help utility managers calculate the water balance

- Accurate production and customer metering ensure that the true NRW level is measured

- The average billing cycle must be factored into NRW calculations to ensure that time period used for the consumption volume measurement matches the production meter volume measurement.

3. STRATEGISING TO REDUCE AND MANAGE NON-REVENUE WATER

The NRW challenge can only be properly understood after NRW and its components are quantified, the appropriate performance indicators calculated, and the lost water volume is translated into its corresponding economic value. Development of the water balance reveals the magnitude of each NRW component. This chapter discusses how to identify the major NRW components and develop a company-wide strategy to reduce targeted components.

3.1 ESTABLISHING THE STRATEGY DEVELOPMENT TEAM

The NRW reduction strategy team ensures that all components of NRW are covered and that the proposed strategy is feasible in terms of physical application and financial requirements. The team should comprise of members from each operational department, including production, distribution, and customer service. It may also include members from the finance, procurement, and human resource departments. Choosing the right members promotes ownership by the utility's various departments involved in the strategy's implementation, and also ensure consensus by senior management.

3.2 IMPORTANCE OF SETTING APPROPRIATE NRW REDUCTION TARGETS

The strategy development team should first set 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. In addition, water utilities may have an active regulator who will set performance

indicators for NRW and other targets. Often, the NRW target is chosen arbitrarily, without any real consideration of cost implications or whether ivvv t is achievable. Identifying the economic level of NRW is essential to setting the initial NRW target, and it requires a comparison of the cost of water being lost versus the cost of undertaking NRW reduction activities.

Figure 3.1: Identifying the economic level of NRW
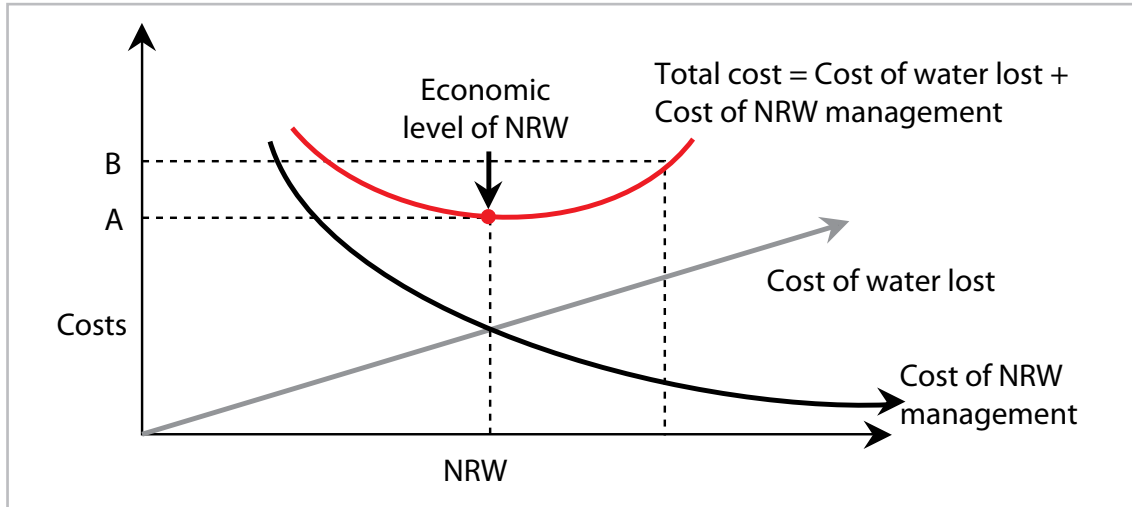
Figure 3.1 highlights how the economic level of NRW is determined. The two components that must be determined are the **cost of water lost** and the **cost of NRW management**:

- The cost of water lost is the value of the water lost through both physical and commercial losses. The volume of physical losses should be multiplied by the variable operational costs, including manpower, chemicals, and electricity. The volume of commercial losses should be multiplied by the average customer tariff. As NRW increases, the cost of water lost increases proportionally.

- The cost of NRW management is the cost of reducing NRW, including staff costs, equipment, transportation, and other factors. As NRW decreases, the cost of NRW management increases.

Adding the two cost components together gives the **total cost**. In Figure 3.1, the intersection of the two component lines coincides with the minimum total cost (cost A), which is the economic level of NRW.

The graph shows that letting NRW increase past the economic level reduces the cost of NRW management, but the total cost for the utility (cost B) will rise. Similarly, reducing NRW lower than the economic level of NRW will cost more than the potential savings. However, utility managers may sometimes decide to push NRW below the economic level, for example in areas where raw water is scarce or the image of the country requires low losses. In such cases, the difference between the cost of NRW management and the savings are usually subsidised by the government.

The economic level of NRW constantly changes with shifts in water tariffs, the cost of electricity and chemicals, staff salaries, and equipment supply costs. Managers should assess the economic level of NRW on a yearly basis and adjust the NRW target accordingly to ensure the efficient use of resources.

3.3 PRIORITISING NRW REDUCTION COMPONENTS

Once the utility-wide NRW target is set, utility managers should calculate the proposed volume of water saved by comparing the NRW baseline with the target level. The various components, as detailed in the water balance, are then prioritised 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 reductions in that component. On the other hand, focusing on another component may cost less while reducing the same volume. The water balance table shows the magnitude of NRW components in terms of volume, which utility managers can use to determine the corresponding financial values.

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 saving will be an immediate revenue increase and thus is based on the water sales

Ensuring customer meter accuracies is just as important as sealing pipe leakages.

tariff. The water sales tariff is higher than the variable production cost for all profitable water utilities; in some cases, the sales tariff is as high as three or four times the production cost. 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 prioritised.

Ranhill Experience: Programme to improve company finances

One of the main reasons water services in Johor, Malaysia were privatised was that the government-run utility had been losing money over the previous five years. As soon as Ranhill assumed operations, it implemented a major customer meter replacement plan, installed a new customer billing software package, and introduced spot billing to improve meter reading practices. Within the first year of operation, the company started to realise a profit. Within two years, revenues had increased by 60% due to the programmes that had been implemented.

Developing an NRW reduction strategy requires water balance results, appropriate targets, and cost-benefit analyses to determine the return on investments.

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

Table 3.1 shows an analysis of NRW actions according to volume and cost, and enables decision-makers to logically proceed with NRW planning.

Table 3.1: Volume and cost analysis for NRW management activities

| | | Cost | | |
		High	Medium	Low
Volume	High	Leakage on mains (P) Leakage on service connections (P)	Unauthorised consumption (C)	Unbilled metered consumption (U)
	Medium	Customer meter replacement (C)	Customer metering inaccuracies and data handling errors (C)	Pressure management (P)
	Low	Reservoir leakage (P)	Unbilled unmetered consumption (U)	Reservoir overflows (P)

NRW Type: U=Unbilled authorised consumption, C=Commercial losses, P=Physical losses

3.4 BASIC PREMISE OF NRW REDUCTION STRATEGY: AWARENESS, LOCATION, AND REPAIR (ALR)

Once the utility-wide NRW target is set and the different components analysed to prioritise areas for achieving the desired reduction, then individual activities will be identified. The development of the strategy should be based on the concept of Awareness, Location, and Repair, or ALR. This concept states that any loss occurring from leaks, overflows, faulty customer meters, or other sources will have three stages as shown in the diagram below.

- Awareness time—time required for the utility to become aware of the leak
- Location time—time required to locate the leak
- Repair time—time required to repair the leak

Figure 3.2: The effect of time on the total volume lost
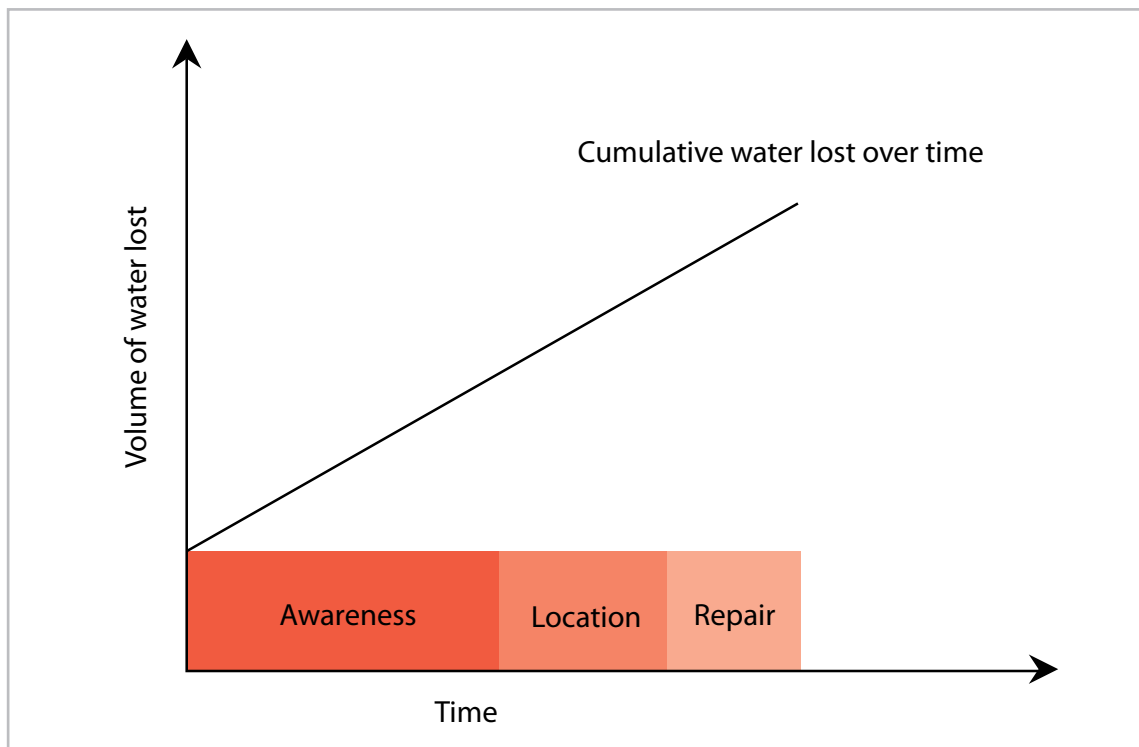
The volume of water lost will continue to increase until the water utility is aware of the problem, locates or pinpoints it, and finally repairs or resolves it. An underground leak could run for several months or even years without anyone being aware that it exists. Therefore, the NRW strategy must ensure that the company reduces its awareness, location, and repair times for all NRW components.

Many losses occur because of poor or limited maintenance, so in addition to reducing ALR, a fourth element of the NRW strategy should be system maintenance. This is critical to maintaining

good asset condition and reducing the incidence of new leaks, meter failures, reservoir leaks, and other problems.

Chapters 5, 6, and 7 detail the activities required to shorten the ALR periods. When developing an NRW management strategy, remember that reducing NRW is not a short-term process, especially in aging, large, open, or high pressure systems. The timeframe for implementing each strategy component should be outlined, with some activities possibly spanning years rather than months. NRW strategies spanning between four and seven years are reasonable—any less is ambitious, and any more will not be as cost-effective.

3.5 BUDGET CONSIDERATIONS FOR IMPLEMENTING THE STRATEGY

Managers reviewing the most cost effective and applicable investments to implement water loss reduction activities.

The development and implementation of activities to achieve the targeted level of NRW incurs a financial cost. With some NRW management strategies lasting years, the overall cost could be quite substantial. A long-term budget that is thoroughly discussed with key stakeholders will ensure that all parties are aware of the costs required and that the strategy is financially viable. Many NRW strategies start off at full speed but often fail due to budget cuts over time.

Undertaking pilot projects to demonstrate the effectiveness of the NRW strategy is useful. The pilot should cover a smaller area, be substantial enough to ensure that all components of the NRW strategy are tested, and operate under financial conditions that can be replicated when activities are implemented throughout the entire network. The analysis of the pilot results should be used in the development of the economic level of NRW for the entire system.

In preparing a budget, the utility manager needs to identify the following costs:

- Staffing—Include staff for both direct NRW works (e.g. leakage technicians) and indirect support (e.g. procurement staff).

- Equipment—Include equipment installed permanently (e.g. DMA meters) and those used on a day-to-day basis (e.g. leakage detection equipment).

- Vehicles—Include transportation costs, which can become an important issue in maximising the work rate of all staff. Small teams generally cover the entire supply system for undertaking NRW works.

- Works—Include the costs for installing all equipment, such as meters and pressure reducing valves, and also detecting and repair all leaks.

KEY MESSAGES

- The NRW reduction strategy team ensures that all components of NRW are covered and that the proposed strategy is feasible in terms of physical application and financial requirements. Choosing the right members promotes ownership by the various utility departments involved in the strategy's implementation, and also ensure consensus by senior management.

- Identifying the economic level of NRW should be the basis for setting the initial utility-wide target for NRW reduction.

- Using the water balance to prioritise components for NRW reduction helps balance the financial and water supply objectives of the NRW strategy.

- The NRW reduction strategy should aim to shorten the awareness, location, and repair (ALR) times in order to minimise water losses.

- NRW reduction is a long-term process and the strategy may cover a period of four to seven years. Pilot projects can help water managers understand the full budget required to implement the entire strategy.

4. RAISING AWARENESS ON THE STRATEGY

Effectively addressing NRW requires a combined effort from management and staff throughout the utility. However, the number of staff with a good knowledge of NRW is usually limited to engineers or others working at an operational level. Everyone, from the Chief Executive Officer to the meter readers and crew, should understand the importance of NRW and how it affects their daily work and the utility. More specifically, the following groups should understand NRW and their role in reducing water losses:

- Top decision-makers, including the Board of Directors, mayors, or political leaders
- All levels of the utility's management and staff
- The general public, or consumers

The public's perception of NRW is shaped by information presented through the media, which often does not include full explanations of the complex issues involved. During the initial implementation period of the NRW reduction strategy, the public will be greatly affected when water supply is stopped to install meters, repair leaks, or undertake other work. The utility must ensure that the public is aware of the strategy and understands that service interruptions will result in long-term benefits for all.

This chapter describes the roles and responsibilities of each type of stakeholder in implementing the NRW reduction strategy. Outreach programs will help build awareness and consensus regarding the importance of reduction activities and the benefits of reducing NRW.

4.1 GAINING HIGH-LEVEL APPROVAL

Top decision-makers, such as the Board of Directors, the mayor, or other political leaders, are responsible for reviewing and approving the strategy. A general presentation and discussion on NRW will help ensure that they understand the value of minimising NRW. The decision-makers should be informed of the present NRW level, the benefits of reducing NRW, operational activities required to achieve reductions, and the budget required to carry out activities. Lack of approval at the highest levels or inadequate funding support has led to the failure of many NRW strategies.

Ranhill Experience: NRW Strategy and Action Plan

In Johor, Ranhill developed an 'NRW Strategy and Action Plan', which outlines the strategies, initiatives, and activities to reduce NRW. Initial brainstorming sessions drew staff from all levels and all operational departments. The document details policies for each department covering the four areas of awareness, location, repair, and maintenance. When changes or improvements are required, the strategy and action plan are revised and presented to senior management for approval.

Securing approval for the NRW reduction strategy from top decision-makers underscores its importance among staff. At the same time, the senior management will be accountable to the decision-makers for achieving results, and will report back on improvements to the strategy and any additional budget requirements.

4.2 BUILDING STAFF AWARENESS AND CONSENSUS

The utility's staff need to understand NRW and how the NRW reduction programme will improve the organisation. In certain cases, savings from the NRW reduction programme may be shared with the staff through bonuses or other incentives.

All staff, from senior management to the crew, should understand the NRW reduction strategy and their role in achieving the NRW target. Middle managers should participate in briefing sessions to raise their NRW awareness and to provide input to strengthen the strategies. Managers should then brief their operational staff on upcoming activities and changes in policies and practices. Some examples of how individuals in various departments are involved in the strategy's implementation include:

- Meter readers must provide accurate readings as this will immediately affect the NRW calculation.

- Purchasing officers must complete equipment orders as quickly as possible, since delays in the purchasing process will then hinder these necessary installations and upgrades in the system. As a result, district meter areas (DMAs), which can play a key role in reducing NRW, will not be established in a timely manner.

- Financial officers must not delay payments to suppliers, as this may disrupt future equipment or meter supplies.

- Crew must repair burst pipes as quickly as possible so that water losses and water supply disruptions are minimal. Fast repairs increase the utility's efficiency and promote customers' willingness to pay their water bill.

Figure 4.1: Chart to help staff understand NRW components
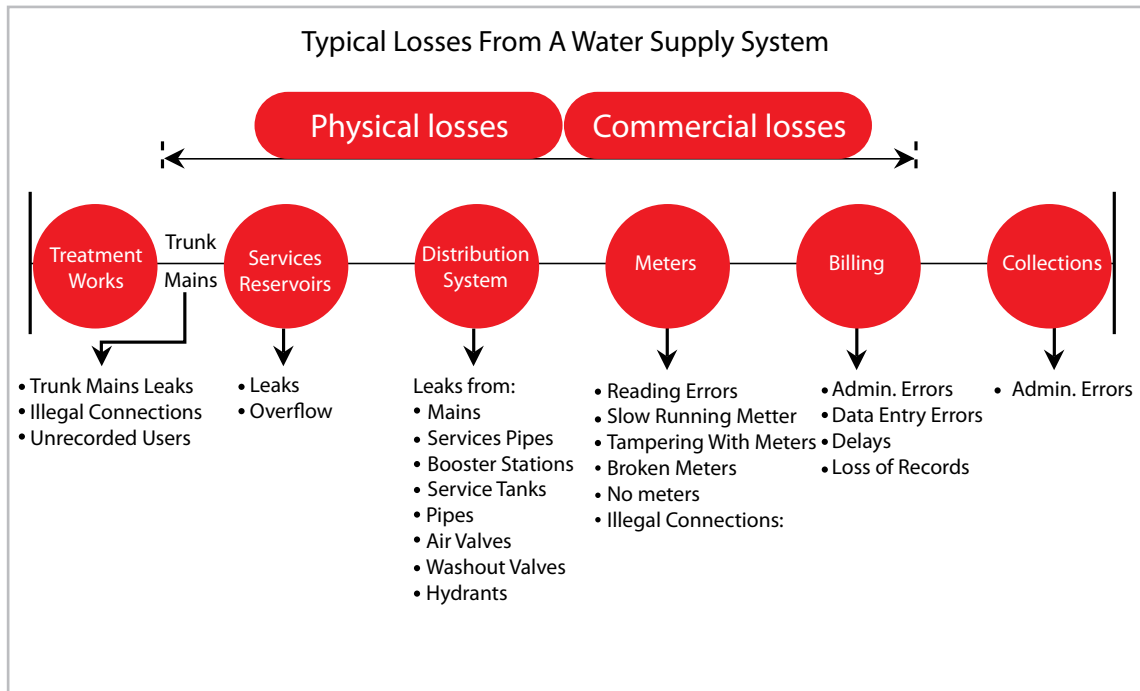
Source: Ranhill

In certain cases, contractors rather than utility staff will undertake repair works. These contractors should also understand NRW and any new repair standards or practices that are implemented.

Water utility senior managers participating in NRW awareness sessions to understand the causes of water loss.

Ranhill Experience: NRW awareness programme

Ranhill's NRW management team organised an NRW Strategy Road Show in eight operational districts, with two additional sessions at the headquarters, to ensure that all 1,700 staff members could attend the NRW awareness sessions. After the awareness programme was completed, the Corporate Communication Department conducted a survey to assess staff members' understanding of NRW. The results showed that after the Road Show, staff awareness of NRW increased significantly. The Road Show produced other benefits: staff members were more motivated to do their work; planning became more effective; and inter-department communication and communication between managers and crews improved.

4.3 REACHING OUT TO CUSTOMERS

Engaging customers helps water utilities target water loss sources, such as house connection leakages, water theft, and meter tampering.

One of the goals of reducing NRW is also to provide better and more efficient services to the public. To accomplish this, the public must also understand how they can help manage NRW by reporting burst pipes, faulty valves, leaks, or other problems that limited utility crews may not detect. The earlier the utility becomes aware of a burst pipe or leak, the faster it will be repaired, thus reducing the losses (see Figure 3.2 in section 3.4 on the relationship between awareness, location, and repair times and water losses).

Awareness programmes should be organised with a variety of stakeholders from the public, including politicians, community leaders, and household and industrial consumers. Programmes generally focus on basic NRW concepts and how reducing NRW helps ensure that communities receive better water supply and services.

Ranhill Experience: Customer awareness

Ranhill organises a programme called 'Mesra Pelanggan' (or 'Engaging the Customer') eight to ten times a year to improve awareness among community leaders and consumers throughout the state of Johor. During the programme, the NRW Department Head explains NRW, its effect on service delivery, and the activities Ranhill is undertaking to tackle NRW. The presentation is followed by a Q&A session. Participants can also browse posters and videos highlighting NRW activities in their communities.

Customers aware of poor service caused by water losses will report defective connections.

Call centre to receive information from the public

After awareness programmes are conducted in each community, all staff should work to ensure that customer confidence in the utility's services is maintained. A key element in this is open communication. For example, the public should be able to easily contact the utility to report burst pipes, leakages, or other concerns. The utility should establish a system to receive information or complaints from customers, and then to disseminate it to the relevant operational units so action is taken quickly.

Ranhill Experience: Customer call centre

Ranhill operates a 24/7 customer call centre with toll-free lines, and it encourages the public to provide information on any problems with the water supply. On average, the call centre receives 550 calls on pipe bursts and 3,600 calls on pipe leakages each month.

KEY MESSAGES

- Awareness at all levels, from top decision-makers to the end consumer, is critical to improving NRW.

- Building the understanding of top-level management on NRW and the budget required to reduce it supports the financial sustainability of the strategy.

- Middle management and staff must understand their roles and responsibilities in reducing NRW, since it requires a long-term, combined effort from all departments in the utility.

- Reaching out to customers helps to increase their awareness of NRW and how reducing water losses will result in improved water supply and quality.

5. UNDERSTANDING COMMERCIAL LOSSES

5.1 DEFINITION OF COMMERCIAL LOSSES

Commercial losses, sometimes called 'apparent losses', include water that is consumed but not paid for by the user. In most cases, water has passed through the meters but is not recorded accurately. In contrast to leaks or reservoir overflows, the lost water is not visible, which leads many water utilities to overlook commercial losses and concentrate instead on physical losses.

Commercial losses can amount to a higher volume of water than physical losses and often have a greater value, since reducing commercial losses increases revenue, whereas physical losses reduce production costs. For any profitable utility, the water tariff will be higher than the variable production cost—sometimes up to four times higher. Thus, 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 losses and presents options to address them.

5.2 COMMERCIAL LOSS ELEMENTS AND MANAGEMENT STRATEGIES

Commercial losses can be broken down into four fundamental elements, which are:

- Customer meter inaccuracy
- Unauthorised consumption
- Meter reading errors
- Data handling and accounting errors

Figure 5.1: Four pillars of commercial losses

Meter errors

Water accounting errors

Economic target for commercial loss

Existing commercial loss

Meter under registration

Water theft
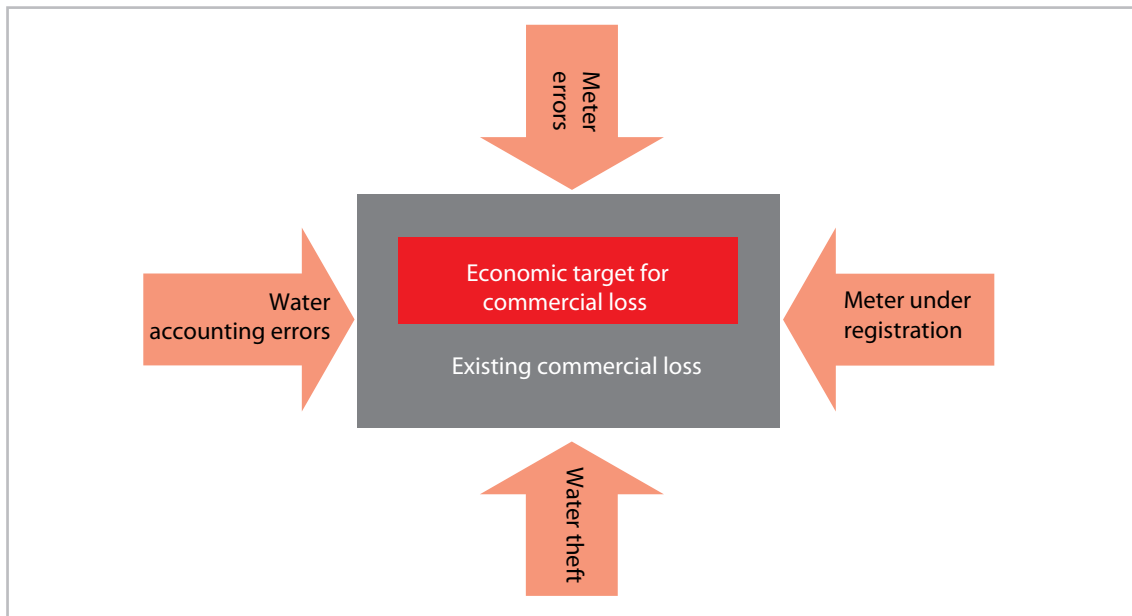
Water utilities should aim for commercial losses that are no more than 4-6% of authorised consumption. Reducing commercial losses requires a low level of investment with a short payback period, but it needs sustained management commitment, political will, and community support. Utilities should focus on commercial losses in the beginning of an NRW reduction programme since the activities can be undertaken in-house with little effort and the payback is immediate.

5.2.1 How to address customer meter inaccuracy

Inaccurate meters tend to under-register water consumption—leading to reduced sales and therefore reduced revenue. Only very rarely do meters over-register consumption. Utilities should focus initially on large customers, such as industrial or commercial users, since they consume a larger volume of water and often pay a higher tariff. Using data from accurate meters to bill customers, rather than charging them based on an assumed per capita basis, ensures that customers are charged according to their actual consumption and encourages them to preserve water. The paragraphs below discuss common problems with customer meter accuracies and solutions for utilities.

Installing meters properly

Meters should be installed properly according to the manufacturer's specifications. For example, some meters require a specific straight length of pipe upstream and downstream of the meter. Therefore a standard meter stand should be designed and constructed onsite. Utilities should purchase the meters on the customers' behalf, so that only standard, high quality meters are used. Meters should also be installed where meter readers can easily read them, and where it is easy to identify each property's meter. In addition, the management and staff responsible for meter installations should be trained on proper handling of meters.

Improper meter installation leads to inaccurate data and billing errors. Meter readers in the pictured situation will find it difficult to determine which meter belongs to which property.

Ranhill Experience: Customer meter standards

Ranhill ensures the quality of its customer meter installations by preparing standard meter stand designs, and then circulating the drawings to all plumbers. Meters are only installed after all of the internal plumbing and meter stands are constructed according to standards. Finally, Ranhill technicians inspect and approve the installations.

Sedimentation is a major cause of meter recording inaccuracies.

Monitoring water quality

Poor water quality—resulting from poor raw water, inadequate treatment processes, or dirt infiltration due to pipe shutdowns—may cause sediments to form in the pipes. These sediments can also build up on the internal parts of meters, especially mechanical meters. The build-up in sediment affects the meter's accuracy by increasing friction losses, which causes the meter to run more slowly and thus under-register consumption. Utilities must regularly monitor water quality and clean mechanical meters to minimise sediment levels and promote accurate meter measurements.

Monitoring intermittent water supply

Where water supply is intermittent, i.e. the customer receives water only a few hours a day, customer meters will register a certain volume of air when the water supply is first turned on. In addition, the sudden large increase in pressure can damage the meter's components. Intermittent supply should be avoided for a number of reasons, including the negative impact on customer meter accuracy. See Chapter 7 for information on utilising District Meter Areas to implement a 24-hour supply system.

Sizing meters properly

Customer meters work within a defined flow range, with the maximum and minimum flows specified by each manufacturer. Large meters will not register low flows when the flow rate is lower than the specified minimum. Therefore, utilities should conduct customer surveys to understand the nature of each customer's water demand and their likely consumption. This information helps to determine the proper meter size for households and businesses. For customers with a high demand, checking the flow pattern and the newly installed meter verifies whether the correct meter size is used.

Problems with low flows can occur when a storage tank, with the water flow controlled by a ball or float valve, is installed on the customer's premises. These valves operate by slowly closing as the water level in the tank rises, which has the effect of reducing the flow through the meter, often below the minimum flow specification. This problem is compounded even further if the size of the storage tank is large in comparison to the customer's consumption because the ball or float valve will never fully open and the flow through the meter will be continually low.

Using the appropriate class and type of meter

Choosing the appropriate meter helps to ensure the accuracy of customer consumption data. Class B meters are a good choice where water quality is low, as the sediments will not greatly affect the meter. Class D meters are more preferable where roof tanks are used and water quality is good, since they have a lower minimum flow specification and will measure the roof tank inflow more accurately. Class C meters are a suitable compromise in most situations, since they can measure low flows better than Class B meters and are not as expensive as Class D meters.

Common types of meters include positive displacement (PD), multi-jet, single-jet, turbine, and electromagnetic. The most common type of meter for domestic and small commercial installations is the 15 mm and 20 mm PD meter. Single-jet and multi-jet meters are more accurate for small commercial and industrial installations that require 20 mm to 50 mm sizes. Electromagnetic meters are the best choice for sizes 100 mm and above.

Ranhill Experience: Large customer meter replacement

In 2007, Ranhill changed 30 large mechanical meters to electromagnetic meters, which increased consumption readings by up to 20% at some locations. Electromagnetic meters have a higher accuracy at both high and low flows, and the flow through the meter is full bore, reducing any headlosses.

Installing an electromagnetic meter with Ranhill's biggest customer in Johor increased the accuracy of readings and led to an 8% increase in their water bill. The payback period for the new meter was only half a month.

Maintaining and replacing meters properly

All meters should be installed above ground and located where they can be audited easily, including by the meter readers during their regular rounds. The utility should replace the meters systematically, beginning with the oldest meters and those in the worst condition. Poor maintenance will not only encourage inaccuracy but may shorten the life span of the meter. A scheduled maintenance and replacement programme should be in place to manage this problem.

Meter servicing is essential, especially in areas of poor water quality. The accuracy of mechanical meters changes over time as the mechanical bearings wear down, causing friction to increase

Examining meters regularly enables utilities to detect the need for calibration or replacement, and builds trust with customers.

and thus the meters to under-register. These changes will occur over a number of years, depending on the quality of manufacture. The water utility should regularly test a sample of its customer meters, including a range of meter brands and ages, using a calibrated meter test bench. This testing will determine the optimum age at which customer meters should be replaced.

Ranhill Experience: Customer meter servicing

Ranhill services all customer meters 50 mm and above on a 6-month to 1-year frequency, depending on the water quality in the area. In addition, analyses of smaller domestic meters within a District Meter Area (DMA) will reveal if the water quality is affecting the meter accuracy. If so, then Ranhill carries out meter servicing for all domestic meters in the DMA.

The customer has tampered with the meter's moving parts.

Addressing meter tampering

Although water tariffs in Asia are relatively low, customers still sometimes tamper with their meters to lower the measured volume. Customers may insert pins or other objects into the meter to disturb its moving parts. Some try to affect the readings of metal meters by attaching a strong magnet to it. In other cases, customers have boiled plastic meters trying to melt the internal plastic parts.

Most reputable meter manufacturers now produce meters that are extremely tamper-resistant, with non-metallic parts, strong clear plastic windows, and impenetrable casings. Although these meters may cost a bit more, reduced tampering helps to reduce commercial water losses. For properties with older meters that are not as tamper-resistant, utility managers should conduct customer surveys to assess expected water usage according to the number of household occupants or the nature of businesses in commercial areas. A comparison of expected and actual water use will highlight cases of likely meter tampering.

5.2.2 Unauthorised consumption

Unauthorised consumption includes illegal connections, meter bypassing, illegal use of hydrants, and poor billing collection systems. The following paragraphs describe common problems and possible solutions.

Water theft occurs at large pipes, as well as in household water connections.

Finding and reducing illegal connections

Illegal connections involve the physical installation of a connection to water distribution pipelines without the knowledge and approval of the water utility. Illegal connections can occur during the installation of a new supply connection, or sometimes the customer's supply is cut off after non-payment and the customer cannot afford, or does not want to pay, to be reconnected.

During customer awareness programmes, customers should be encouraged to report illegal connections, and regulations should be in place to penalise the water thieves. Meter readers should also report cases of direct connections without accompanying meters that they see during their rounds.

Ranhill Experience: Preventing illegal connections

Lockable valves help limit illegal connections. The water utility should have the only keys available for the valves. After a customer's water supply has been disconnected for non-payment, and reconnection has not been requested within one week, the utility should visit the property to check whether the customer has made an illegal connection.

Tackling meter bypassing

Some customers try to reduce their water bills by using a meter bypass, which is an additional pipe installed around the meter. This bypass pipe is often buried and very difficult to detect. This type of unauthorised consumption is usually committed by industrial and commercial premises, where only a small volume of the consumption goes through the meter and the rest through the bypass pipe.

Because large customers tend to steal large volumes of water, the discrepancy will show up when the utility conducts a flow balance analysis. The utility should then undertake customer surveys and leakage step tests to determine where the missing flow occurs.

Preventing illegal use of fire hydrants

Although the only legal use of fire hydrants is for fire fighting, some use them illegally to fill tankers (normally at night) or to provide water supply to construction sites. The utility staff can detect these flows, often high volume over a short period of time, through appropriate flow measurements at DMA meters. Such high flows are not only incidences of water theft, but also a detriment to the pipe network and water quality, which affects the service to the customer.

Through customer awareness programs, the utility staff should encourage customers to report cases of illegal uses of fire hydrants. In addition, the utility manager needs to cooperate with relevant local agencies or departments to identify owners of tankers suspected of drawing water illegally and without proper permission. Developing and enforcing regulations to penalise water thieves together with local agencies will also deter unauthorised consumption.

Ranhill Experience: Fire hydrant vandalism

Ranhill charges water losses to those who vandalise fire hydrants, if the public has provided information to accurately identify them, and the Johor Fire Department also charges them for vandalising the hydrant.

Actively checking the customer billing system

Sometimes connections are made legally, but the billing department is not notified of the new connection; therefore, the customer is never billed. These unregistered customers can be detected during the regular meter reading cycle when diligent meter readers find meters that are not in their reading book. However, this process may not identify all of the errors in the billing system.
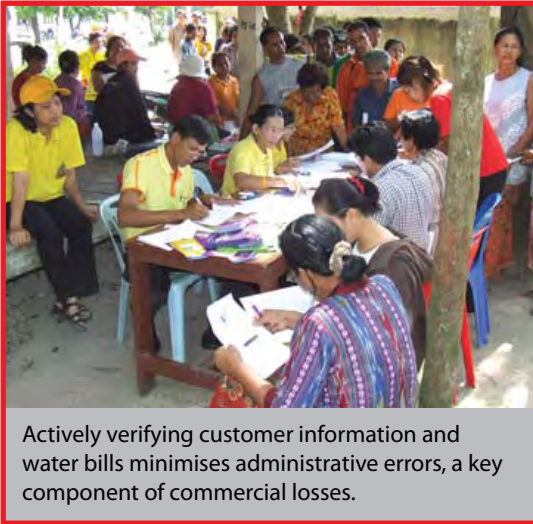
Actively verifying customer information and water bills minimises administrative errors, a key component of commercial losses.

Conducting a complete customer survey within each DMA, whereby utility representatives visit every property in the DMA—whether or not they are recorded in the billing system—is the best method of comprehensively identifying billing system errors. The survey should include the following information: property address, name of owner, and meter make and number (see samples on enclosed CD). The representative should also conduct a meter test to ensure that the accurate flow is recorded.

For metered areas, utilities should focus on large users by encouraging good customer relationships through frequent visits. Checking large customers' accounts monthly will help detect anomalies, which may be due to water theft. In areas of suspected high commercial losses, temporary DMAs can be established to analyse flows through standard monitoring activities, such as step testing and flow balancing, to pinpoint problematic areas.

Avoiding corrupt meter readers

Corrupt meter readers can significantly impact a utility's monthly billed consumption. For instance, the same meter reader who walks the same route for an extended period of time, thus becoming familiar with the customers and their monthly billed consumption, may collude with those customers to record lower meter readings in exchange for a monetary incentive. To reduce this risk, the utility manager needs to rotate meter readers to different routes on a regular basis.

Ranhill Experience: Meter reading practices

Ranhill's meter readers in Johor are assigned rotating meter reading routes, so that each person reads a particular meter not more than once every four cycles, or approximately every four months.

5.2.3   Meter reading errors

Errors can be easily introduced through negligence, aging meters, or even corruption during the process of reading the meters and billing customers. Incompetent or inexperienced meter readers may read the meter incorrectly or make simple errors, such as placing a decimal in the wrong place. Dirty dials, faulty meters, and jammed meters can also contribute to meter reading errors. The meter readers should immediately report any observed problems, and the maintenance team should take action to remedy the problem immediately. If remedial action is too slow, meter readers may become demoralised and less inclined to report problems.

Because meter readers are the utility's frontline in liaising with customers, their activities have an immediate impact on cash flow. Utility managers should therefore invest in training and motivating

their meter readers to record and report information effectively and efficiently. The manager should also establish systems and procedures to prevent meter reading errors by improving its meter reading and billing processes through greater supervision of meter readers, implementation of rotating reading routes, and frequent spot checks.

5.2.4   Data handling and accounting errors

The typical method of data handling and billing requires a meter reader to visit each property and read the customer meter. The data is then recorded by hand on a form, taken back to the office, given to the billing department, and typed into the billing system. A bill is then printed and mailed to the customer. In this scenario, a variety of errors may occur at the different stages: the

Spot billing minimises data handling errors.

meter reader writes down incorrect data; the billing department transfers incorrect data into the billing system; or the bill is sent to the wrong address.

A robust billing database is one of the key elements of minimising these errors and should be the initial purchase of any water utility striving to improve its revenues. The latest billing software has built-in analysis functions that can identify potential data handling errors and report them for verification. In addition, billing software will report monthly estimate readings and zero reads, both of which may indicate a problem with the customer's meter. Site visits will help identify meters needing replacement.

Training of meter readers promotes diligence, good customer meter maintenance, and decreased meter reading errors. If financially viable, utilities should consider electronic meter-reading devices, which reduce data handling errors to a minimum since all data transfers to the billing system are done electronically.

⚷ KEY MESSAGES

- For any profitable utility, the water tariff will be higher than the variable production cost—sometimes up to four times higher. Thus, even a small volume of commercial loss will have a large financial impact.
- Commercial losses occur mostly through faulty or tampered meters and through errors committed during meter reading or processing in the billing system.
- Meters are essential tools for measuring water consumption and should be as accurate as possible.
- Coordination from the public and relevant local authorities is required to overcome illegal uses of water.
- Training meter readers, staff, and crews is a continuous process to ensure competent customer service.
- Investing in high quality meters and a robust billing system can result in higher returns.

6. UNDERSTANDING PHYSICAL LOSSES

6.1 DEFINITION OF PHYSICAL LOSSES

Water losses occur in all distribution networks, even new ones. Physical losses, sometimes called 'real losses' or 'leakage', includes the total volume of water losses minus commercial losses. However, the water balance process, as described in Section 2.3, indicates that commercial losses are estimated and therefore the resulting leakage volume may be incorrect. Utility managers must therefore verify the results using component analysis (the top-down approach) or physical loss assessment (the bottom-up approach, see Chapter 7 on aggregating night flows in DMAs).

The three main components of physical losses include:

- Leakage from transmission and distribution mains
- Leakage and overflows from the utility's reservoirs and storage tanks
- Leakage on service connections up to the customer's meter

The first and second types of leakage are usually quite visible to either the public or utility staff, so they are easy to detect and are repaired relatively quickly. The third type is more difficult to detect and can therefore lead to a greater volume of physical losses. This chapter describes these three types of losses and solutions for reducing them.

6.2 PHYSICAL LOSS ELEMENTS

6.2.1 Leakage from transmission and distribution mains

Leakages occurring from transmission and distribution mains are usually large events, sometimes catastrophic, causing damage to highway infrastructure and vehicles. The majority of such bursts are usually not very severe although they cause supply disruptions. Because of their size and visibility, the bursts are reported quickly, and are then repaired or shut off soon afterwards.

By using data from repair records, utility managers can calculate the number of leaks on mains repaired during the reporting period (usually 12 months) and estimate an average flow rate of the leaks. This gives the total annual volume of leakage from mains as follows:

$$\text{Total annual volume of leakage from mains} = \frac{\text{Number of reported bursts}}{\text{x Average leak flow rate x Average leak duration}}$$

If no detailed data are available, utility managers can use approximate flow rates from Table 6.1.

'Catastrophic' mains bursts

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Table 6.1: Flow rates for reported and unreported bursts

Location of Burst	Flow Rate for Reported Bursts [l/hour/m pressure]	Flow Rate for Unreported Bursts [l/hour/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 an active leak detection survey can discover them. Table 6.2 shows background losses from various components of the network with average infrastructure condition.

Table 6.2: Calculating background losses

Location of Burst	Litres	Unit of Measure
Mains	9.6	Litres per km of mains per day per metre of pressure
Service Connection – main to property boundary	0.6	Litres per service connection per day per metre of pressure
Service Connection – property boundary to customer meter	16.0	Litres per km of service connection per day per metre of pressure

Source: IWA Water Loss Task Force

Excess losses include the water lost from leaks that are not detected and repaired under the current leakage control policy:

Excess Losses = Physical losses from water balance - known physical loss components

If this equation results in a negative value for excess losses, the assumptions for the physical loss component analysis (e.g. values for leak durations) should be rechecked, and if necessary, corrected. If the value is still negative after rechecking the assumptions, this indicates that faulty data was used in the water balance calculation. For example, utility managers may have underestimated system input or overestimated commercial losses), and all the components should be checked.

6.2.2 Leakage and overflows from the utility's reservoirs and storage tanks

Leakage and overflows from reservoirs and storage tanks are easily quantified. Utility managers should observe overflows then estimate the average duration and flow rate of the events. Most overflows occur at night when demands are low and therefore it is essential to undertake regular nightly observations of each reservoir. These observations can be undertaken either physical or by installing a data logger which will then record reservoir levels automatically at preset intervals.

Leakage from tanks is calculated using a drop test where the utility closes all inflow and outflow valves, measures the rate of water level drop, and then calculates the volume of water lost. However, repairing these leaks is a major operation, requiring draining down the reservoir and planning an alternative supply.

Ranhill Experience: Reservoir monitoring

Ranhill's dedicated reservoir monitoring teams place plastic bottles in the overflow pipes in all 456 of its reservoirs. Teams check the location of these bottles monthly. If bottles are outside of the pipe, indicating a possible overflow, the monitoring teams undertake further investigations using data loggers.

Typically more difficult to detect, service connection leaks result in significant water losses.

6.2.3 Leakage on service connections up to the customer's meter

This type of leakage is usually more difficult to detect and results in the greatest volume of physical losses. Utility managers should calculate the approximate volume of leakage from service connections by deducting the mains leakage and storage tank leakage from the total volume of physical losses.

6.3 CHARACTERISTICS OF LEAKAGES

Having defined where leakage can occur in the transmission and distribution network, utility managers should familiarise themselves with the different types of leaks and understand the effect of the leak run time, or ALR, on the total volume of physical losses (see Figure 6.1, and Section 3.3 for a discussion of the ALR concept).

The type and location (e.g. main or service connection) of a burst influences the total run time:

- **Reported bursts**—Visible and usually quickly reported by the public or observed by water utility staff. They have a short awareness time.

- **Unreported bursts**—Commonly occur underground and are not visible at the surface. They are usually discovered during leak detection surveys and often have a long awareness time.

- **Background leakage**—An accumulation of very small leaks that are difficult and not cost-effective to detect and repair individually.

Figure 6.1: Leak run time and volume of water loss
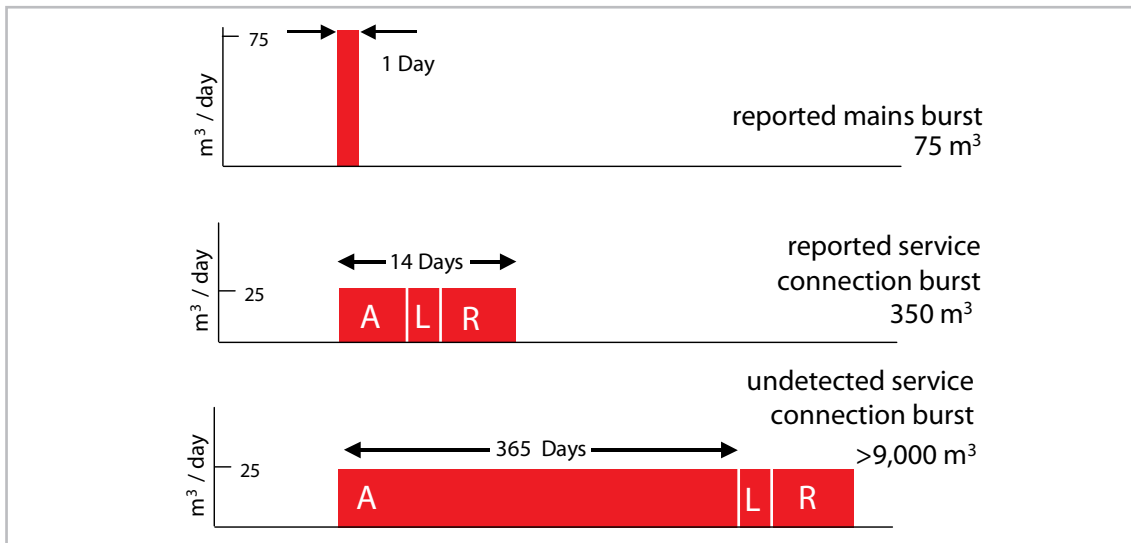
General conclusions concerning leakage include:

- Most leaks are invisible
- The majority of leaks do not come to the surface
- Managers need to be aware that most leaks are on service connections
- The absence of an active programme to detect invisible leaks is an indication of high levels of leakage

6.4 DEVELOPING A LEAKAGE MANAGEMENT STRATEGY

The four pillars of a leak management strategy include pressure management, repairs, active leakage control, and asset management (Figure 6.2). These factors influence how leakage is managed—and therefore the volume and economic value of leakage—in any utility's distribution network.

The large square represents the **C**urrent **A**nnual Volume of **P**hysical **L**osses (CAPL), which tends to increase as the distribution network ages. But the rate of increase can be constrained by an appropriate combination of the four components of a successful leakage management strategy. The black box represents the **M**inimum **A**chievable **A**nnual **P**hysical **L**osses (MAAPL), or the lowest technically achievable volume of physical losses at the current operating pressure. Introducing or strengthening any of the four components will have an effect on the potentially recoverable losses.

Figure 6.2: The four pillars of a successful leakage management strategy
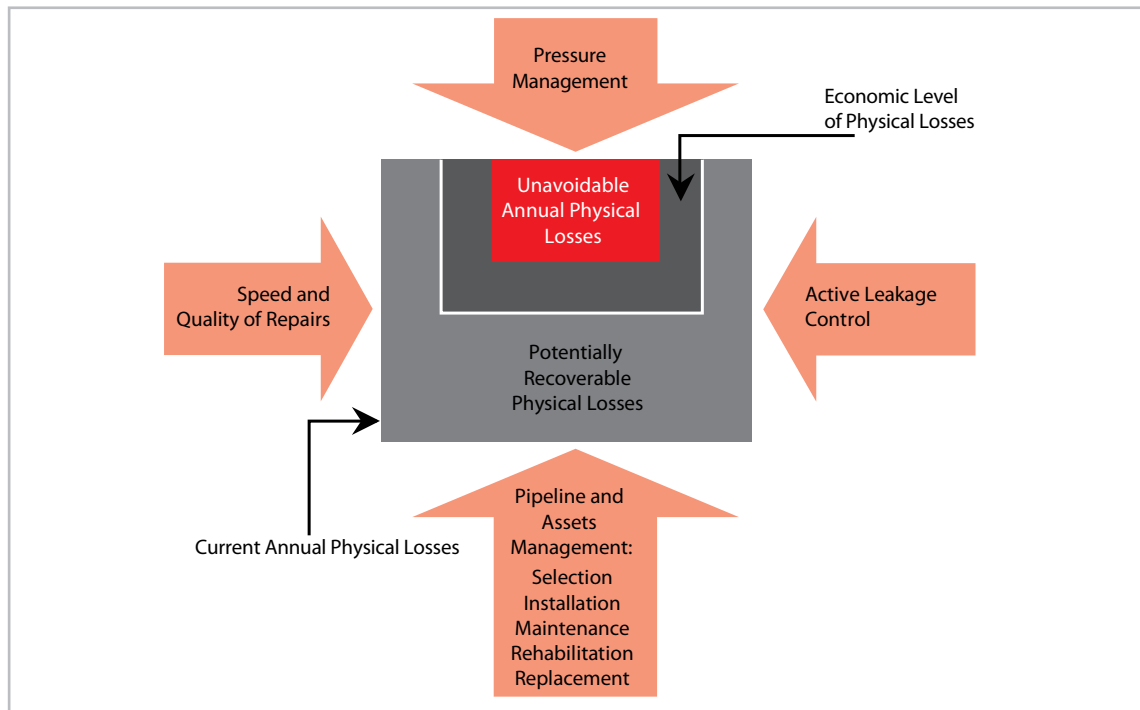
6.4.1 Active leakage control (ALC)

Active leakage control (ALC) is vital to cost-effective and efficient leakage management. The concept of monitoring flows into zones, or district meter areas (DMAs), where bursts and leaks are unreported is now an internationally accepted and well-established technique to determine where leak location activities should be undertaken. The quicker the operator can analyse DMA flow data, the quicker bursts or leaks can be located. This, together with speedy repair, limits the total volume of water lost.

There are many points in a distribution network where leakages can occur and where they are best monitored (Figure 6.3). The DMA concept, and the associated technology and equipment for leakage monitoring, detection, and location, is described in detail in Chapter 7.

Figure 6.3: A typical distribution network
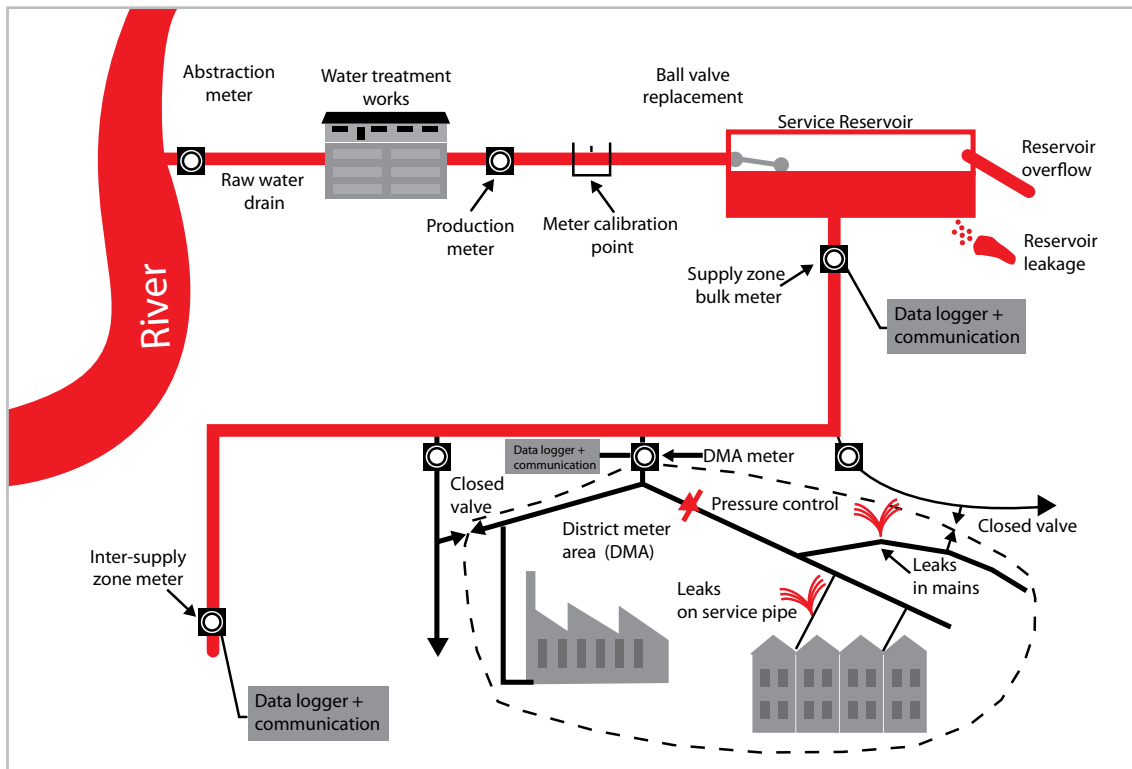
Flow metering

Modern flow metering and data capture technologies play a major part in quickly identifying bursts and in estimating the gradual accumulation of smaller leaks. Many water utilities integrate data from DMAs via telemetry into their supervisory control and data acquisition (SCADA) systems. This approach is particularly effective when implemented together with an analysis package that helps the utility manager identify DMAs that requiring leak location work.

Leak localising, locating, and pinpointing

Utility managers need to ensure a detailed process is undertaken to locate leaks:

- Use flow meter data to identify DMAs that contain unreported bursts or an accumulation of leaks
- Narrow down the area of leakage within the DMA
- Pinpoint the exact (or nearly exact) position of the leak.

This process requires reasonable accuracy at each step to avoid high excavation costs and 'dry holes' (excavations at suspected leak points that reveal no obvious leak). The basic method of detecting and locating a leak is to listen for the noise of the water being released from the pipe under pressure. The effectiveness of this activity is dependent on the system pressure, the size and shape of the leak and the pipe material.

For ensuring accuracy the utility has a wealth of acoustic equipments to pinpoint leaks and bursts, including noise loggers, leak noise correlators, ground microphones, and sounding sticks. Although these tools are extremely helpful for ALC, utility managers must understand the proper applications and maintenance requirements of each tool to maximise their use.

- **Noise loggers**—Noise loggers narrow down areas of a DMA that contain suspected bursts or number of leaks. A cluster of loggers, usually 6, 12, or 18, is deployed in the survey area, with each logger placed on a hydrant, meter, or other surface fitting. Noises that are suspected of being caused by leaks can be confirmed, and the leak is located using other location equipment as described below. Some noise logger systems also incorporate data from multiple points to 'instantly' locate leaks.

Noise logger deployment

- **Leak noise correlators**—Rather than locating a leak based on the noise level, this instrument uses the velocity of sounds made by the leak as they travel along the pipe wall toward each of two microphones placed on fittings either side of the suspected leak. The effectiveness of this process is dependent on the strength of the leak noise and the sound conductivity of the pipe material. Hydrophones placed in the water column can also enhance the leak sounds in plastic or large pipes and other pipes where the noise conductivity is known to be poor. These hydrophones work by listening to the leak noise travelling through the water, which is a better conductor, than most pipe materials, of sound.

  The latest correlator versions, have the capability of frequency selection and filtering, to quickly locate leaks to within 0.5 metres in most sizes of pipe, provided there are sufficient contact points along the line of the main. Low-cost basic models are available, which are adequate for most situations.

- **Ground microphones**—The ground microphone electronically amplifies the sound of a leak. It can be assembled for use in either contact or survey mode. Contact mode is for sounding on

An 'advanced' leak noise correlator, showing correlation peaks at various frequencies
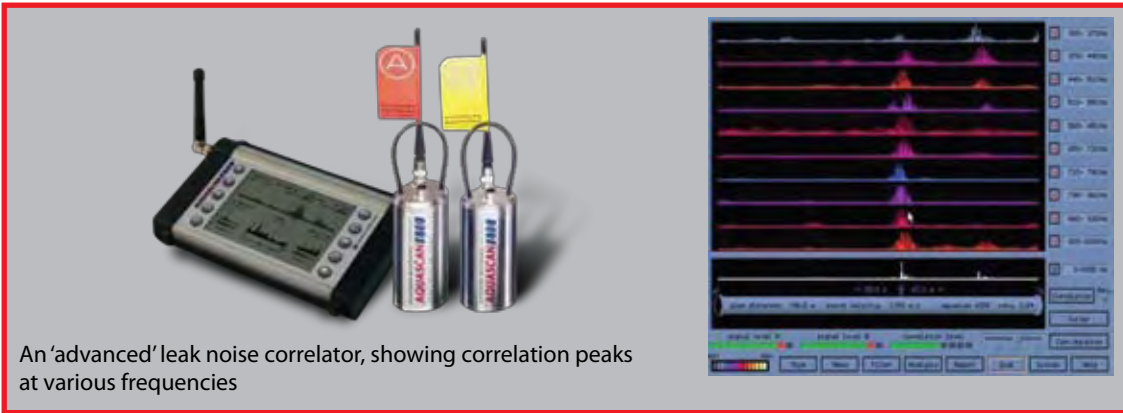
fittings, similar to an electronic listening stick. Survey mode is for searching for leaks on lengths of pipeline between fittings. The technique involves placing the microphone on the ground at intervals along the line of the pipe and noting changes in sound amplification as the microphone nears the leak position. When a leak is detected by the leak noise loggers or leak noise correlator, the utility manager may use either mode to locate the leak.

- **Sounding Sticks**—The sounding stick, or 'stethoscope', is an inexpensive, simple rod made of wood or metal with an ear piece attached to amplify sounds. Utility managers use it to listen to leak sounds on the surface of the highway or on directly exposed pipes and fittings. The sounding stick is invariably used to confirm a leak site that is first identified by a correlator.

All of the equipments above will not only detect the noise that a leak makes but also any other noise in the system, such as a pump, tap, air valve, etc, It is therefore important to have a team

Using a sounding stick

of experienced leakage detection staff who not only can use the equipment correctly but have the skills to identify leaks effectively.

6.4.2 Pressure management

Pressure management is one of the fundamental elements of a well-developed leakage management strategy. The rate of leakage in water distribution networks is a function of the pressure applied by pumps or by gravity. There is a physical relationship between leakage flow rate and pressure (Figure 6.4), and the frequency of new bursts is also a function of pressure:

- The higher or lower the pressure, the higher or lower the leakage

- The relationship is complex, but utility managers should initially assume a linear relationship (10% less pressure = 10% less leakage)

- Pressure level and pressure cycling strongly influence burst frequency

Figure 6.4: Pressure/leakage relationship

N1=0.5 N1 is the scaling factor to account for different pipe and network characteristics, but large networks with a mix of pipe materials tend towards a linear relationship, with N1 = 1.0

N1=1 For leaks from metallic pipes, N1 = 0.5

N1=1.5 Small leaks from joints and fittings (background leakage), N1 = 1.5

N1=2.5 In exceptional cases, e.g. splits in plastic pipes, N1 could be as high as 2.5
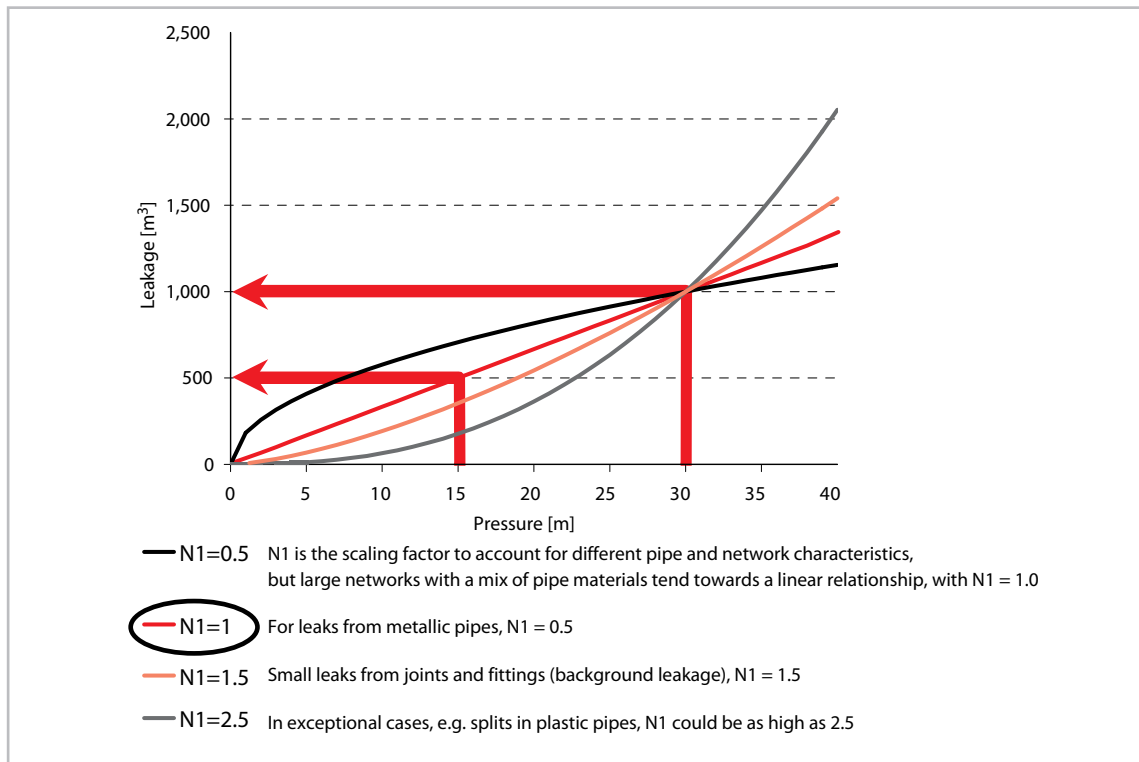
Source: World Bank Institute

To assess the suitability of pressure management in a particular system, utilities should first carry out a series of tasks, including:

- Identify potential zones, installation points, and customer issues through a desktop study

- Identify customer types and control limitations through demand analysis

- Gather field measurements of flow and pressure (the latter usually at inlet, average zone point, and critical node points)

- Model potential benefit using specialized models

- Identify correct control valves and control devices

- Model correct control regimes to provide desired results

- Analyse the costs and benefits

There are a number of methods for reducing pressure in the system, including variable speed pump controllers and break pressure tanks. However the most common and cost effective is the automatic pressure reducing valve or PRV.

PRVs are instruments that are installed at strategic points in the network to reduce or maintain network pressure at a set level. The valve maintains the pre-set downstream pressure regardless of

PRVs installed in meter chambers

the upstream pressure or flow-rate fluctuations. PRVs are usually sited within a DMA, next to the flow meter, as shown in the photos below. The PRV should be downstream of the meter so that turbulence from the valve does not affect the meter's accuracy. It is good practice to install the PRV on a bypass pipe to enable future major maintenance works.

Ranhill Experience: Pressure management

Ranhill has installed approximately 200 pressure reducing valves (PRVs), which are distributed throughout 25% of the established DMAs. The PRVs use fixed pressure outlets, but Ranhill is currently investigating the viability of installing timers to reduce pressure further during low demand periods.

6.4.3 Speed and quality of repairs

The length of time a leak is allowed to run affects the volume of physical losses, so repairs should be completed as soon as possible once a leak is detected. Repair quality also has an effect on whether the repair is sustained. Key issues to consider when formulating a repair policy include:

- Efficient organisation and procedures from the initial alert through to the repair itself
- Availability of equipment and materials
- Sufficient funding
- Appropriate standards for materials and workmanship
- Committed management and staffs
- Good quality of service connections—service connections are often the 'weakest link'

6.4.4 Asset management

Asset management is good engineering and business practice, and it includes all aspects of utility management and operations. Good asset management is a necessity for long-term economic leakage management, and the objective is to tackle leaks in the most cost-effective way. This

requires priority setting and decisions on whether to repair, replace, rehabilitate, or leave the assets as they are, while simultaneously implementing pressure management and improving the operation and maintenance programme. The critical factors of asset management are:

- Understanding how assets are currently performing
- Collecting data and turning it into useful information for planning
- Good information systems

Particularly relevant to developing an NRW reduction strategy is the aging of the pipe network and making decisions on when to replace or renew the network infrastructure. This requires an understanding of the assets' conditions and deterioration rates. Burst frequency modelling, using data from burst records, helps prioritise pipe rehabilitation, renewal, or replacement. In addition, active leakage control will identify clusters of pipes in the network where bursts and repairs are a continuous occurrence.

When these activities do not lead to reduced leakages, utility managers should undertake a condition assessment programme to decide whether to replace pipes or conduct further repairs. During the decision process, utility managers should ask the following questions:

- If repairing, replacing, or rehabilitating assets, what materials should be used?

- Should pipes be replaced now or later during network extensions to address future demand increases?

Ranhill Experience: Asset replacement

The Johor pipe network has over 10,000 kilometres of aging asbestos cement pipes that need to be replaced. Ranhill identifies pipes for replacement based on the number of bursts per kilometre. In addition, whenever a single DMA has undergone three leak detection activities with no significant reduction in leakage, then the pipework within that DMA is replaced.

KEY MESSAGES

- Physical losses include leakage on transmission and distribution mains; leakage and overflows from storage tanks; and leakage on service connections up to the customer meter.

- Leakages from transmission and distribution mains are usually large events so they are reported quickly by the public. They can cause serious damage unless they are repaired quickly. Less conspicuous types of leakage are more difficult to detect and repair.

- A successful leakage management strategy requires pressure management, active leakage control, pipeline and asset management, and speedy and quality repairs.

7. UNDERSTANDING DISTRICT METER AREAS

Many water utilities operate their pipe networks as an open system where water is fed from more than one Water Treatment Plant (WTP) into an inter-connected pipe network. Water from each WTP will mix within the network, which continually affects system pressure and water quality. In an open system, NRW can only be calculated for the entire network, which is effectively an average level for the entire system. Thus, determining the exact locations of NRW occurrences—and where NRW reduction activities should take place—can be quite a challenge, especially for large networks.

Generally NRW management in an open system is undertaken in a passive manner where NRW reduction activities are initiated only when the loss becomes visible or is reported. A more effective approach is to move towards Active NRW Management where dedicated teams are established and sent out to look for water losses, such as leaks, reservoir overflows, and illegal connections.

Active NRW Management is only possible using zones, where the system as a whole is divided into a series of smaller sub-systems for which NRW can be calculated individually. These smaller sub-systems, often referred to as District Meter Areas (DMAs) should be hydraulically isolated so that utility managers are able to calculate the volume of water lost within the DMA. When a supply system is divided into smaller, more manageable areas, the utility can better target NRW reduction activities, isolate water quality problems, and better manage overall system pressure to allow for 24/7 water supply throughout the network.

Dividing the open network into smaller, more manageable areas called District Meter Areas (DMAs) enables network operators to manage the system more effectively in terms of pressure control, water quality, and NRW. This chapter describes how utilities should establish DMAs and then use

information on flow and pressure to better manage NRW. It also discusses the benefits of using DMAs to improve water quality and supply for customers.

7.1 DMA ESTABLISHMENT CRITERIA AND PROCESS

The design of a series of DMAs is very subjective, and it is unlikely that two utility engineers working on the same network would come up with the same design. The engineer typically uses a set of criteria to create a preliminary DMA design that must be tested either in the field or using a network model.

These criteria include:

- Size of DMA (e.g. number of connections—generally between 1,000 and 2,500)

- Number of valves that must be closed to isolate the DMA

- Number of flow meters to measure inflows and outflows (the fewer meters required, the lower the establishment costs)

- Ground-level variations and thus pressures within the DMA (the flatter the area the more stable the pressures and the easier to establish pressure controls)

- Easily visible topographic features that can serve as boundaries for the DMA, such as rivers, drainage channels, railroads, highways, etc.

To divide a large open system into a series of DMAs, it is essential to close valves to isolate a certain area and install flow meters. This process can affect the system's pressures, both within that particular DMA as well as its surrounding areas. The water utility therefore must ensure that the water supply to all customers is not compromised in terms of pressure and supply hours.

Box 7.1: Network Modelling

Network modelling is the process of constructing a computer simulation of a pipe network using specialised computer software. Utility managers then verify the simulation by comparing the simulated flows and pressures with real flow and pressure data recorded onsite. Adjustments are made to the model to ensure that the simulated and the real data correlate, thus creating a calibrated hydraulic network model.

Using a calibrated hydraulic network model of the supply system to simulate possible DMA designs will enable analyses of system pressures and flows without affecting supply to customers. However, many water utilities do not have existing calibrated hydraulic network models. Rather than wait for a model to be developed, which can take up to one year or more, a water utility should begin establishing DMAs in network areas that can be easily isolated, i.e. areas with a separate supply zone.
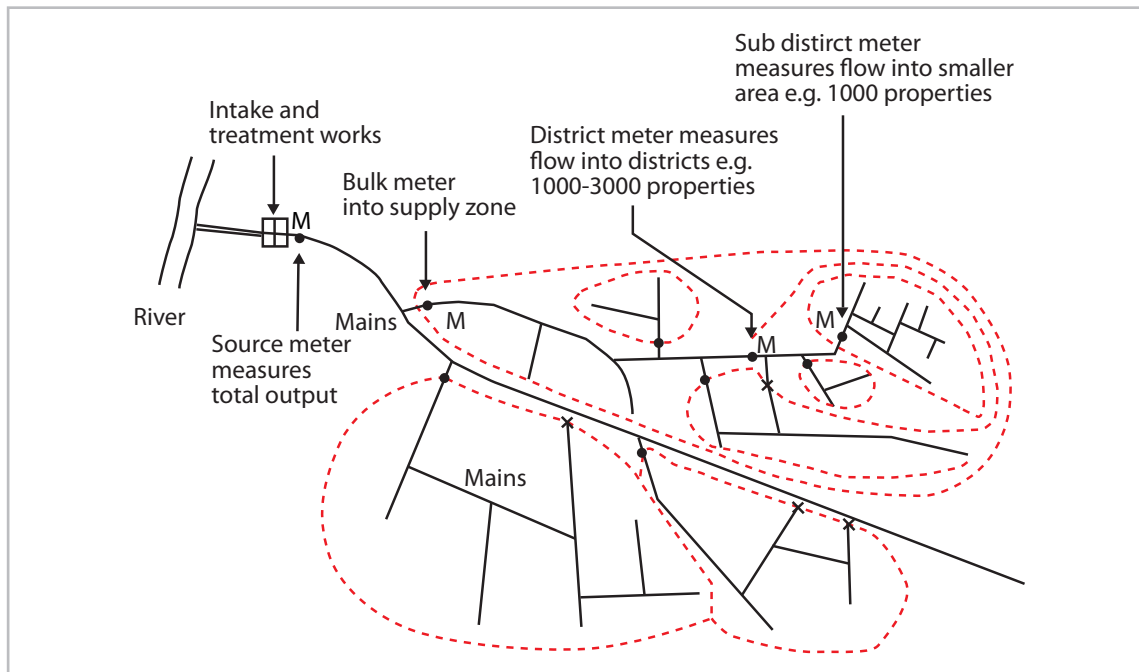
In establishing a DMA, the water utility should limit the number of inflows, which also helps to reduce the cost of flow meter installation. To achieve this, it is necessary to close one or more boundary valves, which must remain shut permanently to ensure that any flow data accurately represents the total inflow for the DMA.

Utility managers will ensure that all pipes into and out of the DMA are either closed or metered by performing an isolation test as follows:

1. Close all metered inlets.

2. 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.

Figure 7.1: Typical DMA layout

If the budget is limited, the water utility should initially establish larger zones of 5,000 or more connections. It can subsequently subdivide them into DMAs and sub-DMAs of 1,000 or fewer connections for those DMAs with high NRW and long lengths of pipework, as detailed in Figure 7.1.

For each DMA, utility managers should develop a detailed operations manual to assist future teams in managing the water supply. The operations manual includes a schematic of the pipe network; location drawings of the flow meters, pressure control valves, and boundary valves; and a copy of the billing database for the DMA. The manual is a working document and operational data should be continually updated, including information on the following:

- Flow and pressure graphs
- Leakage step tests data
- Leak locations
- Illegal connection locations

- Legitimate night flow (LNF) test data
- Pressure T Factor test data

7.2 USING DMA RESULTS TO REDUCE NRW LEVELS

Once the DMA has been established, it becomes an operational tool for monitoring and managing both of the major components of NRW, physical and commercial losses. The calculation for NRW within a DMA is defined as follows:

DMA NRW = Total DMA Inflow - Total DMA Consumption

After flow meters are installed on all inlets to the DMA, the Total DMA Inflow can be measured using the increase in the totaliser, or the meter counter measuring the volume of water passing through the meter, for the calculation period.

The Total DMA Consumption will depend on the customer meter coverage. If the DMA has a 100% domestic meter coverage, meaning all customers within the DMA have a meter, then the Total DMA Consumption can be calculated through a simple summation of all meter measurements for the calculation period.

Ranhill Experience: DMA establishment

The supply system in Johor, Malaysia has approximately 865,000 customers. As part of the NRW reduction programme, Ranhill has established 820 DMAs to date with an average of 1,055 customers per DMA. Ranhill has 100% customer meter coverage within its supply system and all customers have been assigned to one of the 820 DMAs. To identify unacceptably high NRW levels, the total DMA consumption and NRW is determined through a simple monthly summation within the billing system database.

If 100% domestic meter coverage does not exist within the DMA, then the Total DMA Consumption can be estimated by using per capita consumption figures. Initially, a survey of all properties within the DMA should be undertaken; this survey may be limited to counting the number of properties and estimating the average number of occupants per property. For a more detailed estimate, surveyors will interview all households and ask how many occupants live within each property.

7.2.1 Estimating physical losses

Most DMAs will not contain any reservoirs or trunk mains, so these components are not usually considered when analysing physical losses within a DMA. Physical losses within a DMA are effectively pipe leaks on the main pipes and customer connections. Leakage occurs through holes or cracks in the main pipes or at pipe joints, which will leak water constantly over a 24-hour period. In contrast, leaks from customer connections fluctuate with customer demand throughout the day, with peak demand in the morning and evening, and a minimum demand at night when most customers are asleep and not using water.

Because leakage from the main pipes is continuous, while customer demand is minimal at night, water operators should monitor leakage during the night period. Figure 7.2 shows the flow pattern into a typical DMA with mainly domestic customers.

Figure 7.2: Typical 24-hour DMA flow profile
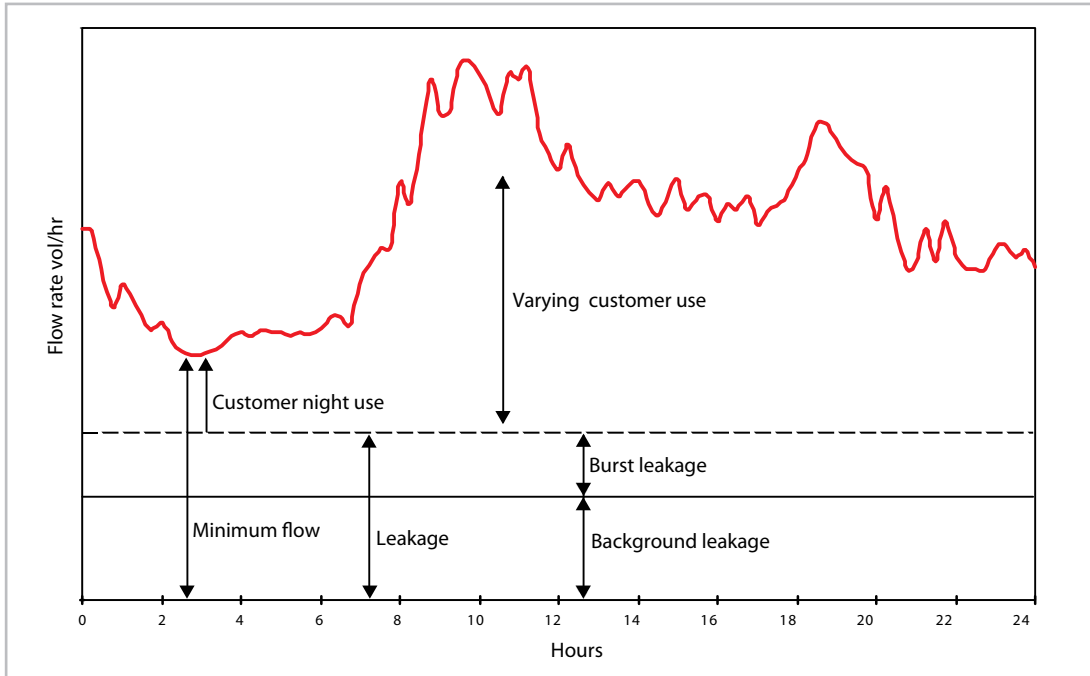
To estimate the level of leakage in the DMA the operator needs to calculate the system's Net Night Flow (NNF), which is determined by subtracting the Legitimate Night Flow (LNF) from the Minimum Night Flow (MNF).

The MNF is the lowest flow into the DMA over a 24-hour period, which generally occurs at night when most consumers are inactive. This MNF can be measured directly from the data logging device or the flow graph. Although customer demand is minimal at night, water operators still have to account for the small amount of legitimate night flow, i.e. the night-time customer demand, such as toilet flushing, washing machines, etc.

In a system with 100% metering, LNF is calculated by measuring the hourly night flow for all non-domestic demand and a portion (e.g. 10%) of domestic meters within the DMA. The utility will then estimate the total LNF in terms of litres per hour and litres per second.

Ranhill Experience: Legitimate Night Flow (LNF)

Ranhill conducts LNF tests within each DMA by measuring the consumption of all non-domestic and 10% of all domestic meters for a two-hour period between 2:00 am and 4:00 am to calculate the average LNF.

For systems without 100% customer metering, water operators can approximate LNF based on estimated per capita night consumption. Utility managers should conduct a customer survey of all the properties, both domestic and non-domestic, within the DMA, and then determine the total number of connections per demand group (domestic, industrial, commercial, or others). Based on data from other areas with 100% customer metering, the utility can estimate a night-time flow rate for each demand group and multiply that by the number of connections within the demand group to get the total LNF.

To determine the level of Net Night Flow (NNF) or the portion of night flow directly attribute to leakage, subtract the LNF from the recorded MNF.

$$NNF = MNF - LNF$$

Leakage is proportional to the pressure in the system. Similar to water flows into the DMA, the DMA average pressure will change over a 24-hour period. Pressure is directly proportional to flow due to frictional headlosses within the system, and thus when the DMA has its lowest inflows, the pressure will be at its highest (Figure 7.3). This is because frictional headloss is proportional to velocity, so when flows are low, the velocities in the pipes are also low and less headloss occurs.

Therefore, the NNF or leakage calculated for the minimum night flow period will not be a true representation of leakage across a 24-hour period. Utility managers must also determine a pressure factor, or T Factor, that creates a true average 24-hour leakage value when applied to the NNF. The T Factor is calculated by using a data logger to record pressure over a 24-hour period, and then using those measurements to calculate the average 24-hour pressure. This average 24-hour pressure is compared to the system pressure during the minimum night period and a factor applied.

Figure 7.3: DMA flow and pressure relationship over a three-day period
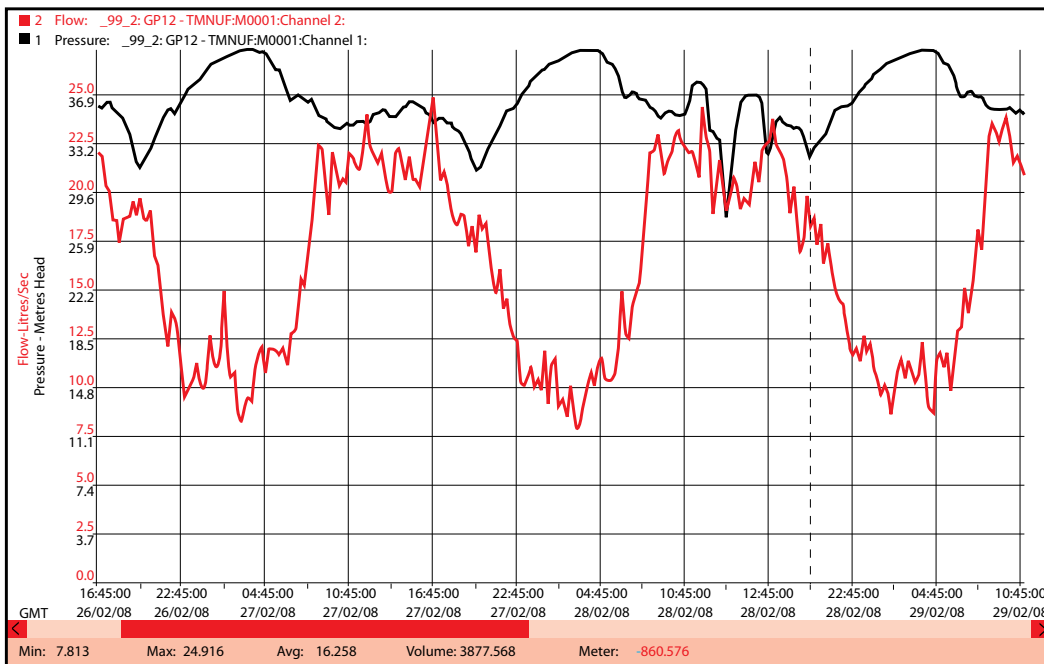
7.2.2 Determining commercial losses

The level of NRW within a DMA can be calculated by subtracting the recorded consumption from the inflow. Section 7.2.1 shows how to determine the leakage level or NNF within each DMA using the minimum night flow. This section discusses how to calculate commercial losses through a simple subtraction of leakage from the NRW, as follows:

Commercial loss = NRW - NNF

Once utility managers identify the DMAs with significantly high commercial losses, they should investigation for faulty meters, tampered meters, and illegal connections. They may also conduct a series of customer surveys of each property within the DMA to verify the property's inclusion in the billing database, interview the occupants, and assess the water meter.

7.3 DMA MANAGEMENT APPROACH

When a DMA is first established, water utility managers should undertake the initial calculations of NRW, NNF, and commercial losses, and identify the main areas of concern. If the DMA has high leakage or high commercial losses, then NRW reduction activities discussed in Chapters 5 and 6 should be implemented.

Once NRW is reduced to an acceptable level, the operations staff should set up a monitoring regime for DMA inflows. In its simplest form, this consists of a monthly reading of the flow meter totaliser. However, the installation of a data logger to record flows will reveal more detailed data, including the daily NNF, which enables more precise corrections to the system. Eventually, the NNF effectively becomes NRW with minimal levels of commercial loss. The daily NNFs can be plotted on a graph against time, to monitor DMA NRW levels (Figure 7.4).

Figure 7.4: NNF against time
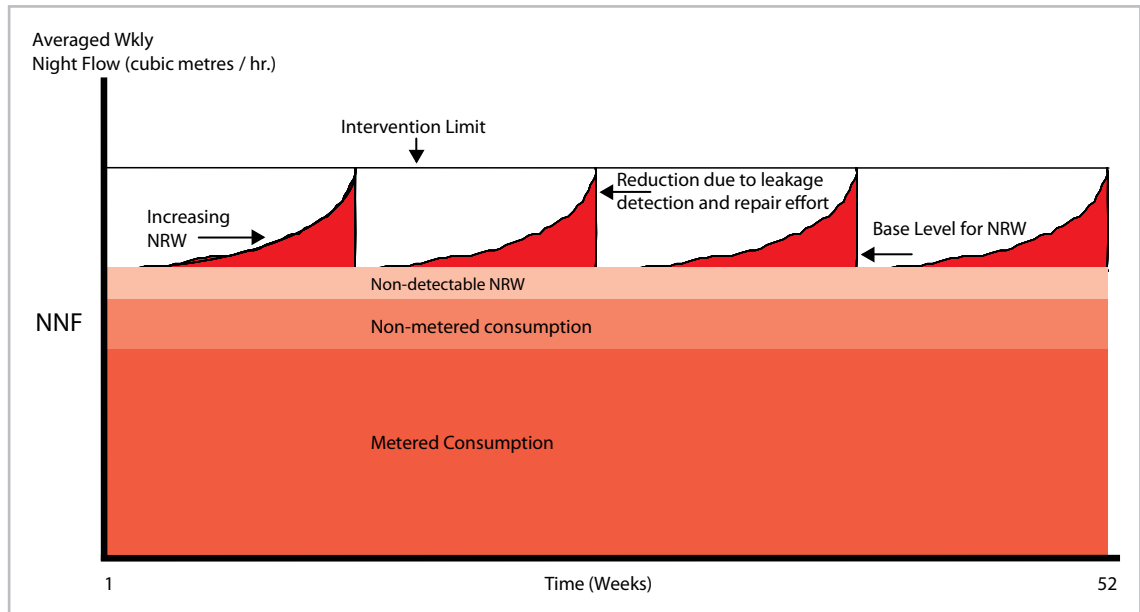
Managers walking the line to monitor the DMA

Figure 7.4 shows that the NRW level within the DMA continues to increase, and the rate of increase depends on a number of issues, including pipe network age and condition, system pressures, and the number of illegal connections and tampered meters. For most water utilities, it is inefficient for leakage detection and customer survey teams to work in the DMA continually. Therefore, the monitoring team should set an intervention limit, or the level at which NRW becomes unacceptable. Once the intervention limit is reached, the teams should be sent in to detect and resolve losses. Generally, once the utility manager deploys teams into the DMA, they can reduce the NRW level within two to four weeks. Afterwards, the manager should ensure that the NRW level is monitored until the intervention level is reached again. This process is the optimal management cycle of an established DMA.

Water utilities should maintain a record of the time taken for NRW to return to the intervention level. If this time decreases between detection exercises, it indicates that losses within the DMA are occurring more frequently and that the system's assets are deteriorating. For such a case, water utility managers should consider asset rehabilitation such as pipe rehabilitation, relining, or replacement, rather than continual leak detection and repair (Figure 7.5).

Figure 7.5: Moving from leak detection and repairs to pipe rehabilitation
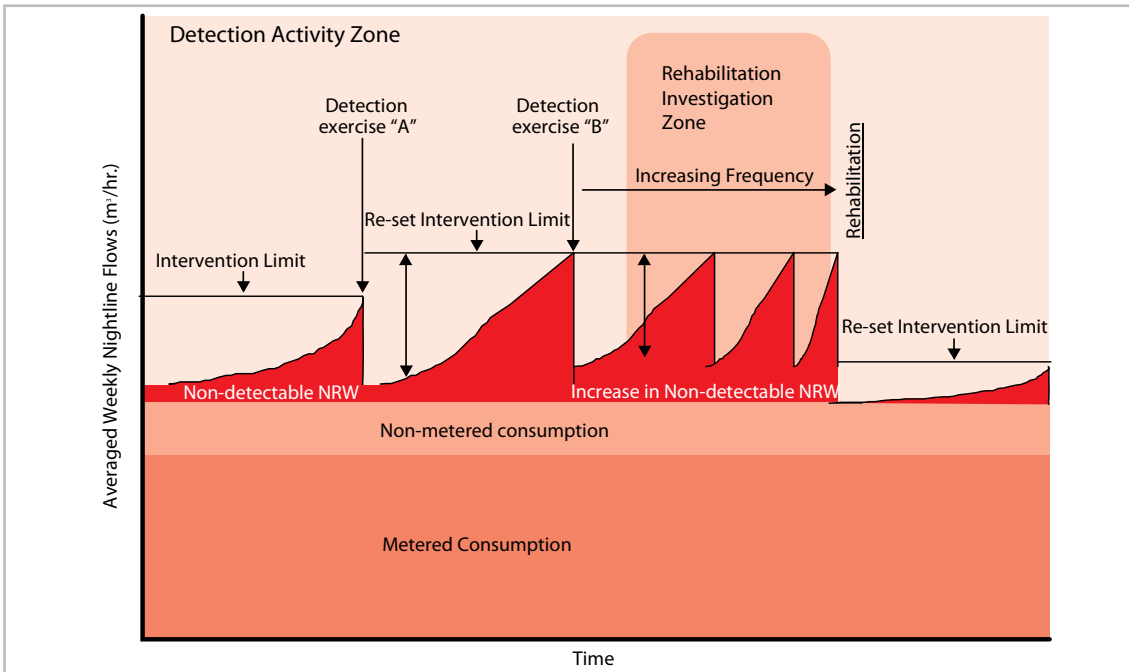
Upon completion of asset rehabilitation activities, the level of NRW typically decreases due to fewer leaks, especially underground or previously undetected leaks. Monitoring teams should also detect a much slower increase in the NRW level over time with the much-improved asset condition, and the intervention level should be re-set to a lower level (Figure 7.5).

7.4 ADDITIONAL BENEFITS OF THE DMA

Establishing a series of DMAs not only targets NRW reduction but it also improves asset condition and customer service by:

- Maintaining asset life through pressure management
- Safeguarding water quality
- Enabling continuous water supply

7.4.1 Improved pressure management

Establishing a DMA and the subsequent reduction in NRW will improve the water pressure within the DMA. As leaks are repaired, the flows within the DMA will decrease and thus the friction headlosses are reduced, which has the effect of increasing DMA system pressures. These increases in pressure will become even more pronounced at night when demands are low and friction headlosses are even lower.

Improved pressure control presents dual benefits of reducing leakages and stabilising system pressures, which increase asset life. Most pipe bursts occur not because of high pressure but rather due to ongoing pressure fluctuations that force the pipe to continually expand and contract, resulting in stress fractures. Installing a pressure control device, such as a pressure reducing valve (PRV), helps to reduce pressure throughout the day, stabilise fluctuations, and reduce stress on pipes.

By design, PRVs reduce pressure to a set level during the day and night-time. A pressure of 30 m is sufficient for most customer demand. However, the pressure in a gravity system can be much higher at night when there is little customer demand. To activate a lower pressure at night and during periods of low demand, and to further reduce leakage levels, water utilities should install a timer device with two set levels—one for daytime when customers need water, and the second for night-time when demand is low. The night-time setting, generally adjusted between 15 m and 20 m pressure, is typically lower than the daytime setting,

7.4.2 Safeguarding water quality

Establishing DMAs helps water utilities to prevent water quality deterioration in the distribution network. Closing a number of boundary valves to isolate each DMA, as per standard DMA establishment protocol, reduces the ebb and varying flow of water within the pipe network. As a result, sediments accumulated in the bottom of pipe will be disturbed less, thereby reducing water discolouration.

Water utilities benefit from decreased pipe leaks and repairs as a result of a more stable system pressure. Utilities can better locate pipe leakages that commonly cause infiltration of dirt and potentially contaminated groundwater into the pipes. The need for fewer repairs results in fewer system shutdowns, which in turn keeps sediments undisturbed.

Each DMA should include a water sampling point. Regular sampling and testing will help to identify water quality issues and assist asset rehabilitation teams in identifying pipes that need replacement or repair.

7.4.3 Providing continuous (24/7) water supply

In some systems, the water supply is not continuously available to customers 24 hours a day, so they tend to hoard water whenever it is available in case of delays in getting reconnected. As a result, they often store more water than is required for the period of non-supply. When the water supply is reconnected, they then discard the old water and hoard fresh water once again.

Water consumption per capita per day is therefore often much higher in intermittent supply systems compared to continuous supply systems. Converting to a 24-hour supply will result in lower water consumption and lower demand from the water production plant. However, turning the entire network into 24-hour supply remains challenging since the process normally requires five to seven days for the water consumption to decrease to normal (or actual use) levels. During this period, the demand would be so high that the system pressure would be greatly reduced, causing people to continue hoarding water.

DMA principles can be applied to convert from an intermittent to continuous water supply system. First, the water utility should consider installing a small number of DMAs that gradually feed continuous water supply, leading users in those DMAs to adjust to the new system and reduce excessive collection of water. Once consumption stabilises, the inflow volume into the DMAs should decrease within the five to seven day period. The water utility should then undertake leak detection activities and customer surveys to reduce water losses to an acceptable level, creating spare capacity at the production plant. This spare capacity represents additional water that can be supplied to other areas. Once these first DMAs have successfully supplied water continuously and effectively reduced water losses, then the next set of DMAs can be established for conversion to 24-hour supply.

The additional benefit of having 24-hour supply is that the pipe will be constantly pressurised, meaning that infiltration from outside the pipe is minimal. This will ensure that the quality of the water is kept to a premium and that the customer receives water of an acceptable quality.

KEY MESSAGES

- Dividing the open network into smaller, more manageable DMAs enables utility managers to manage the system more effectively in terms of pressure control, water quality, and NRW.

- Criteria in establishing DMAs include the size (or number of connections); number of valves that must be closed; number of flow meters; ground-level variations; and visible topographic features that can serve as DMA boundaries.

- Utility managers use the minimum night flow (MNF) and legitimate night flow (LNF) to calculate the net night flow (NNF), along with commercial losses, to determine NRW in a DMA

- Establishing DMAs helps to manage pressure, improve water quality, and enable continuous water supply.

8. MONITORING PERFORMANCE OF NRW MANAGEMENT

NRW is a measure of a utility's efficiency in terms of both operational performance and financial performance. Managers, policymakers, regulatory agencies, and financing institutions use NRW performance indicators (Pls) to rank the utility's performance against industry standards and other water utilities. This chapter reviews common performance indicators for physical and commercial losses and briefly describes monitoring programmes.

8.1 CHARACTERISTICS OF PERFORMANCE INDICATORS

Performance indicators help a utility:

- Better understand water losses
- Define and set targets for improvement
- Measure and compare performance
- Develop standards
- Monitor compliance
- Prioritise investments

A good NRW PI should be clear and easy to understand and have a rational basis. It should also be easy to calculate using data that the utility gathers regularly. Finally, utilities should include standard performance indicators to measure performance to facilitate comparisons with other utilities. Tools such as decision trees are available for managers to select appropriate performance indicators for their utility's needs and operating context.

Figure 8.1: Decision tree to select performance indicators
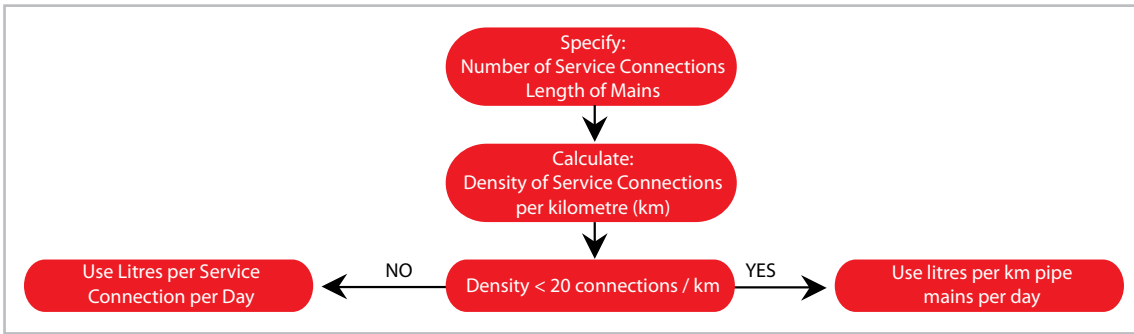
Source: Malcolm Farley and Stuart Trow, Losses in Water Distribution Networks, IWA Publishing, 2003

Utility managers can use Figure 8.1 to help choose PIs for their network. For example, in an urban network, where the housing density is usually greater than 20 connections per kilometre of mains, the answer to the question in the middle box in the bottom row would be 'NO' and the PI would be litres/service connection/day. To take account of networks with varying pressures, the utility can enhance the PI by expressing losses in litres per connection per day per metre of pressure (l/conn/day/m).

8.2 PERFORMANCE INDICATORS FOR PHYSICAL LOSSES

8.2.1 Expressing NRW as a percentage

NRW has traditionally been expressed as a percentage of input volume. Although this is preferable to setting no targets at all, it is misleading as a PI because it favours utilities with high consumption, low pressure, and intermittent supply. In addition, it does not differentiate between physical losses and commercial losses. Nevertheless, NRW as a percentage of input is sometimes useful for its 'shock value'—a high result can be a spur a utility to initiate a study of the network's operational performance and to conduct a water balance calculation. It is also useful as a measure of the utility's year-on-year financial performance, as long as the measurement principles are consistent. In that case, it should be expressed as the *value*, not the volume, of water lost.

8.2.2 Other performance indicators for physical losses

Appropriate indicators of physical losses include:

- Litres per service connection per day (l/c/d)
- Litres per service connection per day per metre of pressure (l/c/d/m pressure)
- Litres per kilometre of pipeline per day (l/km/d)
- Infrastructure Leakage Index (ILI)

Table 8.1 shows the Infrastructure Leakage Index (ILI) and other recommended NRW and physical loss performance indicators based on the IWA's *Performance Indicators for Water Supply Services: IWA*

Manual of Best Practice.[5] L/c/d gives a more accurate picture than NRW as a percentage of input volume, but taking system pressure into account (l/c/d/m pressure) is an even better indicator. The PIs are categorized by function and level, defined as follows:

- Level 1 (basic): A first layer of indicators that provides a general management overview of the efficiency and effectiveness of the water undertaking.

- Level 2 (intermediate): Additional indicators that provide a better insight than the Level 1 indicators; for users who need to go further in depth.

- Level 3 (detailed): Indicators that provide the greatest amount of specific detail, but are still relevant at the top management level.

Table 8.1: Recommended indicators for physical losses and NRW

Function	Level	Performance Indicator	Comments
Financial: NRW by Volume	1 (Basic)	Volume of NRW [% of System Input Volume]	Can be calculated from simple water balance not too meaningful
Operational: Physical Losses	1 (Basic)	[Litres/service connection/day or [Litres/km of mains/day] *(only if service connection density is < 20/km)*	Best of the simple 'traditional' performance indicators, useful for target setting, limited use for comparisons between systems
Operational: Physical Losses	2 (Intermed.)	[Litres/service connection/day/m pressure] or [Litres/km of mains/day/m pressure] *[only if service connection density is < 20/km)*	Easy to calculate indicator if the ILI is not known yet, useful for comparisons between systems
Financial: NRW by cost	3 (Detailed)	Value of NRW [% of annual cost of running system]	Allows different unit costs for NRW component, good financial indicator
Operational: Physical Losses	3 (Detailed)	Infrastructure Leakage Index (ILI)	Ratio of current annual Physical losses to unavidable annual real losses, most powerful indictor for comparisons between systems

5   Alegre H., Hirner W., Baptista J.M. and Parena R. (2000) *Performance Indicators for Water Supply Services: IWA Manual of Best Practice.* ISBN 900222272

8.2.3 The Infrastructure Leakage Index (ILI)

The Infrastructure Leakage Index (ILI) is an excellent indicator of physical losses, one that takes into account how the network is managed. The IWA, which developed the index, and the American Water Works Association (AWWA) Water Loss Control Committee both recommend this indicator. The ILI is particularly useful in networks where NRW is relatively low, for example below 20%, as the ILI can help to identify which areas can be reduced further.

The ILI is a measure of how well a distribution network is managed (i.e. maintained, repaired, and rehabilitated) for the control of physical losses, at the current operating pressure. It is the ratio of **C**urrent **A**nnual Volume of **P**hysical **L**osses (CAPL) to **M**inimum **A**chievable **A**nnual **P**hysical **L**osses (MAPL).

<div align="center">

ILI = CAPL/MAAPL

</div>

Being a ratio, the ILI has no units and thus facilitates comparisons between utilities and countries that use different measurement units. The complex initial components of the MAAPL formula have been converted to a format using a pre-defined pressure for practical use:

<div align="center">

MAAPL (litres/day) = (18 x Lm + 0.8 x Nc + 25 x Lp) x P

</div>

Where Lm = mains length (km); Nc = number of service connections; Lp = total length of private pipe, property boundary to customer meter (km); and P = average pressure (m).

Figure 8.2 illustrates the ILI concept with the factors that influence leakage management. The large square represents the CAPL, which tends to increase as the distribution networks grow older. This increase, however, can be constrained by a successful leakage management policy. The black box represents the MAAPL, or the lowest technically achievable volume of physical losses at the current operating pressure.

<div align="center">

Figure 8.2: The ILI Concept

</div>
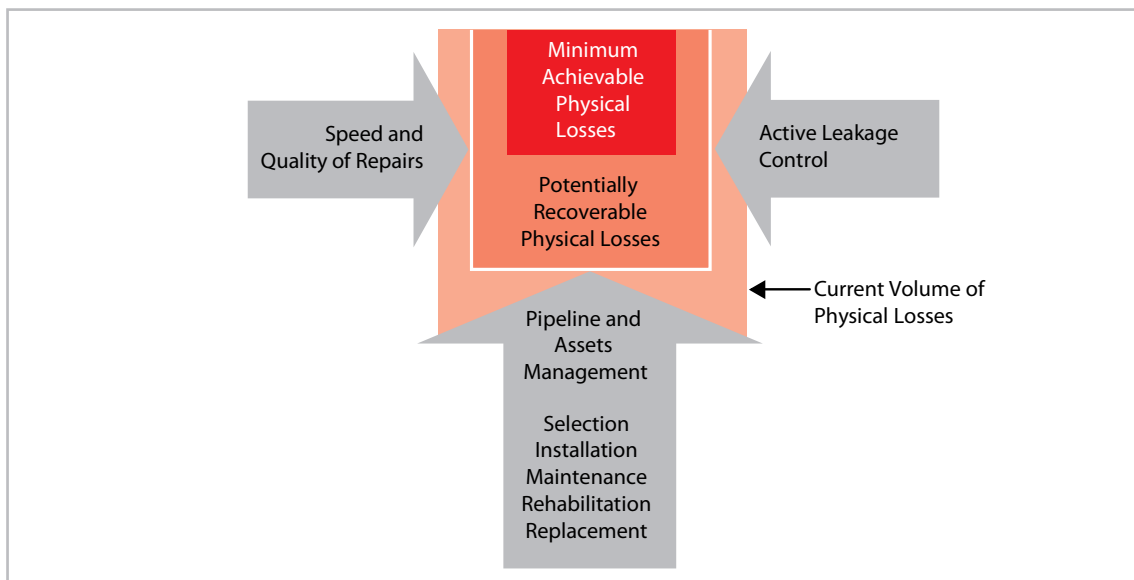
The ratio of the CAPL to MAAPL, or the ILI, is a measure of how well the utility implements the three infrastructure management functions—repairs, pipelines and asset management, and active leakage control. Although a well-managed system can have an ILI of 1.0 (CAPL = MAAPL), the utility may not necessarily aim for this target, since the ILI is a purely technical performance indicator and does not take economic considerations into account.

Calculating the ILI

- **Step 1.** Calculate the MAAPL

- **Step 2.** Calculate the CAPL (e.g. from the Water Balance)

- **Step 3.** Calculate the ILI (CAPL/MAAPL)

- **Step 4.** Adjust for intermittent supply (divide MAAPL by the average number of supply hours per day)

- **Step 5**. Compare ILI with physical loss target matrix (Figure 8.3.)

The physical loss target matrix shows the expected level of ILI and physical losses in l/c/day from utilities in countries at differing levels of network pressure.

Table 8.2: Physical loss target matrix

Technical Performance Category		ILI	Physical Losses [litres/connection/day] (when the system is pressured) at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
Developed Countries	A	1 - 2		< 50	< 75	< 100	< 125
	B	2 - 4		50 - 100	75 - 150	100 - 200	125 - 250
	C	4 - 8		100 - 200	150 - 300	200 - 400	250 - 500
	D	> 8		> 200	> 300	> 400	> 500
Developing Countries	A	1 - 4	< 50	< 100	< 150	< 200	< 250
	B	4 - 8	50 - 100	100 - 200	150 - 300	200 - 400	250 - 500
	C	8 - 16	100 - 200	200 - 400	300 - 600	400 - 800	500 - 1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

Source: World Bank Institute

Utility managers can use the matrix to guide further network development and improvement:

- Category A—Good. Further loss reduction may be uneconomic and careful analysis needed to identify cost-effective improvements.

- Category B—Potential for marked improvements. Consider pressure management, better active leakage control, and better maintenance.

- Category C—Poor. Tolerable only if water is plentiful and cheap, and even then intensify NRW reduction efforts.

- Category D—Bad. The utility is using resources inefficiently and NRW reduction programmes are imperative.

8.3 PERFORMANCE INDICATORS FOR COMMERCIAL LOSSES

The IWA Water Loss Task Force is also developing a performance indicator for commercial losses similar to the ILI.[6] The indicator uses a base value of 5% of water sales as a reference, and the actual commercial loss value is calculated against this benchmark. This is the Apparent (Commercial) Loss Index (ALI).

Apparent Loss Index (ALI) = Apparent loss value ÷ 5% of water sales

A commonly used indicator that expresses commercial losses as a percentage of water supplied is misleading because it does not reflect the true value of lost revenue. Currently, the best indicator is to measure commercial losses as a percentage of authorised consumption.

8.4 IMPLEMENTING A MONITORING PROGRAM

Utilities should continuously monitor NRW levels

A water utility embarking on the implementation of an NRW strategy needs to monitor its progress using some or all of the indicators detailed above. Since it is a utility-wide undertaking, an independent team should be established to audit progress. This NRW audit team should not be responsible for any physical activities to reduce NRW, but should be dedicated to auditing all of the departments involved with NRW strategy activities.

The implementation of the NRW strategy is a long-term process, often requiring four to seven years to complete. During this time, staff changes will occur, and the NRW audit team should train all incoming staff on the NRW strategy and its importance to the company.

The NRW audit team should also establish yearly targets for each department using one or more of the indicators, and monitor progress on a monthly progress. The number and type of indicators depends on the department and its activities. For example, the Network Department may be responsible for leakage detection and repair; in this case, the physical loss indicators of litres/connections/day and litres/connections/km can be used.

A monthly NRW strategy progress meeting should include representatives from all departments, with discussions on progress and hindrances. A senior member of the management team should chair the meeting, to stress the importance of the NRW strategy implementation. The head of the NRW audit team will support the chair by providing technical details and progress reports.

6 'Apparent Water Loss Control—The Way Forward'. WLTF article, Water 21, April 2008

KEY MESSAGES

- Utility managers use performance indicators to measure progress in reducing NRW, develop standards, and prioritise investments.

- The best performance indicator for physical losses is the Infrastructure Leakage Index (ILI).

- A commonly used performance indicator for commercial losses is the Apparent Loss Index (ALI). Currently, the best commercial loss indicator is to measure it as a percentage of authorised consumption.

- Utility managers must establish an independent NRW audit team to monitor progress in the NRW strategy implementation.

- Performance targets should be set on a yearly basis with progress monitored and reported monthly.

9. BUILDING CAPACITY TO MANAGE NRW THROUGH UTILITY-TO-UTILITY TWINNING PARTNERSHIPS: A CASE STUDY

Reducing and managing NRW remains a challenge for many utilities and service providers in Asia, especially those where dwindling water supply, worsening water quality, and aging infrastructure. To overcome these challenges, water service providers have demonstrated the value of 'twinning', or focused and sustained practitioner-to-practitioner exchange in promoting the adoption of improved policies and best practices, and in building human and institutional capacity.

This chapter describes twinning partnerships between Ranhill Utilities Berhad (Ranhill), a Malaysian utility recognised for effectively reducing and managing NRW, with two water utilities in Asia: the Provincial Waterworks Authority (PWA) of Thailand, and the Bac Ninh Water Supply and Sewerage Company (Bac Ninh) in Vietnam. Both twinning partnerships highlight Ranhill best practices, and the value of practitioner-to-practitioner exchange in enabling utilities to address NRW. These twinning partnerships draw on the lessons and best practices detailed in this handbook, and have contributed to the development of this handbook.

The Environmental Cooperation–Asia (ECO-Asia) Water and Sanitation Programme of the United States Agency for International Development provided direct funding and facilitation support for both twinning partnerships with Ranhill. Throughout Asia, ECO-Asia demonstrates how twinning arrangements can help water utilities meet the challenges of reducing water losses and improving operational efficiencies to support the achievement of the Millennium Development Goals (MDGs) in urban areas. ECO-Asia facilitates linkages between utilities to address specific priority needs, such as NRW management. Utility strengthening through these collaborative arrangements promotes self-reliance and long-term sustainability, which in the long run results in not only improved efficiencies but also expanded service areas and increased revenues.

Box 9.1: Twinning and Water Operator Partnerships

During the 4th World Water Forum in 2006, the UN Secretary General's Advisory Board on Water and Sanitation announced the Hashimoto Action Plan, calling for the establishment of a platform to launch and coordinate twinning arrangements or Water Operators Partnerships (WOPs) *'in order to strengthen the capacities of the public water operators that currently provide over 90 per cent of the water and sanitation services and who are key players for attaining the [Millennium Development Goals] on drinking water supply and sanitation.'*

Throughout 2006 and 2007, ECO-Asia facilitated the twinning partnerships between Ranhill and PWA, and between Ranhill and Bac Ninh. The Ranhill-PWA link focused on strengthening PWA's approach to identifying NRW components based on an international best practice employed by Ranhill (see Chapters 2 and 3 of this handbook), raising awareness of NRW management activities among senior decision-makers (Chapter 4), and expanding its knowledge of district meter area (DMA) management (Chapter 7). The Ranhill-Bac Ninh partnership centred on building the capacity of key Bac Ninh staff to comprehend and implement the water balance (Chapter 2), gain basic understanding of NRW components according to Ranhill experiences (Chapters 5 and 6), and specifically to undertake DMA design and piloting efforts per Ranhill best practices (Chapter 7). In these twinning arrangements, ECO-Asia helped facilitate practitioner-to-practitioner exchange of practical solutions and practices applied by Ranhill in Johor, Malaysia, to manage and reduce NRW.

9.1 TWINNING APPROACH

9.1.1 Understanding priorities and facilitating linkages

Practitioners share best practices and new systems to build capacity and realise tangible improvements for managing NRW.

In a utility-to-utility twinning arrangement, ECO-Asia links a utilities on a range of technical areas, including improving services delivery (such as through enhanced water supply quality or water loss reduction), expanding services to the urban poor, and converting systems to continuous water supply. In a typical twinning arrangement, ECO-Asia identifies a 'mentor' utility with proven success in addressing specific challenges that is willing to share its knowledge and innovations. As the facilitator, ECO-Asia identifies potential linkages, matches counterpart institutions, and facilitates the initiation, establishment, and implementation of twinning partnerships. ECO-Asia establishes partnerships that are mutually beneficial, result in tangible improvements to service delivery, and are relevant to other utilities in Asia.

In the case of PWA in Thailand, PWA's top priority was to strengthen its capacity in understanding and managing NRW, especially in managing DMAs. Similarly, Bac Ninh was interested in best practices related to determining and addressing major NRW components and designing, establishing and operating DMAs. To link both partners with a counterpart utility, ECO-Asia identified various utilities in the region that successfully reduced NRW and were interested in a twinning partnership. Of several utilities approached, Ranhill agreed to become the mentor partner for both PWA and Bac Ninh, and was willing to share its best practices and technical expertise. As 'recipient' partners, PWA and Bac Ninh agreed to link with Ranhill.

As a first step for each partnership, the counterpart utilities held detailed discussions to understand the mutual benefits for both twinning partners. ECO-Asia facilitated these discussions and initiated site visits that enabled Ranhill practitioners to become familiar with the operational challenges in each recipient country. Building trust and relationships, as well as understanding of each partner's interests and incentives to twin, were outcomes of the initial introduction.

Box 9.2: Twinning Principles

- Practitioner-to-practitioner exchange forms the basis of twinning partnerships.

- Benefits from the twinning partnerships are mutual, but not necessarily equal.

- Twinning partnerships are demand-driven in line with partner strategies, plans, and interests, and results-oriented, ensuring the adoption of best practices and activities that result in real improvements and tangible outcomes.

- Partners cooperate on a cost-share basis, providing in-kind and funding support

- All partnerships operate on a non-profit basis.

9.1.2 Preparing to implement twinning partnerships that achieve results

After initiation, for each twinning arrangement, ECO-Asia facilitated the development of a joint programme of activities and a work plan that included a series of activities that enabled Ranhill to share targeted best practices based on partner needs. In both cases, partners set milestones and allocated resources to implement the work plan activities. In both arrangements, partners aimed at building current capacities to manage NRW and at adopting best practices for reducing NRW. ECO-Asia facilitated the work plan development process and also committed necessary resources to ensure that the work plan was implemented and results achieved. Upon agreeing to the joint programme, partners in each twinning arrangement signed an agreement committing them to implementing the twinning activities and achieving their expected results.

Box 9.3: Basic Steps in Establishing Effective Twinning Partnerships

1. Identification — Identifying possible partners and understanding their priorities and interests

2. Selection — Selecting the right partners to twin

3. Initiation — Introducing partners

4. Establishment — Getting started in working together and setting goals

5. Implementation — Jointly achieving results

6. Replication — Expanding and replicating twinning partnerships and best practices

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9.2 TWINNING ACTIVITIES

Twinning activities typically include peer-to-peer exchanges, specialised classroom and on-the-job training, technical assistance, short internships, peer review of current systems, technology demonstrations, and discussion workshops. In implementing these activities, both partners provide in-kind or cash contributions that support such inputs as workshop costs, translation services, and local travel.

In the Ranhill-PWA partnership, activities included a series of classroom and on-the-job training workshops and field practices that enabled the transfer of practical solutions. Initially, Ranhill trained PWA senior managers and operations staff to better understand NRW and its impact on a utility's finances and operations. Building on this training, operations staff next learned how to conduct an internationally-recognised water balance to detect key sources of NRW, followed by further hands-on training on approaches to reduce NRW, such as DMA design and establishment.

Although twinning activities were similar in the Ranhill-Bac Ninh arrangement, Ranhill provided additional technical assistance for Bac Ninh for the design and establishment DMAs. Ranhill introduced established vendors and suppliers of specific equipment required for setting up and monitoring DMAs. Ranhill also assisted Bac Ninh to properly design and operate a pilot DMA.

Key PWA and Bac Ninh managers also visited Ranhill operations in Johor to advance their understanding of field applications for NRW reduction techniques. During the visit, Ranhill shared its practical lessons and field experience in effectively managing NRW.

ECO-Asia supported and monitored all activities to better enable integration and replication of best practices and solutions from Ranhill to PWA and to Bac Ninh.

9.3 ILLUSTRATIVE RESULTS OF TWINNING PARTNERSHIPS

The ECO-Asia twinning model demonstrates how regional collaboration and sharing of best practices among peers can benefit all parties involved, although the benefits vary in form and results. Ranhill shared key best practices for NRW reduction identified in this handbook with PWA and Bac Ninh during the twinning arrangements.

9.3.1 Provincial Waterworks Authority of Thailand

PWA noted that the twinning programme enabled its management and staff to adopt new approaches in support of its evolving policies to better manage NRW. Major results from the twinning partnership with Ranhill include:

- Key staff gained practical knowledge for applying an international water balance method using a free water audit software programme translated into Thai, and to use the balance results to systematically address NRW (see Chapters 2 and 3).

- Senior decision-makers gained a basic understanding of the importance of properly identifying NRW components and effectively managing NRW (see Chapter 4).

- Regional training centres integrated several training modules presented by Ranhill for training key operations staff on NRW, and ensuring targeted actions for reducing NRW components. The main modules adapted include conducting a water audit, identifying NRW components, developing NRW management strategies, and understanding DMAs and their management.

PWA engineers learning practical approaches implemented by Ranhill to analyse key field data for determining water losses.

- Technical staff responsible for preparing specifications for future DMA establishment contracts incorporated the DMA design criteria, principles, and onsite commissioning procedures introduced by Ranhill (see Chapter 7).

- Several engineers and managers applied hands-on and practical techniques for managing and operating DMAs, including best practices for collecting and analysing DMA data to verify DMA establishment, monitor performance, and maintain target NRW levels in service areas.

- Select engineers utilised simple spreadsheets offered by Ranhill to measure minimum night flow, locate leakages, calculate pressure, and monitor customer meter performance (see Chapter 6 and 7).

'Working with Ranhill practitioners through the twinning partnership has really enabled PWA managers and staff to better understand the critical steps and practical approaches required to reduce water losses and manage non-revenue water. We value the peer-to-peer sharing and transfer of information and expertise, which allowed us to access international best practices and apply them on the ground as we strive to improve our operations.'

––Vichian Udomratanasilpa, Deputy Governor of Planning and Technical Affairs, PWA

9.3.2 Bac Ninh Water Supply and Sewerage Company, Vietnam

For Bac Ninh, the twinning partnership built the capacity of its staff to improve its operations by strengthening the basic understanding of NRW management and introducing various activities needed to lower NRW. Main results from the partnership with Ranhill include:

- Key staff from both technical and non-technical departments improved their understanding of NRW, especially in identifying the major causes of NRW, developing practical solutions necessary to manage NRW, and performing a water balance as the critical step in developing an NRW management strategy (see Chapters 2-4).

- Technical staff members conducted water balances on discrete service areas and attributed inconsistent NRW to inadequate billing and collection processes, a key source of commercial losses (see Chapter 5).

Experts from Ranhill working hand-in-hand with their counterparts in Bac Ninh, Vietnam, to test DMA operations.

- Technical staff members incorporated best practices introduced by Ranhill for establishing DMAs, such as ensuring adequate water pressure and closing all boundary valves, to their current procedures and tested them on a pilot DMA (see Chapter 6 and 7).

- Key engineers worked with Ranhill to revise its current DMA design to enable improved NRW management following training events.

- As part of the pilot DMA activities, with guidance from Ranhill, Bac Ninh purchased and commissioned critical equipment, such as data loggers and a bulk meter to lower NRW levels (see Chapter 7).

9.3.3 Ranhill Utilities Berhad, Malaysia

The twinning partnerships with PWA and the Bac Ninh benefited Ranhill in several ways:

- The twinning showcased Ranhill's strengths in water supply services delivery in line with Ranhill's strategic plan to expand its services beyond Malaysia.

- The partnerships provided a platform for Ranhill staff to familiarise themselves with new challenges and the conditions of water supply services and operations outside of Malaysia.

- Ranhill staff networked with water professionals in Thailand and Vietnam, which may lead to downstream commercial opportunities.

- Ranhill added value to its portfolio of activities in Thailand and Vietnam and gained exposure in Asia.

'We believe twinning arrangements add value to Ranhill's corporate strategies to position itself as a leading global brand. Twinning helps our staff to understand the challenges and conditions beyond our operations in Malaysia, preparing them for future activities, and allows them to build relations and network with other service providers, creating opportunities for downstream commercial linkages. It also gives us a chance to use our strengths to help others become better at providing water services to their customers while building trust and confidence of our services at the international level.'

– Ahmad Zahdi Jamil, Chief Executive Officer, Ranhill Utilities Berhad

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Box 9.4: Promoting Twinning Partnerships through WaterLinks

To promote twinning, ECO-Asia provides support to WaterLinks (www.waterlinks.org), a regional knowledge hub and platform for facilitating and sustaining partnerships, and sharing information and best practices in Asia.
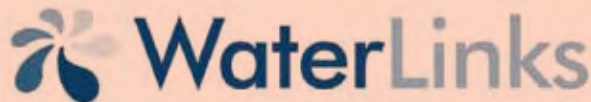
KEY MESSAGES

- Water service providers worldwide have demonstrated the value of 'twinning' in promoting the adoption of improved policies and best practices, and in building human and institutional capacity.

- Effective twinning partnerships are demand driven, addressing the interests and priorities of 'recipient' and 'mentor' partners through activities that aim to ensure the adoption and replication of best practices and solutions.

- The twinning model demonstrates how regional collaboration and sharing of best practices among peers can benefit all parties involved, although the benefits vary in form and results.

- Twinning activities typically include peer-to-peer exchanges, specialised classroom and on-the-job training, technical assistance, short internships, peer review of current systems, technology demonstrations, and discussion workshops. In implementing the activities, twinning partners provide in-kind or cash contributions.

- Twinning partnerships leverage counterpart exchange to help strengthen the capacity of utilities in improving services delivery (such as NRW reduction), expanding services and converting to continuous water supply.

ANNEX 1: GLOSSARY

The Water Balance

System Input Volume (allow for known errors)	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water (NRW)
			Unbilled Unmetered Consumption	
	Water Losses	Commercial Losses	Unauthorised Consumption	
			Customer Meter Inaccuracies and Data Handling Erros	
		Physical Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to the Point Customer Use	

Water Balance Definitions

In the following, all terms used in Figure above are listed in hierarchical order – as one would read the water balance from left to right. Some of the terms are self-explanatory but are still listed for consistency.

System Input Volume

The volume of treated water input to that part of the water supply system to which the water balance calculation relates.

Authorised Consumption

The volume of metered and/or un-metered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorised to do so by the water supplier, for residential, commercial and industrial purposes. It also includes water exported across operational boundaries.

Authorised consumption may include items such as fire fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered or unmetered.

Water Losses

The difference between System Input and Authorised Consumption. Water losses can be considered as a total volume for the whole system, or for partial systems such as transmission or distribution schemes, or individual zones. Water Losses consist of Physical Losses and Commercial Losses (also known as Real Losses and Apparent Losses)

Billed Authorised Consumption

Those components of Authorised Consumption which are billed and produce revenue (also known as Revenue Water). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.

Unbilled Authorised Consumption

Those components of Authorised Consumption which are legitimate but not billed and therefore do not produce revenue. Equal to Unbilled Metered Consumption plus Unbilled Unmetered Consumption.

Commercial Losses

Includes all types of inaccuracies associated with customer metering as well as data handling errors (meter reading and billing), plus unauthorised consumption (theft or illegal use).

Commercial losses are called "Apparent Losses" by the International Water Association and in some countries the misleading term "Non-Technical Losses" is used.

Physical Losses

Physical water losses from the pressurized system and the utility's storage tanks, up to the point of customer use. In metered systems this is the customer meter, in unmetered situations this is the first point of use (stop tap/tap) within the property. Physical losses are called "Real Losses" by the International Water Association and in some countries the misleading term "Technical Losses" is used.

Billed Metered Consumption

All metered consumption which is also billed. This includes all groups of customers such as domestic, commercial, industrial or institutional and also includes water transferred across operational boundaries (water exported) which is metered and billed.

Billed Unmetered Consumtion

All billed consumption which is calculated based on estimates or norms but is not metered. This might be a very small component in fully metered systems (for example billing based on estimates for the period a customer meter is out of order) but can be the key consumption component in systems without universal metering. This component might also include water transferred across operational boundaries (water exported) which is unmetered but billed.

Unbilled Metered Consumption

Metered Consumption which is for any reason unbilled. This might for example include metered consumption by the utility itself or water provided to institutions free of charge, including water transferred across operational boundaries (water exported) which is metered but unbilled.

Unbilled Unmetered Consumption

Any kind of Authorised Consumption which is neither billed nor metered. This component typically includes items such as fire fighting, flushing of mains and sewers, street cleaning, frost protection, etc. In a well run utility it is a small component which is very often substantially overestimated. Theoretically this might also include water transferred across operational boundaries (water exported) which is unmetered and unbilled – although this is an unlikely case.

Unauthorised Consumption

Any unauthorised use of water. This may include illegal water withdrawal from hydrants (for example for construction purposes), illegal connections, bypasses to consumption meters or meter tampering.

Customer Metering Inaccuracies and Data Handling Errors

Commercial water losses caused by customer meter inaccuracies and data handling errors in the meter reading and billing system.

Leakage on Transmission and/or Distribution Mains

Water lost from leaks and breaks on transmission and distribution pipelines. These might either be small leaks which are still unreported (e.g. leaking joints) or large bursts which were reported and repaired but did obviously leak for a certain period before that.

Leakage and Overflows at Utility's Storage Tanks

Water lost from leaking storage tank structures or overflows of such tanks caused by e.g. operational or technical problems.

Leakage on Service Connections up to point of Customer Metering

Water lost from leaks and breaks of service connections from (and including) the tapping point until the point of customer use. In metered systems this is the customer meter, in unmetered situations this is the first point of use (stop tap/tap) within the property. Leakage on service connections might be reported breaks but will predominately be small leaks which do not surface and which run for long periods (often years).

Revenue Water

Those components of Authorised Consumption which are billed and produce revenue (also known as Billed Authorised Consumption). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.

Non-Revenue Water

Those components of System Input which are not billed and do not produce revenue. Equal to Unbilled Authorised Consumption plus Physical and Commercial Water Losses.

(Unaccounted-for Water)

Because of the widely varying interpretations and definitions of the term 'Unaccounted for Water', it is strongly recommend that this term be no longer used. It is equivalent to 'Water Losses' in the Water Balance diagram

Understanding Leakage

Background Leakage

Background leakage (also called background losses) are individual events (small leaks and weeps) that will continue to flow, with flow rates too low to be detected by an active leakage control campaign unless either detected by chance or until they gradually worsen to the point that they can be detected. As the term is nearly untranslatable, it is often referred to as "unavoidable losses". The level of background leakage depends on the overall infrastructure condition, the pipe material(s) and the soil. It is furthermore heavily influenced by pressure (N1=1.5 or even higher).

Bursts

Events with flow rates grater than those of background losses and therefore detectable by standard leak detection techniques. Bursts can be visible or hidden.

Reported Bursts

Reported Bursts are visible leaks that are brought to the attention of the water utility by the general public or the water supply organization's own operatives.

Unreported Bursts

Unreported bursts are those that are located by leak detection teams as part of their normal everyday active leakage control duties. These breaks go undetected without some form of active leakage control.

Active Leakage Control (ALC)

ALC is the policy a water utility implements if it decides to pro-actively search for hidden leaks. ALC in its most basic form consists of regular sounding (e.g. listening to leak noise on fire hydrants, valves and accessible parts of service connections (e.g. stop cock) with listening sticks or electronic devices.

Leak Duration

The length of time for which a leak runs consists of three separate time components - awareness, location and repair time.

Awareness Time

Awareness Time is the average time from the occurrence of a leak until the water utility becomes aware of its existence. The awareness time is influenced by the type of applied ALC policy.

Location Time

For reported bursts, this is the time it takes for the water utility to investigate the report of a leak or break and to correctly locate its position so that a repair can be carried out. For Unreported bursts, depending on the ALC method used, the location duration may be zero since the burst is detected during the leak detection survey and therefore awareness and location occur simultaneously.

Repair Time

The time it takes the water utility to organize and affect the repair once a leak has been located.

N1 Factor

The N1 Factor is used to calculate pressure/leakage relationships:

Leakage Rate L (Volume/unit time) varies with $Pressure^{N1}$ or $L_1/L_0 = (P_1/P_0)^{N1}$

The higher the N1 value, the more sensitive existing leakage flow rates will be to changes in pressures. N1 Factors range between 0.5 (corrosion holes only in metallic systems) and 1.5 with occasional values of up to 2.5. In distribution systems with a mix of pipe materials, N1 values might be in the order of 1 to 1.15. Therefore a linear relationship can be assumed initially until N1 Step Tests are carried out to derive better data.

N1 Step Test

The N1 Step Test is used to determine the N1 value for areas of the distribution network. Inflow to the area as well as pressure at the Average Zone Point are recorded. During the test supply pressure into the area is reduced in a series of steps. This pressure reduction together with the corresponding inflow reduction forms the basis for the calculation of N1.

Pressure Step Test

Equivalent to N^1 Step Test.

Average Zone Point (AZP)

The AZP is the point in a certain zone or area of the distribution network which is representative for the average pressure in this particular part of the distribution network.

Quantifying Losses

Physical Loss Component Analysis

Determination and quantification of the components of physical losses in order to calculate the expected level of physical losses in a distribution system. The BABE concepts were the first component analysis model.

BABE Concepts

The Bursts And Background Estimates (BABE) concepts were developed by the UK National Leakage Initiative between 1991 and 1993. The concepts were the first to model physical losses objectively, rather than empirically, thus permitting rational planning management and operational control of strategies for their reduction.

Leakage Modeling

Leakage modeling is a methodology to analyze 24h inflow and pressure data of a hydraulically discreet part of the distribution system. Using the N1 pressure:leakage relationship principles and the results of the N1 Step Test the measured inflow can be split into:

- Consumption; and
- Leakage; and further into:
- Background Losses
- Losses from Bursts (= losses which can be recovered)

Equivalent Service Pipe Bursts (ESPBs)

The number of ESPBs is an indication of how many hidden leaks can be expected in a certain part of the distribution network. It is calculated by dividing the volume of excess (or hidden) losses by the volume of water lost through an average service pipe burst.

Hidden Losses (Excess Losses)

Physical loss component analysis is used to determine the part of physical losses which is in "excess" of all other leakage components. The volume of Hidden (Excess) Losses represents the quantity of water lost by "hidden" leaks that are not being detected and repaired with the current leakage control policy.

District Metered Area (DMA)

A discrete zone with a permanent boundary defined by flow meters and/or closed valves.

Night Flow Test (NFT)

Zone inflow and pressure measurement carried out during night hours, usually between 02:00 and 04:00 hours to measure Minimum Night Flow and corresponding Average Zone Night Pressure.

Average Zone Night Pressure (AZNP)

The AZNP is the average pressure during (low consumption) night hours measured at the Average Zone Point.

Minimum Night Flow (MNF)

The Minimum Night Flow (MNF) in urban situations normally occurs during the early morning period, usually between around 02:00 and 04:00 hours. The MNF is the most meaningful piece of data as far as physical loss levels are concerned. During this period, consumption is at a minimum and therefore physical losses are at the maximum percentage of the total flow. The estimation of the physical loss component at Minimum Night Flow is carried out by subtracting an assessed amount of Minimum Night Consumption for each of the customers connected in the zone being studied.

Minimum Night Consumption

Minimum Night Consumption is part of the Minimum Night Flow and is normally composed of three elements:

- Household night use
- Non-household night use
- Exceptional night use

Net Night Flow

Net Night Flow is the difference between Minimum Night Flow and Minimum Night Consumption and is equivalent to Night Leakage

[Net Night Flow] = [Minimum Night Flow] - [Minimum Night Consumption]

Performance Indicators

Infrastructure Leakage Index (ILI)

The ILI is a measure of how well a distribution network is managed (maintained, repaired, rehabilitated) for the control of real losses, at the current operating pressure. It is the ratio of Current Annual volume of Physical Losses (CAPL) to Minimum Achievable Annual Physical Losses (MAAPL).

ILI = CAPL / MAAPL

Being a ratio, the ILI has no units and thus it facilitates comparisons between countries that use different measurement units (metric, U.S., or imperial).

Minimum Achievable Annual Physical Losses (MAAPL)

Physical Losses cannot be totally eliminated. The volume of Minimum Achievable Annual Physical Losses represent the lowest technically achievable annual volume of Physical Losses for a well-

maintained and well-managed system. The standard equation for calculating MAAPL for individual systems was developed and tested by the IWA Water Losses Task Force. It allows for:

- background leakage – small leaks with flow rates too low for sonic detection if non-visible

- reported leaks and breaks – based on average frequencies, typical flow rates, target average durations

- unreported leaks and breaks – based on average frequencies, typical flow rates, target average durations

- pressure/leakage rate relationships (a linear relationship being assumed)

The MAAPL equation requires data on four key system-specific factors:

- Length of mains (all pipelines except service connections)

- Number of service connections

- Length of service connection between property boundary and customer meter. (Note: this is not the same as the total length of the service connection. Losses on the service connection between the tapping point at the main pipeline are included in the allowance per service connection. The additional allowance for length of connections on private land was included to take the longer leak run-times in situations were visible leaks would not be seen by public into account. In most urban situations, if the customer meter is inside the building, the length of service connection between property boundary and customer meter is obviously nil.)

- Average operating pressure

Minimum Achievable Annual Physical Losses (MAAPL) is called "Unavoidable Annual Real Losses (UARL)" by the International Water Association.

ANNEX 2: STEPS FOR CALCULATING NRW USING THE IWA WATER BALANCE TABLE

A	B	C	D		E
System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption		Revenue Water
			Billed Unmetered Consumption		
		Unbilled Authorised Consumption	Unbilled Metered Consumption		Non-Revenue Water
			Unbilled Unmetered Consumption		
	Water Losses	Commercial Losses	Unauthorised Consumption		
			Customer Meter Inaccuracies and Data Handling Erros		
		Physical Losses	Leakage on Transmission and Distribution Mains		
			Leakage and Overflows from the Utilities Storage Tanks		
			Leakage on Service Connections up to the Customer Meter		

Water balance results in volumes and consumptions in cubic meters per year.

Step 1 – Determine System Input Volume

Identify sources of input (and export) volume:

- Water supplied to the network from own WTW sources
- Water transferred in from adjacent networks
- Water purchased from bulk suppliers
- Water exported from the network

Ensure meter accuracy:

- Establish meter accuracy from manufacturers' manuals (eg +/- 2%)
- Check meter readings using downstream master meter or insertion meter
- Replace or re-calibrate meters as necessary
- Correct System Input Volume for all known errors
- Apply 95% Confidence Limits

If there are any un-metered sources the annual flow should be estimated by using any (or a combination) of the following:

- Temporary flow measurements using portable devices
- Reservoir drop tests
- Analysis of pump curves, pressures and average pumping hours

Step 2 – Determine Authorised Consumption

Billed Metered Consumption

- Extract consumption of the different consumer categories (e.g. domestic, commercial, industrial) from the utility's billing system

- Analyse the data, paying special attention to very large consumers.

Process the annual billed metered consumption information taken from the billing system to allow for meter reading time-lag

- Ensure that the billed metered consumption period used in the audit is consistent with the audit period

- Establish meter accuracy from manufacturers' manuals (eg +/- 2%)

- Apply 95% Confidence Limits

Billed Unmetered Consumption

- Extract data from the utility's billing system

- Identify and monitor unmetered domestic customers for a certain period, either by the installation of meters on those non-metered connections or by measuring a small area with a number of unmetered customers (the latter avoids customers changing consumption habits)

Unbilled Metered Consumption

- Establish the volume of unbilled metered consumption in a way similar to that for billed metered consumption

Unbilled Unmetered Consumption

Unbilled unmetered consumption, traditionally including water used by the utility for operational purposes, is often seriously overestimated. This might be caused by simplifications (a certain % of total system input) or deliberate overestimates to 'reduce' water losses. Components of unbilled unmetered consumption should be identified and individually estimated, for example:

- Mains flushing: How many times per month? For how long? How much water?

- Fire fighting: Has there been a big fire? How much water was used?

Step 3 – Estimate Commercial Losses

Unauthorised Consumption

It is difficult to provide general guidelines for estimating unauthorised consumption. There is a wide variation of situations and knowledge of the local situation will be most important to estimate this component. Unauthorised consumption can include:

- Illegal connections
- Misuse of fire hydrants and fire fighting systems
- Vandalised or bypassed consumption meters
- Corrupt practices of meter readers
- Open boundary valves to external distribution systems (unknown export of water).

The estimation of unauthorised consumption is always a difficult task and should at least be done in a transparent, component based way so that the assumptions can be easily checked and/or modified later.

Customer Metering Inaccuracies and Data Handling Errors

The extent of customer meter inaccuracies, namely under- or over-registration, has to be established based on tests of a representative sample of meters. The composition of the sample should reflect the various brands and age groups of domestic meters. Tests are done either at the utility's own test bench, or by specialized contractors. Large customer meters are usually tested on site with a test rig. Based on the results of the accuracy tests, average meter inaccuracy values (as % of metered consumption) will be established for different user groups.

Data handling errors are sometimes a very substantial component of commercial losses. Many billing systems do not reach the expectations of the utilities but problems often remain unrecognised for years. It is possible to detect data handling errors and problems with the billing system by exporting billing data (of say the last 24 months) and analysing it using standard database software.

The detected problems have to be quantified and a best estimate of the annual volume of this component has to be calculated.

Step 4 – Calculate Physical Losses

The calculation of real losses in its simplest form is now straightforward:

Physical Losses = Volume of NRW minus Volume of Commercial Losses

This figure is useful for the start of the analysis in order to get a feeling for the expected magnitude of physical losses. However, it always has to be kept in mind that the water balance might have errors – and that the calculated volume of real losses might simply be wrong.

Step 5 – Estimating Real Loss Components

To accurately split real losses into its components will only be possible with a detailed component analysis. However, a first estimate can be made using a few basic estimates.:

Leakage on Transmission and/or Distribution Mains

Bursts on distribution and especially transmission mains are primarily large events – they are visible, reported and normally repaired quickly. By using data from the repair records, the number of leaks on mains repaired during the reporting period (usually 12 months) can be calculated, an average flow rate estimated and the total annual volume of leakage from mains calculated as follows:

Number of reported bursts x average leak flow rate x average leak duration (say 2 days)

A certain provision for background losses and current undetected leaks on mains can then be added.

Leakage and Overflows at Utility's Storage Tanks

Leakage and overflows at storage tanks are usually known and can be quantified. Overflows can be observed and the average duration and flow rate of the events estimated. Leakage of storage tanks can be calculated by making a level drop test with in and outflow valves closed.

By deducting mains leakage and storage tank leakage from the total volume of real losses, the approximate quantity of service connection leakage can be calculated. This volume of leakage includes reported and repaired service connection leaks as well as hidden (so far unknown) leaks and background losses from service connections.

Step 1: Enter System Input Volume in Column A

Step 2: Enter in Column C: Billed Authorised Consumption

Enter in Column D:

- Billed Water Exported (none exported = 0)
- Billed Metered Consumption
- Billed Un-metered Consumption

Enter in Column E: Revenue Water

(NOTE: Billed Authorised Consumption should equal to the summation of the three Billed components above and. All billed water use is the same as a utility's revenue).

Step 3: Calculate the Volume of Non-Revenue Water (E) as:

System Input Volume (A) - Revenue Water (E).

Step 4: Enter in Column D:
- Unbilled Metered Consumption
- Unbilled Un-metered Consumption

Enter in Column C: Total Unbilled Authorised Consumption

Step 5: In Column C: Add volumes of Billed Authorised Consumption and Unbilled Authorised Consumption

Enter sum in Column B (top) as Authorised Consumption

Step 6: Calculate Water Losses (B) = System Input Volume (A) - Authorised Consumption (B)

Step 7: Assess components of Unauthorised Consumption, and Metering Inaccuracies and Data Handling Errors (D) by best means available through field verification in random service area and by estimation.

Add Unauthorised Consumption and Metering Inaccuracies (D)

Enter sum in Commercial Losses (C)

Step 8: Calculate Physical Losses (C) = Water Losses (B) - Commercial Losses (C).

Step 9: Assess components of Physical Losses (D) by best means available in the field and through desk studies (e.g. night flow analysis, burst frequency/ flow rate/duration calculations, modeling etc)

Add components of Physical Losses (D)

Cross-check with volume of Physical Losses (C) as derived from Step 8

This approach yields best results when meters are installed and regularly calibrated. Results will remain approximate to the extent that factors are based on estimates.

ANNEX 3: SAMPLE WATER AUDIT CHECKLIST

Objectives for a Water Audit:

- To assess whether the waterwork is serving its customers effectively, efficiently and equitably;

- To estimate water losses and their sources; and

- To assess how different groups are connected to piped water and to determine how waterworks and informal service providers respond to concerns of different groups.

Analysis

The important aspect of the analysis is to reveal:

- The actual coverage of the community with piped water and 24-hour service.

- The official NRW and the use of NRW.

- Unit cost of water from various sources and the numbers who use.

- Unit consumption of water from various sources and the numbers who use.

- The extent of informal water supplies.

Use of Analysis

The analysis may be used to:

- Reduce water losses.

- Register and assist water vendors.

- Monitor investment and intervention results and gauge impact over time.

Service Area

1. Population in City

2. Population in Waterwork Service Area

3. Population Served by Waterwork (Direct)

4. Population Served by Waterwork (Bulk Supply / Indirect)

5. Population Served by House Connection

6. Population Served by Shared Connection

7. Population Served by Standpipe or Community Tank

8. Population Served by Waterwork Tanker

Service Delivery – Metering

9. Number of Connections Domestic Metered / Not Metered

10. Number of Standpipes / Community Tank Metered / Not Metered

11. Number of Bulk Connections Metered / Not Metered

12. Number of Non-Domestic Connections Metered / Not Metered

13. Number of Sources of Treated Water for Piped Supply Metered / Not Metered

14. Are all master meters accurate? Yes / No

15. Is there any chance of backflow, bypass or double metering of water? Yes / No

16. Number of Waterwork Tankers / Capacity

17. Are all parks, schools, wastewater treatment plants and government buildings metered? Yes / No

18. Are meter readers motivated to find leaks and trained to do so? Yes / No

19. Are slow or stopped meters identified by the billing department? Yes / No

20. Are both system and customer meters regularly tested and properly sized? Yes / No

21. Are authorised unmetered uses estimated and reported? Yes / No

Service Delivery – Level of Service and Operations

22. Proportion of House Connections with 24 hour Supply %

23. Percentage of Service Area with 24 Hour Supply %

24. Production Volume (m³ / day)

25. Consumption Volume Domestic (m³ / month)

26. Consumption Volume Non-Domestic (m³ / month)

27. Are comparisons made between water produced and water used, on a regular basis?

28. New Connections Installed in last 12 months (Domestic)

29. New Connection Fee and Terms of Payment (Domestic)

30. Average Household Water Consumption Per Month

31. Average Household Water Bill Per Month

32. Number of People Employed by Waterwork

33. Is the public notified via advertising, to report leaks and bursts? Yes / No

34. Are there any unusual pressure drops in any part of the system or isolated complaints about low pressure? Yes / No

35. Are there high flows occurring during periods when flows should be low? Yes / No

36. Are all valves and backflow preventers between pressure zones working properly? Yes / No

37. Is the telemetry available? Yes / No. If yes, is it accurate? Yes / No

38. Are streams and storm channels routinely checked for unusual flows or possible leaks? Yes / No

39. Once estimated, are non-revenue water figure monitored over time? Yes / No

40. Is the volume of non-revenue water increasing? Yes / No

Financial Parameters

41. Money Billed Per Month for Domestic Customers

42. Money Billed per Month for Non-Domestic Customers

43. Are there any known major errors or are any corrections used in billing records such as wrong multipliers on meters? Yes / No

44. O&M Expenses Power / Staff / Other Per Annum

45. Operating Ratio Expenses / Total Billings

46. Accounts Receivables in Equivalent Months Billings

47. Annual Capital Expenditure

48. O&M Cost

49. Capital Cost

50. Lifeline Rate for Poor

51. Cross Subsidy Non-Domestic to Domestic

52. Cross Subsidy City to Town

53. Sources of Capital Works Funding (Central Govt, Local Govt, Donors, Other)

54. Average Household Income Per Month

ANNEX 4: LIST OF CD CONTENTS

1. EasyCALC Water Balance Software

2. International Water Association Leakage (IWA) Detection Guidance Notes

3. IWA District Meter Area (DMA) Guidance Notes

4. Pressure Release Valve Cost Benefit Analysis

5. T Factor Calculation

6. Customer Survey

7. Legitimate Night Flow Calculation

8. Other various forms utility managers can use in reducing water losses