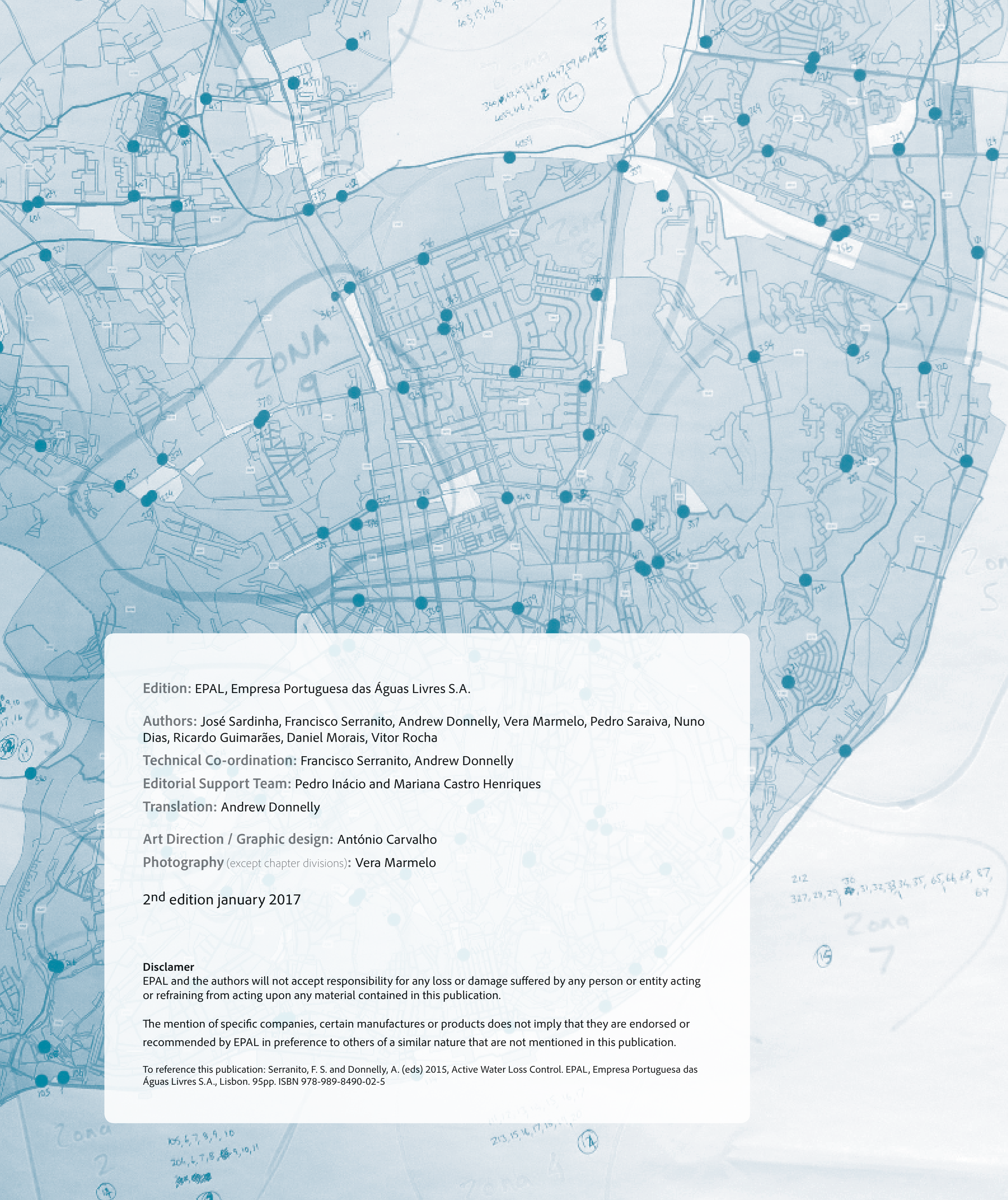
Active Water Loss Control

EPAL Technical Editions

EPAL
Grupo Águas de Portugal



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Preamble

This book presents, in a systematic way, the most modern and internationally recognized concepts, strategies and methodologies for water loss reduction and incorporates important innovations and improvements resulting from their practical application in one of the oldest and most prestigious companies in the world: EPAL.

Essential aspects are addressed with clarity and objectivity, including the water balance, calculation of economic level of losses, control of flow rates and pressures in the network, active leakage control, leak detection techniques and location, DMAs – District Monitoring Areas as well as the minimum requirements for any water loss reduction process. Also highlighted are the requirements for Geographic Information Systems (GIS), infrastructure registers, customer information systems, network hydraulic models and especially, the link between all areas of a company in order to achieve a common goal.

This work, which is very consistent and easy to read, reflects the knowledge accumulated within the company in regard to this field, the work undertaken by a great water loss control team and, above all, the commitment of top management that has defined water loss reduction as a priority corporate objective over the past few years.

This initiative by the administration board, chaired by José Sardinha, to widely divulge EPAL's expertise in this area should be welcomed, a move which has led to non-revenue water levels being amongst the lowest internationally and allowed development of new products such as WONE, which is being used successfully in other companies.

Without partiality to present methodologies and sophisticated technologies, based on state of the art information systems with data collection and processing in real time, applicable in the best companies, the book also includes internationally recognized basic concepts, essential for utilities wishing to undertake the first steps on the long journey towards efficiency and excellence.

The fact that I had the privilege of working with the outstanding employees of EPAL a decade ago, does not affect my objectivity to welcome and recommend, without reservation, this timely and excellent publication that will certainly inspire and technically support the many aspects of water loss reduction, especially in Portuguese-speaking countries.

Joaquim Poças Martins
Professor at the Faculty of Engineering of the University of Porto
General Secretary of the Portuguese National Water Council

Foreward

Throughout human history, water is undoubtedly the deciding factor for human settlement and for sustainable development of society. At present, due to population growth on Earth and progressive concentration in large urban areas, the water requirements for human consumption have reached critical levels in many areas, making water features as one of the determining factors for sustainability of life on the planet.

This situation reinforces the urgent need for all stakeholders in the sector to seek to ensure increasingly efficient management of water resources, a goal that is advocated by major international organizations, thus forming one of the fundamental aspects of their operations. Given the high level of water losses in supply systems, the reduction of losses has been established as one of the most relevant factors and challenges for the years to come.

EPAL, as the oldest and largest utility in Portugal and a reference company as regards water supply, shares these objectives of continuous efficiency improvement and increased operational sustainability, having integrated these into their mission. Thus, the constant search for operational optimization and increased levels of efficiency over the various aspects of the company's activity has been one of the main concerns of EPAL over the past few years, with particular emphasis on reducing levels of water losses. To this end, the company has developed and implemented an active leakage control program, the results of which have allowed the company to reach levels of excellence in the management of the Lisbon distribution network, which is now one of the most efficient global capitals, with water losses of the order of 8%.

Naturally, the implementation of such a strategy, involving the incorporation of some of the best international practices, provides any utility with a very enriching experience at different levels, allowing its workers to continue strengthening their knowledge and ability to overcome new challenges. As such, this is seen to be part of our mission as a reference public company, with sharing of experience and knowledge gained with the various sector stakeholders. This book has this intention, being the result of more than a decade of operations, transversely involving several teams and operational areas of EPAL.

In this context, our main goal is that this book will be useful to other utilities as well as technicians and students within the water sector, providing a contribution to the overall objective to reduce water losses in supply systems and thus increase levels of sustainability in terms of use of the essential resource that is water.

José Sardinha

Chairman and CEO of EPAL

1. Introduction

"Water is the start of everything"

Tales of Mileto

The exponential growth of Earth's population, which is estimated to evolve from the current 7 billion to 11 billion people by the end of the century, together with the increasing population concentration in large cities in coastal areas, provokes the tendency to significantly increase water stress in many areas of the globe, making fresh water an increasingly critical resource that must be preserved and managed with maximum efficiency. Indeed, it is estimated that by 2050, around half of the world's population may suffer from a lack of water, so this theme constitutes a crucial issue and is the subject of concern for governments and major international organizations.

In this context, the reduction of water losses in urban supply systems - that reach values of about 50% at a global level - is a key factor for the improvement of efficiency, implying the adoption of a more sustainable approach, through the use of new management methods and technologies that should be implemented by managers as well as by the various water sector stakeholders.

The intention of the book is to contribute to the dissemination of strategies and methodologies to control water losses in supply systems through a systematic approach to practices and technologies that have been properly tested and proven in the Empresa Portuguesa das Águas Livres, S.A., EPAL system and which may be used by other supply system utilities and technical sector, in differing contexts.

Thus throughout the text, the main concepts and approaches related to the theme of active water loss control are outlined, including clarification of internationally applied monitoring systems and leak detection procedures, culminating with the one factor that will undoubtedly be the most important in the whole process – namely, the change of mentality as regards water resource management.

2. Losses in Water Supply Networks

2.1 Context

Freshwater is essential for all life forms. Although about 70% of the surface of the planet Earth is covered with water, only about 2.5% of available water is fresh, making a total volume of approximately 35 million m^3, a significant portion of this volume is concentrated at the polar caps and glaciers (68.7%) and in underground aquifers (30.1%), with water in rivers and lakes corresponding to only about 1.2% of the total freshwater on the planet (Shiklomanov, 1993).

Water from annual rainfall amounts to only 0.12% of existing freshwater has its importance enhanced by the fact that it has to be a major long-term sustainable resource, especially under climate change scenarios and progressive concentration of human populations in large urban areas.

Figure 2.1 presents the way in which water is distributed around the globe, distribution of freshwater by their different forms and surface water.

It should be noted that a large variation of resource availability exists as regards freshwater around the globe, with areas of profound water shortages and other resource richer areas (see Figure 2.2), which, combined with the continued growth in population human on the planet, particularly concentrated in coastal areas, is leading to growing imbalances that cause areas of

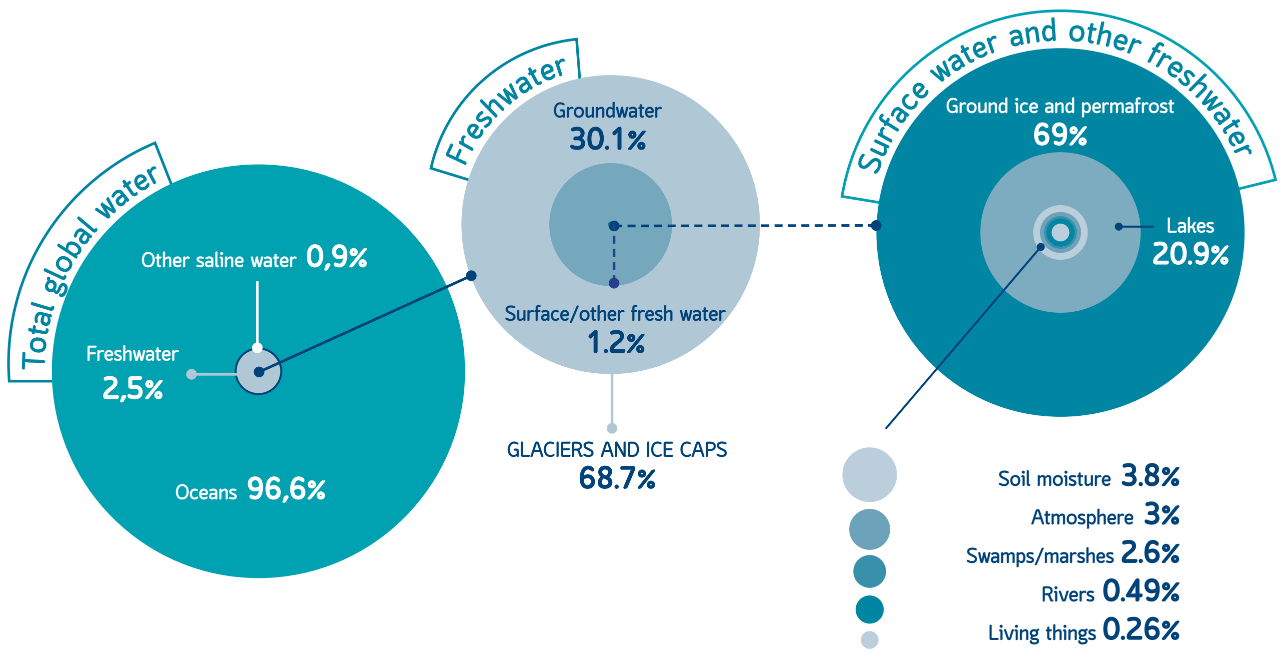


Figure 2.1 **Distribution of water on Earth** (adapted from Shiklomanov, 1993)

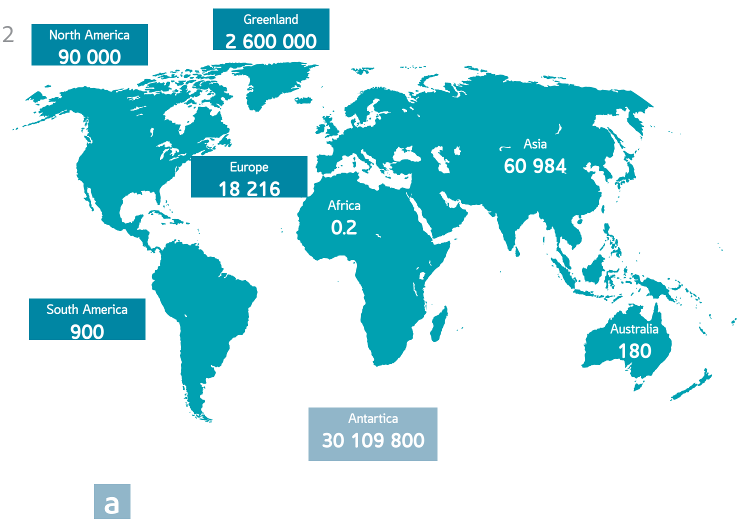
high water stress. This situation will, in the near future, become the key critical element for water resources - potentially provoking contentious disputes at all levels. Compounding this scenario, it seems that the phenomena associated with the effects of climate change will accelerate and accentuate this situation even further.

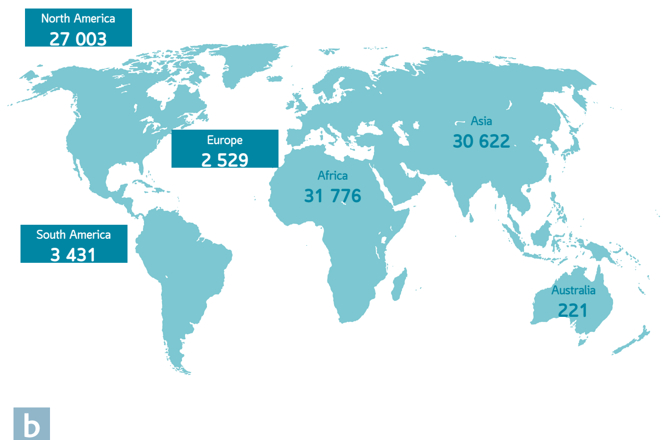
This idea is further reinforced if one considers that in 2006, the estimated number of people who suffered water shortages in the world - considering only the situations of high water stress – were of the order of 1.200 million, whilst it is estimated that this number is likely to increase to almost 1.800 million in 2025 (UN Water, 2007)

Throughout the ages, man has been interfering with the hydrological cycle, extracting and utilizing available water for various purposes and uses, corresponding to the following approximate percentages in terms of extracted volumes:

- Agriculture: **70,1%**,
- Industry: **20%**,
- Domestic/urban: **9,9%**.

In the current context, there is a fundamental awareness that water resources are limited and the need to protect and preserve them. This process of awareness must be





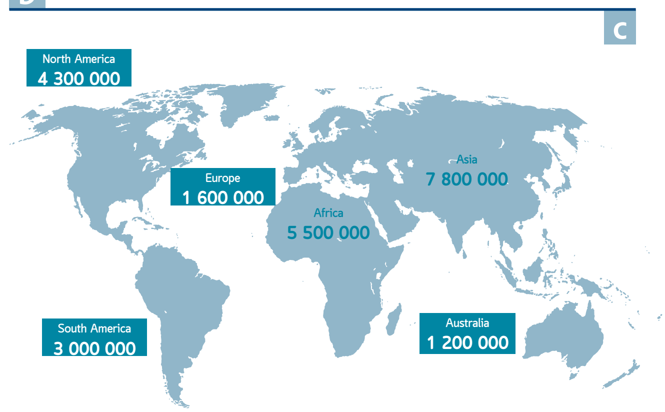


Figure 2.2 **Change in availability of fresh water on the globe (a) in polar ice caps and permafrost (b) in underground aquifers (c) in lakes, reservoirs and rivers** (values in km3, 2000)

accompanied by concrete steps that lead to changes in practices relating to the management and use of water, particularly through the development of strategies for efficient use of water (Almeida *et al.*, 2001). Indeed, the issue of resource scarcity is still placed only in certain areas of the planet, the issue of quality is discussed as a whole (Marques, 1999).

From the above it is very clear that, from a perspective of integrated water resources management, it is essential to seek increased levels of efficiency of resource utilization, whether through new technology, improved management methods or changing behaviour.

In this dominion, though the vision of a community or a country, it is evident that promoting increased efficiency and competitiveness should be focused on agriculture and industry, since they account for about 90% of consumption.

The urban sector, which accounts for only 10% of global water consumption, must find opportunities for improvement given the very considerable economic consequences, as global water losses reach values of the order of 50%. In Portugal, utilities have water losses rates that, on average, reach 40% (ERSAR, 2012) and register a great diversity in performance between different entities with volumes of non-revenue water ranging between 8% and 80%.

It is therefore important to find ways to improve efficiency in water use, with reducing losses in water supply systems a crucial factor to achieve this and which involves the adoption of an active and responsible attitude in order to ensure proper management and sustainability of this increasingly scarce and essential natural resource.

Currently, a significant portion of the operating cost associated with water supply system management results from the consumption of electrical energy required for the extraction, treatment and transport of water over long distances, especially in the case of large cities. Thus, water loss reduction, beyond the environmental component due to greater water resources use efficiency, also corresponds to a direct reduction in energy and reagents consumption, with its attendant economic benefits.

Thus, it is evident that the environmental and economic importance of water losses in water supply systems is a problem on a global scale and which is becoming of an increasingly significant dimension and with a central role in the focus of water supply utilities.

In terms of common sense, water losses in supply systems are best known as the result of poor quality or degradation of infrastructure, commonly referred to as "real" losses. This component of water losses, usually more relevant globally, can be reduced through control and combatting of water leaks and appropriate strategies for renewal of network programs.

There is, however, another aspect, which contributes to water loss, usually associated with the term "economic" or "apparent" losses. This component arises from situations of losses from unauthorized use of water, such as theft, often reflecting urban structure (or lack thereof) and local customs, as well as situations of water usage without metering or tampering with metering systems, inadequate metering policies or an asset management policy that does not sufficiently consider the losses from under-metering.

These losses, which can be reduced by promoting the adoption of appropriate socio-economic policies are equally important, whilst in many cases, these actions may follow urban space redevelopment projects and social inclusion in an overall action plan.

In this area it is important that utilities promote the implementation of integrated strategies for demand management and water conservation, whether through environmental awareness or through provision of innovative services or products and to help communities adopt more effective behavioural patterns.

The size and importance of water loss at the global level has justified many studies of good practices in this area, as well as the development of specific rules aimed at promoting improvements in processes and management systems, aimed at increasing efficiency. It is however, a process that requires awareness and involvement of all stakeholders, from industry professionals to the final consumer, being necessary to motivate behavioural changes (McKenzie and Hamilton, 2014).

It is for this purpose that the following chapters are intended to contribute to the discussion and advancement, comprising of a set of concepts and good practices inherent in the theme of water loss control. To complete the study, the final chapter comprises a case study on the experience of controlling water losses at EPAL, SA, the utility responsible for supplying water to the city of Lisbon.

2.2 The importance of policy and strategy in combating water losses

2.2.1 General Considerations

The approach to the problem of water loss depends on several factors that influence implementation of the most appropriate and effective strategies for their control and reduction. The level of economic development of the country, environmental awareness, government policy priorities, the level of corporate utility management and even the cultural population habits can dictate the choices of policy interventions.

Institutional policies are mainly focused on the perception and attitude toward water losses, which in turn, influences the investment and human resources for their control. The attitude of governments, national and local agencies, municipal authorities and the community strongly affect not only the organization itself, as the mode of operation of water supply systems. Influences of a political nature can also be very relevant - in fact, a community shown a service such as the expansion of a new water source or the construction of a new treatment service is likely to create "greater visibility" than the beginning of a leakage policy, which tends to produce results in the medium term.

Thus, a utility should preferentially promote public and consumer awareness to the reality of water resource scarcity, as well as supporting the increasing media coverage of this issue. Changes in position around water issues that have been experienced in recent times, water sector regulation and even creation of plans to support developing countries, have contributed to encourage a new way of intervention aimed at reducing water losses in all areas of the globe.

In this context, environmental and economic sustainability, reflected in the need for greater efficiency of water supply systems, are pressing governments and fund managers to define and implement strategies that enable them to improve the performance of their systems. The challenges dictated by the new water saving policies and the perception of more demanding consumer incentives in order to implement strategies to control and combat water losses, which will create the potential to obtain economic gains and greater eco-efficiency, in turn leading to overall service improvement.

These strategies to reduce losses should consider special articulation between the need to undertake investment and operating costs, operation and repair of leaks, to establish the best cost-benefit ratio, which determines the starting point or leverage to implement certain control strategy losses.

The main reasons justifying the approach of a water loss reduction strategy are:

- More efficient management with benefits in terms of operating and capital cost reduction;
- Reduction of environmental stress;
- Improvements in metering and billing - since a lower occurrence of breakage and optimum performance level can have positive results in the value of apparent leaks;
- Reduction of structural damage - since leaks can cause voids in the subsoil and consequent collapse of roads and buildings;

- Load reduction in sewers - as the lost water usually seeps into the drainage system and consequently increases the load on treatment wastewater plants;

- Improved client satisfaction through improved service and ensuring water quality and sufficient pressure - since leaks and bursts can result in decreased pressure;

- Reduction of risks to health and greater security of supply - as the proximity of sewage and other pollutants is real and infiltration of these pollutants into the water supply for human consumption through bursts, can result in disease, especially in systems with low pressure or intermittent operation.

The success of a strategy for reducing losses corresponds, in practice, to the increase in water availability which will avoid or delay the need for new water sources, such as the construction of dams, new wells, or abstraction or desalination solutions that usually involve high investment and therefore costs much higher than those inherent in the implementation of a strategic plan to combat losses.

In extreme cases, reducing the volume of water extracted and thus raise the available water resource environment may be the only viable alternative to ensure continuity of supply, involving the implementation of water loss reduction programs in conjunction with demand management techniques along with water conservation, public and consumer awareness programs.

2.2.2 Historical Overview of approaches to reducing losses

The concept of water losses control arose from the construction of the first water supply systems, associated with the guarantee of improved efficiency the supply system, since the leaks, in addition to generating a loss of water supply also implied a service suspension affecting the population supplied. The logic of effectiveness progressively developed into a logic of efficiency, motivated by the water losses which were not generating revenue, despite generating costs.

Dating from 1850, the first activities of acoustic surveys, commonly nicknamed "listening", looked for evidence of leaks in buried pipelines or extensions. The first method developed in this context was based on the same principles that are applied today. Indeed, originally a wooden stick was used, which once placed on the main or any other element of the network, allowed the operator to listen to the sound of a possible water leak. It was a method with reduced operating costs and showed an acceptable success rate in metal pipes, the material used at the time.

A major limitation of this type of activity was not looking for leaks targeted manner, since the entire network was considered indiscriminately. The turning point occurred when leakage activities were separated into two distinct phases: the macro-location or leak localising, which focuses on the identification and prioritization of intervention areas at a zonal level, micro-location or leak locating at the level of the area surrounding a potential leak, whilst finally, the marking or pin-pointing of the leak, which includes the effective identification of the exact leak location.

From the 1930s, the first studies concentrated on defined areas of distribution networks in which the input rate was measured by a flow meter installed temporarily. Within these zones sequential valve closing operations were undertaken for the purpose of quantifying consumption in different sub- zone could be conducted. The sequential closures typically occurred overnight and resulted in a progressive reduction of the size of monitored sub-zone by closing valve and continuous metering. Thus, the pin-pointing was performed only in delineated areas with higher flow rates. From the 1980s, the widespread process of creating District Metered Areas began, allowing the implementation of a proactive strategy to control losses. In the 1990s, came the first acoustic loggers which replaced night leak detection work, valving operations and particularly, the cutting of supply to clients.

As regards leak micro-location, by the 1960s, wooden sticks - and their imitation metal rods - gave way to microphones (geophones) that were placed on the ground or the pipe network, and which amplified noise, thus facilitating detection and leak location. In the 1970s, the first acoustic correlation equipment emerged, obtaining improved results in leak detection compared to the use of listening sticks. These devices, while also using the acoustic leak detection method, autonomously perform a complex mathematical calculation to determine their exact location, with the result made available quickly and simply for interpretation by the operator. Until the late 1990s, acoustic correlators evolved considerably, becoming even more user-friendly, portable and quicker in locating leaks. In 2002 the first digital correlators with noise elimination were introduced, making it even more reliable with a wider field of application technology.

An innovative technique currently available is detecting and locating leaks by a non-acoustic method, which developed by use a trace inert, harmless gas specifically injected into the water main. This technique, although more costly and time consuming, has provided extremely reliable results, with use in exceptionally difficult detection situations, particularly in household service connections or non-metallic mains of small diameter, where the application of acoustic techniques have revealed rates lower success.

Figure 2.3 outlines the chronological evolution of leak detection techniques.

2.2.3 Policies to adopt

The recognition by countries, government agencies and management companies, as to the importance of implementing policies to control losses has led to the topic being examined in different forums, both from a technical standpoint or a legal framework.

a) International

The reports Managing Water Losses, published by United Kingdom Water Industry Research (UKWIR) in

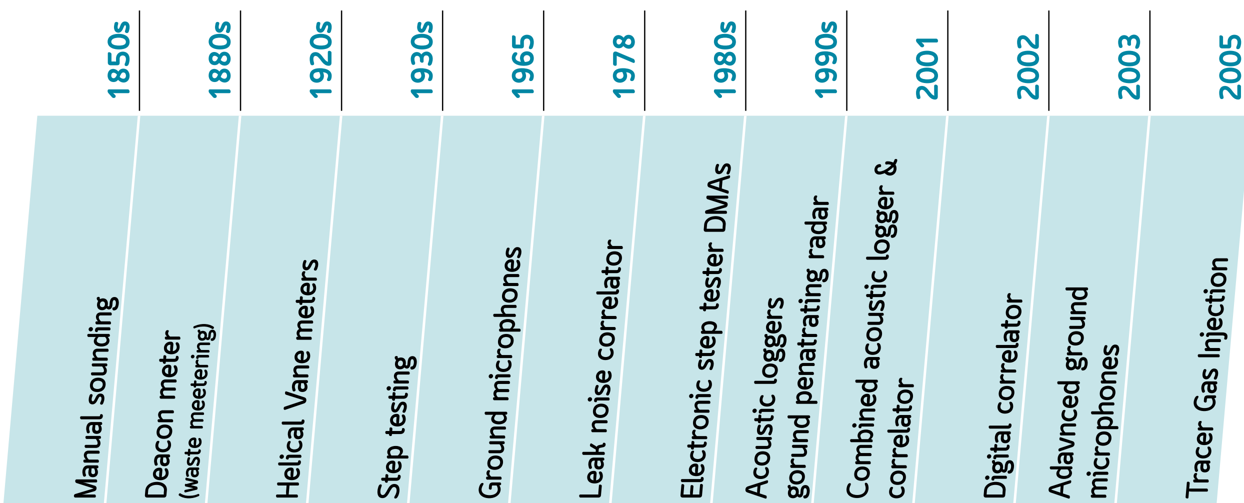


Figure 2.3 **Chronological evolution of leak detection techniques**

1994, included presentation of consistent and systematic methodologies that allowed the understanding, measurement and reduction of losses in distribution networks. These reports have been the starting point for a change in attitude on the part of the water production and supply industry, progressively guiding the course of action towards management of systems losses. The emphasis currently observed as regards this issue, results in the consequent development of a large number of research activities, whilst a major concern is primarily on the ability of managing utilities to measure and evaluate the performance levels of their water supply networks.

The International Water Association (IWA), founded in 1999 as a non-profit organization, aims to observe all stages of the water cycle, serving an international network of water professionals through research and development of "best practices" for managing water sustainably. The association has over 10.000 members in some 130 countries and is annually hosts hundreds of conferences and specialized seminars on various aspects of water management.

In June 2003, the IWA Water Loss Task Force was formed by a group of experts in the operation and maintenance of water supply systems, being organized into six research teams which have focused their activities on various topics related to the practical approach to reducing water losses: Active leakage control zones, Control and Monitoring, Management and Control of Pressure, Developing Performance Indicators for comparing systems, Evaluation of Real Losses and Apparent losses. Following the work of the Water Loss Task Force (currently developed into the Water Loss Specialist Group), IWA started publishing a series of articles on the results of experiments and guidelines for "good management practices" in their corporate magazine, Water21. These are aimed at all kinds of governmental groups within the water sector, management companies and their employees, individuals or partners and community representatives at all levels of government, including national and international agencies, to combat the problem of water losses and above all, to reduce future demand for water.

Studies published in this area have established important groundwork, from which guidelines, best practices, performance indicators and the main forms of action to combat water losses are defined and applied.

Given the increasing awareness of water resource conservation, participants at the 3rd EU Water Conference also promoted the development of a water policies strategy for the European Union - "Blueprint to safeguard Europe's water resources", published in 2012 by the Commission European. This is a matrix designed to preserve water resources in Europe, aimed mainly at the problem of leakage in water distribution networks. The Commission states that "these issues should be addressed to assess the environmental and economic benefits of reducing their levels of losses. The situation is very different between member states, where between them, the rates of water losses vary between 7% and 50% or even more. The Commission will work with the European water industry to accelerate the development and dissemination of best practices with regard to economically sustainable levels of leakage (SELL - Sustainable Economic Level of Leakage) and, more generally, the definition a strategic vision for the future of water supply infrastructure in order to help the sector adapt to climate change in a world where resources are increasingly scarce."

The proposed action consists in a matrix defined in the publication to be made by the Commission, Member States and the water sector, covering best practices and tools to achieve a sustainable economic level of leakage. In order to facilitate implementation of the proposed measures, financial support instruments, consisting of a Structural Fund and the Cohesion Fund and loans from the European Investment Bank (EIB) between 2014 and 2021, were created.

b) In Portugal

From the perspective of evaluating the efficiency of water use and resolution of the Council of Ministers No. 113/2005, which was published in the official Portuguese government record "has been [..] to develop a planning effort" for this purpose. In fact, an important ministerial and interdepartmental effort was developed to establish guidelines of a National Program for the Efficient Use of Water (PNUEA), with the planned initiative becoming the National Water Plan, coordinated by the National Laboratory Civil Engineering. This program, which aims to consolidate and effectively implement various plans, aims to contribute to a new approach to water issues in Portugal, under a framework of sustainable development. Indeed, it was guided by policies aimed at the efficient, rational and effective use of water resources and the preservation of its good ecological quality, so that Portugal can have the water it needs beyond a generational boundary.

The National Plan for Water Efficiency, which has been subject to successive updates in line with relevant European directives, is based on four program areas, each comprising of a set of actions. These actions include metering and re-use of water, awareness, information and education, regulation and standardization, training and technical support. Responsibilities for different stakeholders and sectors or groups of users are assigned along with a set of proposed measures that allow better use of this resource and additionally reducing waste water and energy consumption and associated reagents, thus contributing to a lower environmental impact. Establishment of these priorities have been revalued at the regional scale as a function of the ratio between needs and availability of water. Goal setting for PNUEA defined an indicator that reflects water use efficiency in any of the sectors considered, directly, transparently and effectively allowing comparison between goals and results.

in 2009 under PNUEA, it was identified that the water waste associated with water distribution systems was still very high, although different in every sector of use: 25% in urban use, 38% in agricultural use and 23% in industrial use. This inefficiency in water use is especially onerous during periods of water scarcity. For environmental, economic and ethical reasons it has become imperative to create a set of national objectives to:

- Improve the efficiency of water use in Portugal, without jeopardizing the essential needs and quality of life of the population, as well as the socio-economic development;
- Minimize the risk of failure due to the lack of water under normal situations, but enhanced during periods of drought;
- Develop a new water culture in Portugal that increasingly values this resource, contributing to human and economic development and environmental preservation and a perspective of sustainable development.

In practical terms, the goals set by PNUEA 2020 relating to water losses associated with distribution systems, point to values of 20% losses in urban areas, 35% in agriculture and 15% in medium industrial environment. The recipients of these goals are the management entities, public or private, responsible for operating water supply infrastructure and end-users, households and urban collective units, agricultural and industrial units.

Water losses are occupying a central role in the concerns of managing utilities in Portugal. In this sense, there is more emphasis on the necessity of reducing losses through combating leaks and renewing networks. Beyond combating the actual losses, it is known that a significant number of economic or apparent losses in water supply systems are typically associated with excessive consumption of water and that often results from local customs combined with a low or inadequate tariff policy measurement. This portion of apparent losses should be systematically reduced with the introduction of new policies for demand management and water conservation. Many companies still take encouragement and awareness of clients to an efficient use of this resource programs. Together, these programs must be part of the global strategy for the conservation of water resources.

In Portugal, even before greater emphasis was given to the problem of losses motivated by the establishment of PNUEA, EPAL has demonstrated a significant concern as regards this theme which was motivated by the fact that demand exceeded supply capacity that the company had.

In the mid-1990s, when losses in its supply system were in the order of 25%, the company has proceeded to undertake systematic campaigns of acoustic leak detection in temporary study areas in the network.

Throughout the 1990s the overall values of Non-Revenue Water (NRW) in EPAL were relatively constant, significantly, with greater levels of losses in the Lisbon distribution network. At the turn of the century, there was an overall annual NRW volume of approximately 50 million cubic meters, of which approximately 38 million cubic meters were lost in the distribution network (see Figure 2.4).

Given the scenario described above, in the early 2000s EPAL decided to undertake an effective strategy for control and reduction of water losses, focusing on critical aspects:

- promoting improved quality of information registered in the GIS (Geographic Information System) and compatibility of information with the Customer Management System (AQUAMATRIX®);
- intensification of renovation and rehabilitation of the Lisbon distribution network, progressively based on more consistent and sustainable decision support methodologies for defining intervention priorities.

Such measures have, given the annual volume of non-revenue water in the Lisbon distribution network that in 2002 represented 25% of water entering the network, implied additional measures, including the development and implementation of an active water loss control system, strengthening the approach based on distribution network sectorization into District Monitoring Areas (DMAs) and their continuous management.

In this context, during 2005 the company established objectives for the reduction of Non-Revenue Water in the Lisbon distribution network to sustainable values, setting the goal, until 2010, of attaining levels of water losses of less than 15%, which led to initiatives to reinforce innovation, experience, sustainability, efficiency, optimization and economy, based on six key vectors of action:

- Sectoring and continuous monitoring of the network;
- Development of analytical systems using internal resources;
- Optimization of Active Control Leak procedures;
- Continuous improvement based on experience and results;

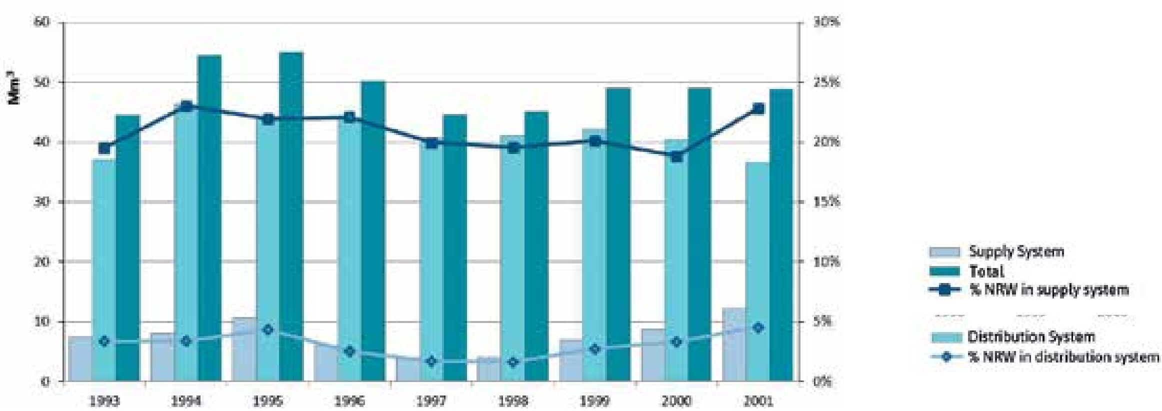


Figure 2.4 **Evolution of Non-Revenue Water (NRW) in the EPAL system during the 1990s**

- Process of simple and effective analysis due to the complexity of the distribution systems;

- Focus on essential and effective cost control.

In addition, a specific computer application was developed to support active water loss control, namely WONE - Water Efficiency for Network Optimization which is also used to support other water utilities.

Project development required a total investment of 2 million euros, including monitoring point construction, installation of flow meters and telemetry equipment, restructuring of leak detection procedures and equipment as well as organization and training of network analysis teams, distribution network hydraulic model development, as well as the development of the WONE computer application. It was also possible to review investment strategies, repair response procedures and implement a number of improvements to the EPANET based hydraulic network model.

This small investment generated significant economic benefits in terms of the substantial reduction in water losses in the network of Lisbon, as shown in Figure 2.5.

In addition to the above mentioned aspects, advantages created in efficiency levels by reducing water losses involve positive outcomes for all stakeholders involved, including clients, company, regulator and shareholders, at different levels:

- **environmental**

  By allowing reduced extraction rates to be obtained, reduce energy consumption and reagents, avoiding, based on cumulative data between 2005 and 2013, 21.000 t CO_2 emissions. As previously stated, there was a dramatic decrease in energy consumption required for the production of distribution network water and treatment reagent consumption, which also resulted in reduction of annual emissions of CO_2, transforming the business into a cleaner performer with a smaller carbon footprint.

- **economic and financial**

  Implementation of the project, allowed a cumulative NRW reduction in the Lisbon distribution network with around 98 million

Figure 2.5 Water Loss reduction evolution in the EPAL distribution network

cubic meters of water no longer entering the distribution system between 2005 and 2013, a volume corresponding to a valuation of around 48 million euros, considering the sale price of water.

These values correspond to a global reduction of, in the same period, of 57 million kWh of energy consumption and 5,7 million t of chemical reagents required to produce drinking water. In addition to these indicators, other financial gains were achieved and although not quantifiable, these include a reduced number of unscheduled repair operations, which are considered ten times more expensive than planned interventions, an increased knowledge of the distribution network, consumption habits of clients and an increase in client service quality. In parallel, financial gains were secured by reducing strategic investments made by the company, resulting from data analysis with the aim of verifying the real need for asset investment.

- **social**

Increased efficiency has allowed the company to increase net profit and added value to the client, including tariff moderation. Economic, financial and environmental gains have been made possible by the increased efficiency and effectiveness of the company. Given the increased financial sustainability of the company, during 2013 it was possible to create a social tariff that benefited a significant number of families in Lisbon with financial difficulties exacerbated by the global crisis. Additionally, The large reduction in water loss volumes in the city of Lisbon water distribution network in the last decade, promoted the company to a restricted group of the most effective cities in the world. Figure 2.6 outlines the levels of water losses in several major cities around the world facing the same challenge.

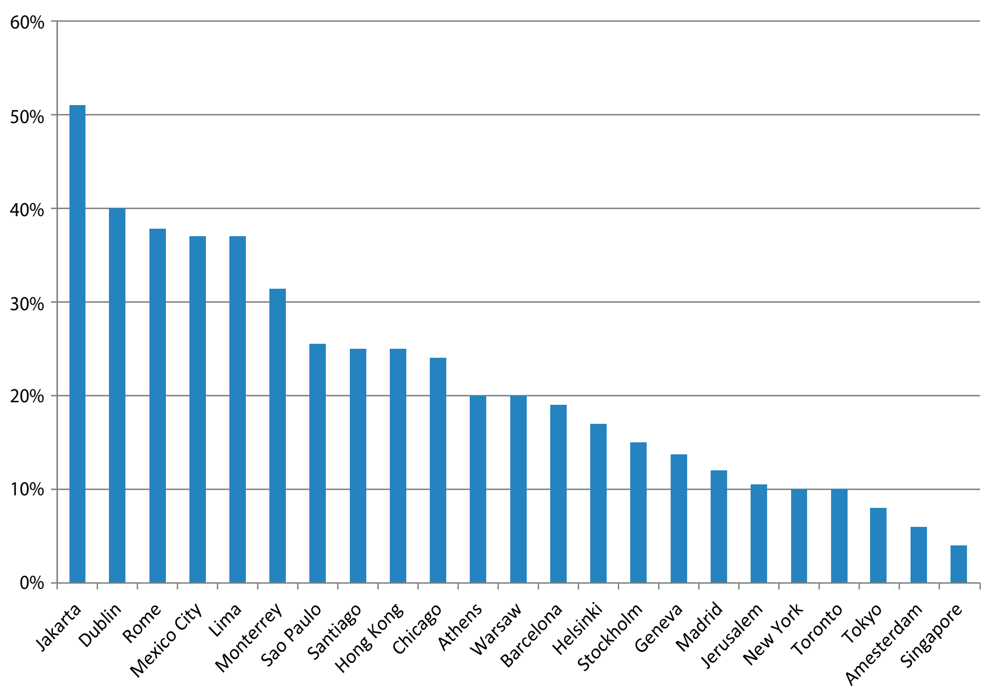


Figure 2.6
Comparison of water loss levels in various major cities
(source: Swan - Smart Water Network Forum, 2011)

3. Definition and Quantification of Water Losses

3.1 Water Balance

3.1.1 Principal Concepts and Definitions

The occurrence of water losses is inherent in all distribution systems, with a variable volume of water actually lost. This volume represents the amount of water that is introduced into the system and which, for various reasons, fails to be delivered or charged to the consumer. It may be further considered that the amount of loss depends on the specifics of each system, in particular the infrastructure condition, operational and maintenance regimes, thus calculating and quantifying losses may be just as important as the challenge of reducing it.

Faced with the need to assess water loss volumes and its components and thus enable an international comparison between the performances of different operators, the IWA Water Loss Task Force undertook a series of investigations and initiatives on the subject. In 2000, the tool which has come to constitute the basis for almost all analysis that takes place regarding water losses was introduced - the Water balance. Added to the concept of water balance, comes a set of definitions of the components related to system inputs and water losses in water supply systems, which are articulated and outlined in the respective water balance table.

This method of calculation, being separated into components, assists with the characterization of the amount of water entering the system that can be individually measured or estimated in order to complete the overall Water balance, as shown in the figure below.

The significance of each principal of water balance components is as follows:

- **System Input Volume (SIV)** - annual volume of water entering the distribution system;

- **Authorized Consumption** - annual volume of water metered or unmetered but actually consumed by clients, the supplier itself or by those who are implicitly or explicitly authorized to consume water, such as social commitments and legitimate use by the fire service. In addition, the volume of water that is exported is also included and existing leaks present on client service connections;

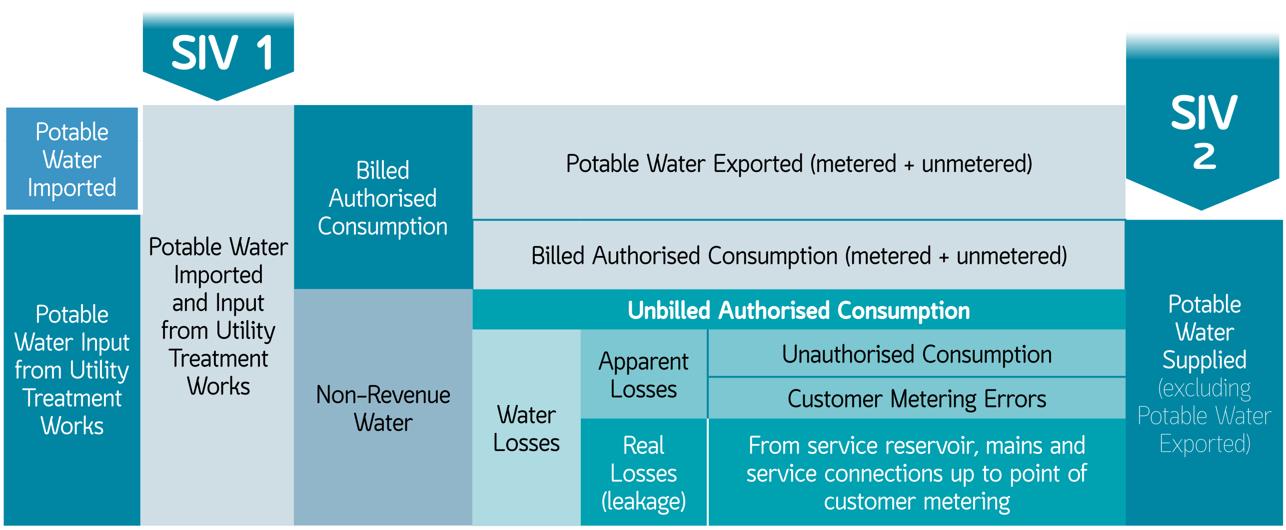


Figure 3.1 **International Water Association (IWA) Simplified Water Balance**

- **Non-Revenue Water (NRW)** - is the difference between the volume of water introduced into the system and the authorized consumption that is actually billed. Thus, NRW is the water loss plus the segment that translates into unbilled authorized consumption;

- **Water losses** – the difference between the volume of water introduced into the system and authorized consumption, representing both real and apparent losses;

- **Apparent Losses** – corresponds to theft and illicit consumption and can be estimated by checking the number of illegal connections, number of defective meters and using estimates of per capita consumption used to calculate the volume;

- **Real Losses** – volume that is lost annually through all types of leaks, bursts and leaks in pipelines, reservoirs and service connections to the point of the client meter.

The estimated loss is obtained by comparing the volume produced or transferred in from one point of the system, with the volume of authorized consumption at one or more points in the same system. NRW includes all losses, real and perceived.

Non-Revenue Water (NRW) = Water Losses + Authorised Unbilled Consumption

Water Losses = Real Losses + Apparent Losses

The NRW calculation may be presented by volume, as indicated above, or, as often happens, in percentages:

% Non-Revenue Water = (Unbilled Volume / System Input) x 100

The various factors of water losses are illustrated graphically in Figure 3.2.

The water balance and the definitions of its components are the most common solution for calculation and evaluation of water losses, having come to form the basis for national and international comparison of utility

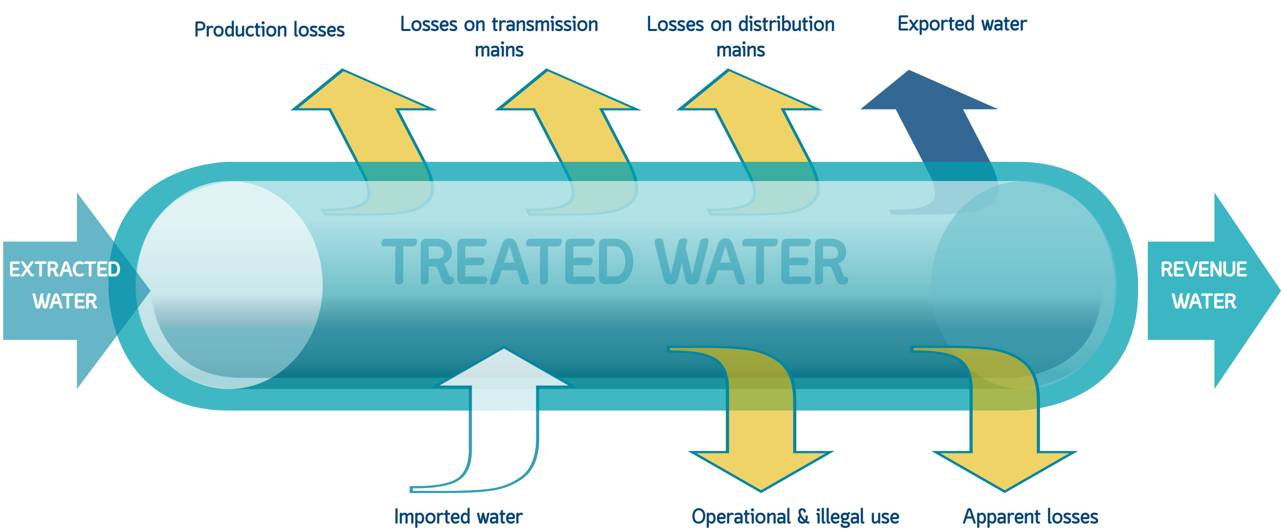


Figure 3.2 **Flowchart of the various water loss factors in a supply system**

performance. Correct and applicable management of water supply systems should include continuous monitoring of flows in order to permit, firstly, the correct calculation of water volumes which are not charged and secondly, identification of potential water loss.

Despite being the far more common and more easily perceived indicator, the use of percentages to quantify NRW is not without some controversy, given the direct influence that the volume of water entering the system has on the final result.

However, given that the size and constraints of utilities are very diverse, direct confrontation between the unbilled volumes amounts does not establish any basis for comparison in performance, so the unbilled water is often expressed as the percentage of the volume of system input volume.

Overall, many other indicators have been established with different levels of sophistication, whose objective is to allow benchmarking between utilities.

3.1.2 Calculation Methods

IWA recommends calculating water balance volumes of prior to determining performance indicators. This calculation is based on the volume of water introduced into the system, quantification of authorized billed and unbilled consumption, metered or unmetered, leading to the determination of volumes of real and apparent losses. The basis for calculation is annual (12 full months), minimizing any time between meter reading and billing discrepancies.

The water balance should be based preferably on the actual measurement of flow rates and volumes. However, whenever a reliable duly verified measurement is not possible, then every effort should be made to evaluate as accurately as possible, each component volume and consumption and estimate realistically each of the water balance component.

The methods used for determining the estimated components should be defined, recorded and subject to continuous improvement. These volumes, calculated or estimated, are liable to error and uncertainties that may have a greater or lesser extent and that will be considered in proportion to the relative volume of unbilled water and actual losses.

For recovery of the loss components, namely the real and apparent losses, complementary approaches should be used for calculation and results obtained can be considered as credible. The following approaches to determining losses are accepted consensually:

- **Top-Down Approach**, which starts the process with all available information, usually being undertaken on paper or as a desktop exercise, in which no field work but a number of estimates are made.

  This approach begins with a macro-analysis of losses that assesses the need for intervention over the whole network. To this end, the system input volumes through metering are analysed, as well as billed and unbilled authorized consumption and apparent losses due to illegal connections and potential measurement errors.

  The analysis evolves, so the whole system is separated into smaller areas, which entails the gradual determination of the current levels of the various potential losses. In this approach, losses are calculated from metering of the various system inputs, minus values obtained by client billing systems.

- **Bottom-Up Approach**, applied in cases of sectorised systems and equipped with continuous monitoring, means it is possible to calculate the volume of real losses from night flow values (OFWAT 2001). This approach serves as a counterpoint to the value of real losses that were calculated by the Top-Down approach and is based on the analysis of Minimum Night Flow obtained from data with high value of certainty. However, this approach requires thorough knowledge of the network and a more sophisticated level of management in terms of network control.

Figure 3.3 illustrates the two approaches mentioned schematically.

Convergence of the values obtained by these two approaches gives credibility to the results of the water balance and ultimately, assists in identifying any uncertainties encountered more accurately.

To adopt this approach, the network should be progressive and properly structured and equipped in accordance with its normal operation, being analysed through permanently sectored District Meter Areas (DMA). The construction of a hydraulic model also has a key role in creating a better understanding of network behaviour, optimizing the process of sectoring and subsequent estimation of combined flows for each of the analysed functions or network zone.

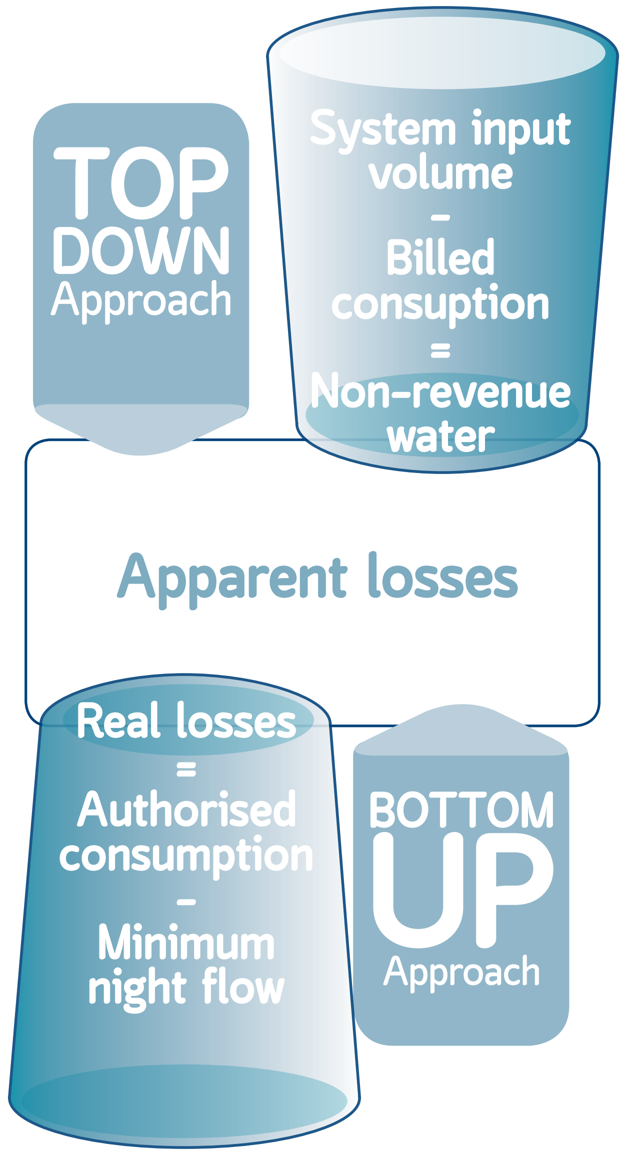


Figure 3.3 **Top-Down & Bottom-Up approaches**

3.2 Real Losses

3.2.1 Characterisation of Real Losses

Real losses represent the volume of water lost in the network and infrastructure of a utility. These losses are further divided into different subcategories within the water balance, depending on where the water leak occurs, namely:

- Leaks in water supply and distribution mains;
- Leaks in the structure of the reservoir and overflow;
- Leaks on client service connections up to the meter, normally underground.

In this context it should be considered that the concept of leakage corresponds in general terms to physical loss of water in each component of the water balance.

Leaks occur in all supply systems varying greatly in size and severity, depending on the circumstances of each site and supplier. Leaks can be visible or invisible, which in the second case can exist for an undefined period of time, which can be prolonged if efforts to detect them are not undertaken. Even the simple detection of a leak cannot quantify the amount lost, so that, in most cases, tests and trials must be undertaken to quantify losses with any precision, whilst recording the process for auditing purposes.

There are also other water loss definitions, which are associated with different types of leakage that can occur, namely:

- **Background losses** – occur through small leaks, undetectable using available detection equipment and characterized by low flow rates, long lasting and thus with large volume losses;
- **Burst losses** – characterized by high flow, short duration, often visible and associated damage, which correspond to moderate loss volume;
- **Unreported leak losses** – characterized by average flow rates and volumes dependent on the duration leak existence, and potentially able to be identified by active leakage control .

Leakage ranking results from experience of observing their causes, with the extent of water loss caused by leakage strongly influenced by system infrastructure characteristics and its surroundings, as well as leak detection and repair strategy, management and operation of the company policy and practices. The most important causes for infrastructure leakage occurrence are:

- Condition of the main transmission and distribution pipelines;
- Material, age and attention to the original settlement of pipelines;
- Number and quality of service connections or extensions;
- Pressure at which the system is operated and pressure fluctuations throughout the day;
- Number and condition of network accessories such as valves, hydrants and air vents;
- State of hydraulic transients protection equipment;
- Protection against corrosion;
- Materials used for repairs;
- State of foundations and walls of the reservoirs;
- Surface or "trop-plein" discharges;
- Geotechnical conditions and instability of the soil;
- Road traffic or other vehicles loadings.

Of all the factors noted, the relevance of each is enhanced by the influence of operating pressures, management of which strongly influences losses in the system, where it is known that high pressures:

- Imply a greater amount of water consumed either by bursts or by the client;
- Are associated with a higher rate of damage and breakage in pipes and fittings;
- Increase the likelihood of hydraulic transients, particularly in the start and stop events of pumping groups and of isolating valve operations. Hydraulic transients can cause bursts in pipelines, shifting stabilising blocks or damaging joints.

In systems subject to significant and recurring variations in pressure there is a greater tendency for fatigue in pipes and accessories, especially designed for plastics. Furthermore, greater efficiency in acoustic leak detection is achieved with higher pressure values due to the increased noise level caused by the escape of water that propagates through the pipeline network and accessories.

A proper estimate of actual losses in a network can be achieved by applying four different methods: Top-Down Analysis of the Water balance, analysis of night flows through the Bottom-Up analysis of water balance components and a combination these approaches.

In the case of top-down approach, it is assumed that:

Volume of Real Losses = System Input Volume - (Authorized Consumption Volume + Apparent Losses Volume)

This approach is dependent on knowledge of variables that are not easily measured or estimated, as is the case of apparent losses, relating in particular to metering losses or theft. For this reason, in this approach, a portion of the value associated with apparent losses remains invariably added to the value attributed to the real losses, overestimating the problem of system leakage. Therefore, assessing the volume of leakage through a combination of other methods is recommended.

In the case of Bottom-Up approach, applicable to sectorised networks equipped with continuous monitoring systems, the volume of real losses is estimated based on the observation of night flow values to the areas in question, typically observed between 2am and 4am and then extrapolated to 24 hours of operation. The IWA has published the result of a series of studies to estimate standard authorized night consumption, defined by the type of client. In this approach, it is essential to calculate the Night-Day Factor, which corresponds to the ratio between the maximum pressure variation present in the network (usually during the night which is the best estimate of losses) and the minimum pressure recorded during peak periods. Figure 3.4 illustrates this approach.

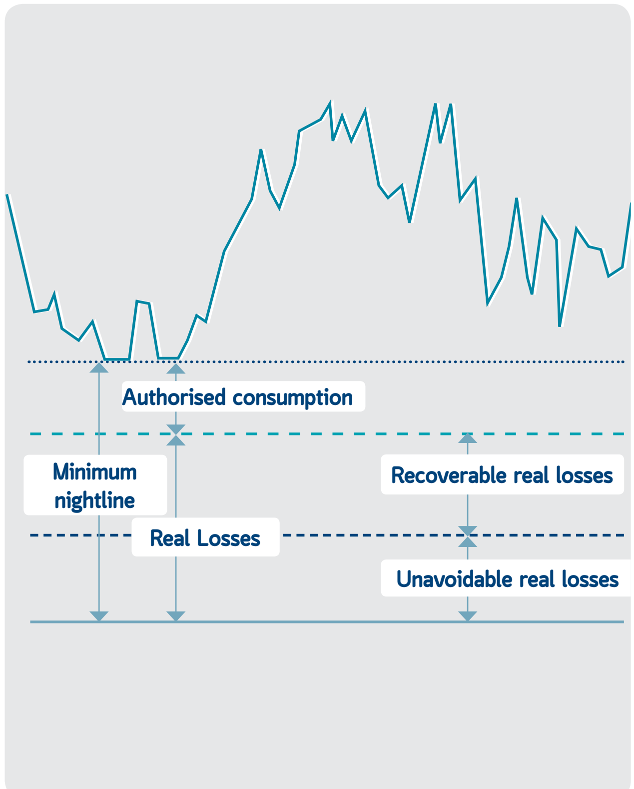


Figure 3.4 Bottom-Up approach for determining real losses

Volume of Real Losses = (Minimum Night consumption - Authorized Consumption) X Night Day Factor

An important advantage of this type of analysis is the possibility to calculate the volume of real losses, either for the whole system or DMAs, enabling the utility to ranking and align areas according to intervention priorities. This type of calculation provides a check of the values obtained by the water balance and determining the relationship between network pressure and the level of losses.

For this purpose, EPAL has developed the WONE application, specifically for treating DMA monitoring data and network management support, enabling automatic implementation of this approach as illustrated in Figure 3.5, referring to one of the DMAs in the Lisbon distribution network.

amount of water lost through real losses and the cost of leak detection and control activities with the objective to minimize the sum of both. This is the concept of Economic Level of Losses - ELL.

The IWA Water Loss Task Force identified four basic factors of real losses management:

- pressure management;
- speed and quality of repairs;
- management of network assets;
- active leakage control.

The following figure highlights the four main areas focused on reducing real losses.

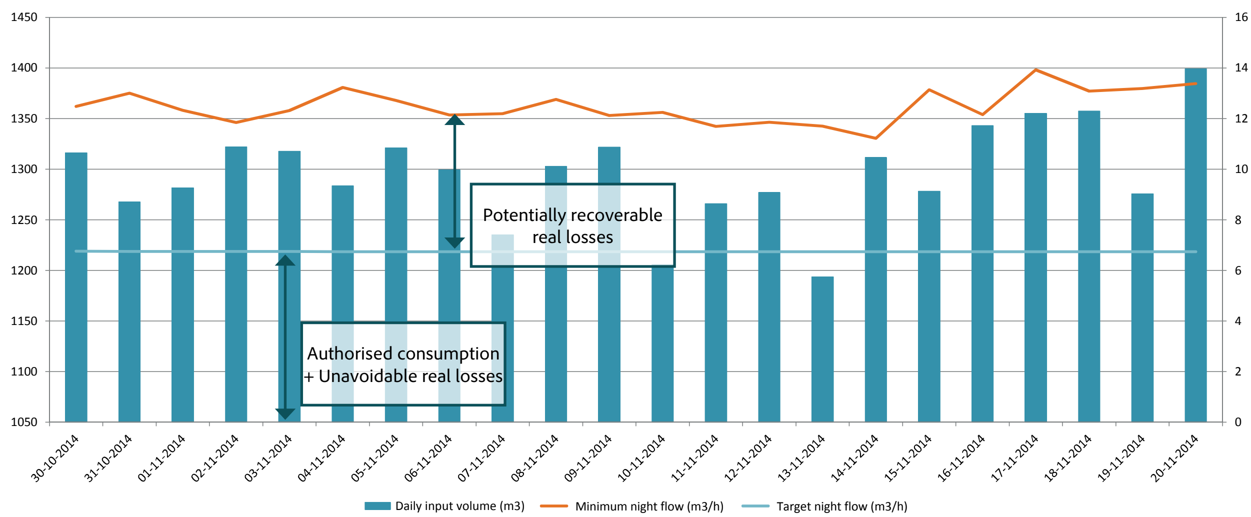


Figure 3.5 **Minimum night consumption and estimate of potentially recoverable real losses**

3.2.2 Management of Real Losses

Real losses can be minimized but not completely eliminated, with the aim being to achieve a level of real losses with the lowest cost combination between the

Water supply system pressures unequivocally influence the occurrence of bursts and leaks, with the correct management of pressure in water supply systems being one of the most effective ways to combat water loss, widely dealt with in several studies. (Trow and Tooms, 2014).

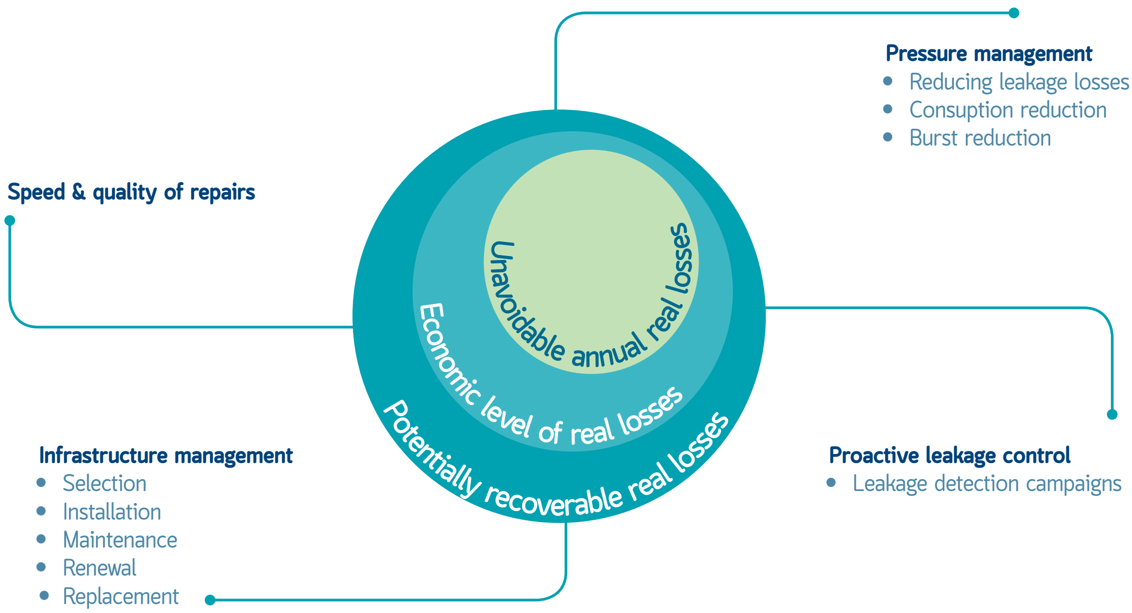


Figure 3.6 **Principal factors for reducing real losses (IWA Water Loss Task Force)**

The speed and quality of repairs carried out on the leaks detected on the network allow the reduction of losses volume, ensuring that it is maintained at controlled levels. Implementation of an integrated asset management system by a utility helps to ensure a balance between performance, cost and asset risk, contributing to a policy of maintenance, replacement or renewal effective and sustainable. The last factor focuses on active leakage control , which calls for a proactive strategy towards the reduction of water losses through the detection of hidden leaks, for which control is possible through the action of specialized teams and continuous monitoring of the supply system.

In the short-term, management of real losses must be undertaken to reduce the duration leaks through the rapid intervention to resolve the detected leakage and improving the quality of repairs. To achieve results in the medium and long term, thus effectively reducing losses in the network, action should be promoted towards pressure management, efficient management of company assets and active leakage control.

Active Control Leak is the focus of this document and began at EPAL in a continuous and objective way in 2005 with the implementation of the first DMAs. Sectorisation

Active Control Leak is the focus of this document and began at EPAL in a continuous and objective way in 2005 with the implementation of the first DMAs. Sectorisation of the distribution network through DMA creation, continuous monitoring of the network and the existence of a team dedicated to monitoring system analysis and leakage control was instrumental in the systematic reduction of NRW at EPAL in recent years.

of the distribution network through DMA creation, continuous monitoring of the network and the existence of a team dedicated to monitoring system analysis and leakage control was instrumental in the systematic reduction of NRW at EPAL in recent years.

3.3 Apparent Losses

3.3.1 Characterisation of Apparent Losses

Apparent volume losses, also referred to as economic or commercial losses, are not accounted for and not attributable to leakage. Such losses are divided according into two components within the water balance, namely unauthorized consumption, which corresponds water theft and metering inaccuracies, which may include meter errors and failures in data handling. Apparent losses can be influenced by social, cultural, political and financial factors, amongst others and may require organizational and institutional changes. As such, they are harder to locate, target under medium and long term action plans.

Control of apparent losses is largely undertaken by analysis and subsequent resolution of problems associated with unauthorized consumption, a situation that is directly related the number and location of existing illegal connections. This identification can be obtained by estimating, analysing a pilot area and extrapolating the value to other areas, whilst considering unauthorized usage as those that include illegal connections or theft caused by misuse of fire hydrants. In turn, the legitimate connections can cause apparent losses from billing errors, such as not recorded in the database or known about, but either intentionally and accidentally omitted from the database.

With the aim of reducing the number of unknown service connections and reconcile the physical registration of the company network with the billing system, EPAL undertook a project to survey and validate compatibility of service connections. This project has had a great impact on the identification of illegal consumption and contributed significantly to the analysis quality undertaken within the Active leakage control actions, especially in increasing reliability in identifying clients and their consumption.

The apparent losses component associated with metering inaccuracy, under-invoicing and commercial potential errors is another aspect to consider. To combat these situations, concern should be shown for the correct choice of meter type, its sizing and installation conditions.

It is recognized that mechanical meters tend to have a gradual tendency for under-registration throughout their life cycle, which can be prematurely exaggerated when subjected to operating systems not covered by the respective manufacturer's guidelines. It is also

With the aim of reducing the number of unknown service connections and reconcile the physical registration of the company network with the billing system, EPAL undertook a project to survey and validate compatibility of service connections. This project had a great impact on the identification of illegal consumption and contributed significantly to the analysis quality undertaken within the Active leakage control actions, especially in increasing reliability in identifying clients and their consumption.

emphasized that oversized meters tend to under-register under low flow conditions and may lead to large differences between the recorded volume and the water that is actually consumed. It will therefore be prudent to adopt a policy of monitoring and replacement of client and revenue meters, as sub-metering may result in a significant loss of revenue.

Some of the key factors contributing to meter degradation are as follows:

- **Metering inaccuracies**
  - Under-registration caused by low flows and poor accuracy due to age or high usage;
  - Low accuracy class meter;
  - Meter stopped, damaged or obsolete;
  - Improper maintenance or replacement policy.
- **Unlawful meter intervention**
  - Meter bypass;
  - Vandalism or abuse intervention.
- **Under-billing (errors and fraud by meter reader or client)**
  - Volume under recorded in the billing system;
  - Fictitious reading;
  - Data transfer errors;
  - Billing software errors.

3.3.2 Control of Apparent Losses

The methodologies applied for active control of apparent losses require careful management of water meters, implementing a control policy for unauthorized consumption, control and analysis of received data and the handling and integrity of billing data.

Thus, plans for meter verification, replacement and selection of meters within the overall management system must be made, whilst it is advisable to perform test bench-based measurement and validation of a significant sample of meters installed in the network.

In this perspective it is recommended to undertake meter validation on test benches of a significant sample of meters installed on the network, to determine any deviations from the expected standard in terms of the average meter error due to age. This is essential for determination of this factor in the water balance and the existence of reliable measurement of bulk volumes transported, exported and imported by the system and registered in any of the various sectors the distribution network.

Indeed, study of DMA behavior an important source of information that helps detect and locate areas with under-metering, as shown in Figure 3.7, which highlights a DMA in the city of Porto, with universal metering and in which the top of the curves allows identification the existence of under-metering.

The control of unauthorized use must go through the identification of illicit connections. Data analysis should consider the activities of identifying stopped meters, in order to reconcile client data and consumption data as well as the rigorous estimation of un-metered consumption.

Finally, monitoring the integrity of billing data can be maximized through use of IT, including more reliable and representative client databases. Figure 3.8 highlights the four main areas to be focused upon as regards reducing apparent losses.

3.4 Principal Water Loss performance indicators

Following preparation of the now universally recognized water balance, used in a growing number of management companies worldwide, the IWA, through specialized working groups, identified a set of performance indicators for the following components of the water balance:

- Non-Revenue Water
- Water Losses

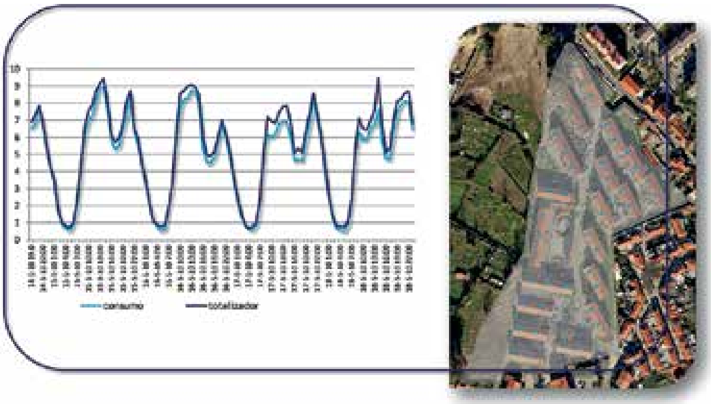


Figure 3.7 **Apparent water loss control in a DMA with 100% metering** (ceded by Águas do Porto)

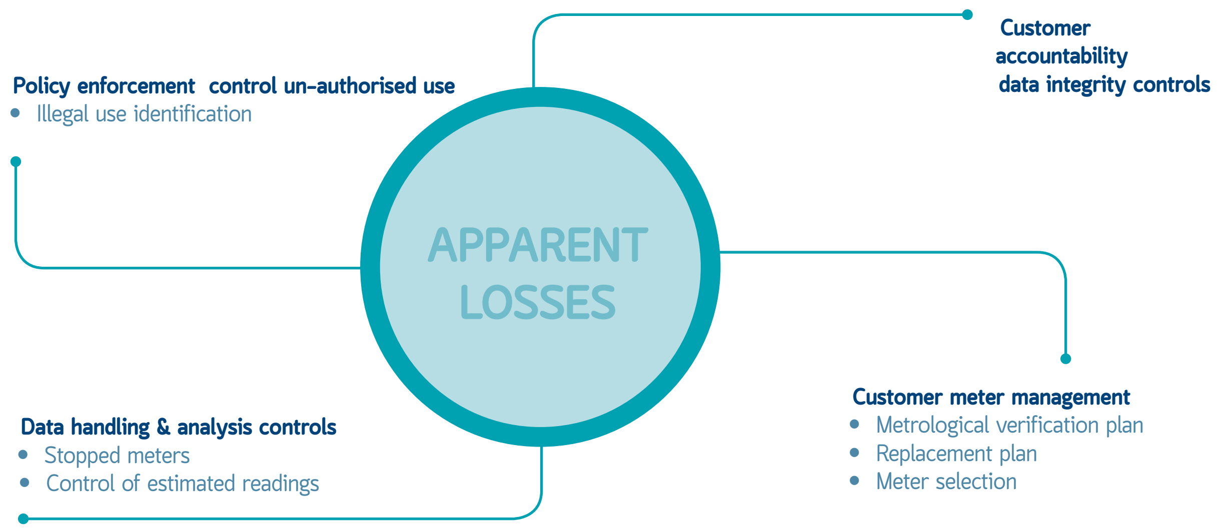


Figure 3.8 **Principal factors for reducing Apparent Losses**

- Real Losses
- Apparent Losses

One of the most commonly used approaches in defining performance indicators is to understand their subdivision into distinct groups, including financial, operational and water resources. Table 3.1, prepared by the IWA Water Task Force, outlines details relating to the most commonly used performance indicators.

The calculation of performance indicators enables a comparison between managing utilities in different countries and of varying dimensions, becoming more relevant as a decision-making tool, aiming towards continuous improvement and cultivating knowledge regarding the supply system condition and performance.

It is stressed that the measurement unit for each indicator varies according to the type of performance indicator referred to. Financial and water resources indicators often use percentage loss in volume or percentage of the water value, whilst operational indicators consider units of volume per service connection or per kilometre of network per time period (hour, day, or year). In the case of operating sample of connections and which have used the installation of flow meters at the start of these connections to compare the volume registered by customer meters served by each individual connections. Only in this way will it be possible to validate if the dimenison of losses on

Component	Type	Performance Indicator base	Performance Indicator detail
Non-Revenue Water	Financial	NRW volume as % of water volume in system	NRW system value as % of system cost
Water Losses	Operational	m^3/service connection/year	-
Apparent Losses	Operational		m^3/service connection/year
Real Losses	Water Resources	Real losses volume as % of water volume in system	-
Real Losses (in each case, this indicator is calculated "per day" when the system is pressurized to allow for the effect of intermittent supply	Operational systems	Litres/service connection/day for systems with 20 or more service connection per km of main or use m^3/km/day for systems with less than 20 service connection per km.	Infrastructure Leakage Index (ILI): defined as the ratio between current annual real losses and unavoidable annual real losses = CARL / UARL.

Table 3.1 **Key Performance Indicators related to water losses**

performance indicators, this differentiation appears to avoid misinterpretation of the results due to differences and changes in volumes consumed, intermittent supply and the presence of client-side storage tanks, a situation that can lead to significant under-metering, due to low flow rates.

Given the diversity of situations that can occur in water supply networks and the intrinsic characteristics of their functions, it is important to contextualize some of the key concepts inherent in the calculation of the indicators mentioned in order to ensure a uniform perception.

First, one of the relevant aspects is related to the issue of service connections. The importance of service connections to the level of water losses stems from the conviction expressed by several authors that a significant proportion of water losses occur in these connections, which constitute an effective weak point in the mains. However, there are no known studies that support this presumption, based on a sufficiently representative service connections is indeed one of the main aspects of water loss. To confirm this, it will therefore be necessary to undertake more concrete studies, involving tests to provide actual data of sufficient statistical dimension, including measurements comparing flow into the service connections with the flow out-going flow at the customer consumption points. In addition, a review of past service connection repairs could be undertaken, in order to assess any potential impact on water losses. In fact, only by investigating the subject more deeply will it be possible to state unambiguously and technically correctly, if most of the losses occur on the service connections or not.

The definition of a service connection should also be clarified as to what types of locations fall into this category. Thus, a service connection is considered to be any connection from a main pipe of a water supply system to an element supplied from this pipe. These locations may be open grounds, buildings, fire hydrants, network elements and irrigation systems, building works extensions, sampling points, air valves, network discharge points and dead ends, irrespective as to whether they are in service or not, being under pressure and always under load since the connections do not have an isolating valve at the beginning and thus can be at risk of leaks.

It is also stressed that due to the topography of many cities, the type of urban planning adopted and even social differences, large differences in the typology of urban areas exist, noting examples where the predominant family housing unit varies between situations where each connection corresponds to a single client to situations in which vertical construction predominates with multi-apartment buildings or even, as in some areas of the city of Lisbon, with numerous apartment buildings with several floors, all served by a single connection. In this latter case, each connection corresponds to a high number of clients. This variety of situations naturally has implications in terms of assessment systems and water loss performance indicator calculation and may give rise to a significant distortion in the comparison between different systems.

In addition to the potential distortion provoked by the situations described above, there are still many doubts and questions about the limits of a service connection entity, justifying particularly careful consideration. Indeed, it would seem logical that the service connection corresponds to the connecting portion between the principal main and the meter of a house, building or condominium for example, or the network element being supplied. This latter situation has a direct correspondence in the case of single dwelling houses, direct supply to network elements and buildings or condominiums which have a totalizing meter at the entrance area. This may, however, be questioned in cases of buildings that have a meter battery, particularly if this battery is away from the building entrance area and therefore with a variable length of section in private ownership. This does not apply to all buildings, such as in cases in which meters are situated in each apartment on different floors. In these cases, there are long building pipes connected to the meters, all of which create possible water losses along these sections, which are still the responsibility of the operator. This is despite the existence of above-ground sections and in private buildings which normally imply the early identification of a leak and respective repair, so that the volume of leakage is much smaller compared to other situations.

Given the above, it is easily understood that it is often considered that the extension length is the distance between the point of contact between the service connection to the main pipe and the limit of private property or building. This is more associated with a simplification of the situation rather than for hydraulic or technical reasons, since it does not have any effective correspondence with the actual physical infrastructure. On the other hand, consideration of water loss indicators based on the number of service connections can lead to questions as to why the number of meters is not considered as an indicator, when there is a signifcant diversity of situations. This is a valid whether or not there are active contracts, given that with a higher number of meters and greater total length of service connections, then the greater the number of weak points that will exist in the infrastructure, whose losses are borne by the utility. In addition, expressing the volume of losses in terms of the number of meters increases the perception of their meaning by the population served, because in most countries all properties have a meter (and those which do not, should have, which is an essential step in the reduction of consumption), so that customers can understand the significance of water loss per meter, an issue which is the responsibility of the utility. Therefore, this helps to convey to both clients and the population, the perception of efficient resource management and resulting economic loss that will ultimately be transferred to the customer in the form of extra costs, either through the fixed or variable component of the client water bill.

It is thus clear that, given the diversity of supply systems contexts, making direct comparisons in terms of such indicators not only is not recommended, it is undesirable. Accordingly, the application and usefulness of most of these indicators should be aimed towards monitoring and assessing trends in the performance of a particular system or managing utility with additional care taken when undertaking benchmarking between utilities, as the IWA has confirmed in several publications on water loss indicators (Alegre *et al.*, 2000).

3.4.1 Financial Indicators

The economic-financial performance indicators for NRW can be expressed in terms of volume, percentage or value, of which the latter is considered the unit of greatest relevance and representativity as a measure.

Unbilled authorized consumption and apparent losses must be evaluated according to the water selling price, since they represent the volume of water that would otherwise be delivered to the consumer. The actual losses may in turn be evaluated based on the average cost of water production or purchase price of treated water and imported, if the water was purchased from another management company. Therefore:

€ Non-Revenue Water = (Volume of Unbilled Authorized Consumption + Volume Apparent Losses) Sale Price * Volume of Real Losses + * Average Cost of Production

Financial indicators should be used by managers to identify the largest financial losses in the system, such as the lack of revenue from sales or excessive costs in water production and distribution in order to identify priority actions for improving cash-flow of the utility.

3.4.2 Real Losses indicators

At first sight, the most immediate indicator of performance for system water losses arise from the relationship between the volume of real losses and the total volume of water entering the system. However, this ratio does not consider network length or service connection density, or average system operating pressure values that all influence network behaviour and burst frequency. Considering just the specificities of different supply systems will enable a consistent comparison between networks of different characteristics.

In order to try to take into account network characteristics in determining performance indicators and seeking to remedy the limitations of indicators that consider only water volumes, the IWA Water Loss Task Force developed the ILI - Infrastructure Leakage Index (Lambert, 2003). This infrastructure losses indicator intended to measure utility efficiency as regards management of real losses against the pressure regime in which it operates, hence ILI is based on components that allow calculation of the comparison of actual losses between networks of different dimensions and structures. Thus, the indicator intends to relate the present value of system annual real losses against an estimate of inevitable losses, considering the five factors with the greatest impact: network length, number of service connections, average operating pressure, meter location and continuity of supply.

The indicator associated with the actual losses understandably used most commonly is the unavoidable annual real losses. This indicator, UARL - Unavoidable Annual Real Losses, accounts for actual losses inherent in the system infrastructure (Lambert, 2009).

UARL (litres / service connection / hour) = [18 x (Lm / Nc) + 0.8 + 25 x Lp] x Pmed / 24

where:

Lm – network length (km);
Nc – number of service connections;
Lp – average underground service connections length (km);
Pmed – average operating pressure in the study area (m).

Thus, the actual losses will be higher in situations of higher pressure and being unable to reduce pressure conditions in the system, the minimum losses value can only be reduced with an investment effort above the gains to be achieved. The expression above presented results from a statistical analysis from international data that includes twenty-seven water supply systems in twenty countries. The UARL can be applied to networks with an average operating pressure between 20 and 100 m, a service connection density of between 10 and 120 connections per km of network and meters for clients on service connections with medium length of up to 30 m.

In networks with a low density of service connections, usually rural areas with less than 20 service connections per km of mains, it is more appropriate to express the indicators of losses in terms of length of mains, rather than relating them with the number of service connections or consumption locations.

The coefficients for the three infrastructure variables used in the UARL equation, shown on the previous page, are calculated using a leakage component analysis model (Background and Bursts) with 24 additional parameters for frequencies, flow rates and durations of different types of leaks (background, reported, unreported), using auditable values and assumptions (Lambert et al, 1999).

- Leakage in mains: 18 l / (km of mains / day / m of pressure)
- Leakage in service connections, mains to property boundary, if meters are located at or close to the edge of the street: 0.8 l / (service connection / day / m of pressure)
- Leakage in underground service connections, if meter located after the edge of the street: 25 l / (km of underground service connections / day / m of pressure).

The ratio of the Current Annual Real Losses (CARL) value to the UARL represents the maximum potential reduction of real losses when the system is pressurized. The relationship between CARL and UARL using the aforementioned ILI indicator is a dimensionless index indicative of the general condition of infrastructure under the pressure regime to which it is subject.

ILI = CARL / UARL

In developed countries, well managed systems and in excellent condition should be close to an ILI of 1 while higher values indicate older systems with infrastructure deficiencies. A value of ILI of below 2 means that a greater reduction of losses is not economically viable. ILI values above 8 may not be indicative of a utility with very inadequate resources, poor system conditions and maintenance and where the implementation of a water loss reduction program is imperative. For developing countries, the values of ILI are doubled (Lambert, 2009).

The ILI is intended to allow comparison of network performance, based on their physical characteristics and pressures, reflecting the degree of management efficiency in terms of infrastructure. This is a purely technical indicator and does not consider economic factors, but it can be applied to international comparisons if the number of service connections is greater than 3.000 and the average pressure over 25 m. (Lambert, 2009).

The indicator results from an auditable component based analysis and should be used with caution. It depends in the first instance, on estimating the amount of real losses and also estimation of the average service connection length, the latter being very difficult to obtain given the varying infrastructure and buildings normally existing in the network.

3.4.3 Apparent Losses Indicators

As mentioned previously, apparent losses are the sum of the volumes lost by errors in metering used for billing clients with unauthorized consumption (illicit consumption) and obviously not invoiced. There is currently no accurate method to calculate apparent losses values, but there are recommendations to estimate indicators for this type of loss.

One of the recommendations to estimate the volume of losses originating from meter errors is the application of the results of metrological tests performed on meters removed from the distribution network using the total volume of water measured and billed. Based on tests conducted on calibrated meter test banks it is possible to estimate measurement errors associated with client meters installed. These systematic tests assume that a representative sample of meters installed in the network need to be removed after several years of service, with the selection being determined by the measurement error meter type, calibre, make, model and age. This is a result which can be positive or negative, which is then applied to the measured volume of water and charged, resulting in a value corresponding to the metering error value of the water balance.

In turn, there is no agreed methodology for determining the portion concerning unauthorized, although the best recommendation advises that calculation of the difference between the total volume of apparent losses consumption less the estimated value associated with measurement errors or billing.

Figure 3.9 outlines metering errors obtained in laboratory tests from a sample of DN15 volumetric type meters after different periods of service. As can be seen, it is clear that this type of meters are usually affected by under-metering errors that worsen over time, a fact that is reflected in economic losses for the utility and falsely elevated real loss values.

However, in either case, it is suggested by the IWA, in the Performance Indicators for Water Supply Services report (2000), that the values of apparent losses and their respective components are always presented through the ratio of volume loss per service connection per year in order to maintain compatibility with the indicators and units used for ascertaining real losses.

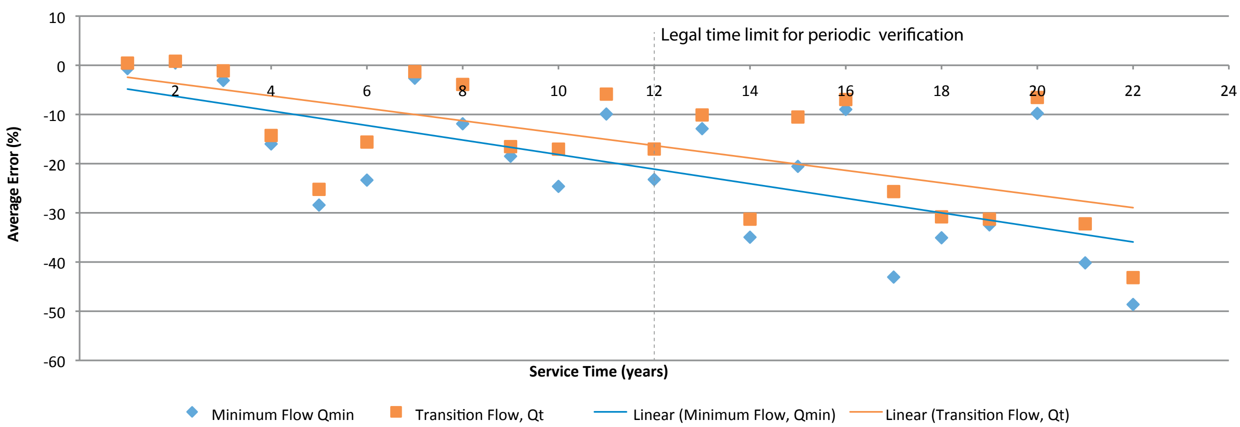


Figure 3.9 **Graph of measurement errors of meters removed from service**

4. Strategies for control and reduction of real water losses

4.1 General Considerations

In chapter 2, a number of assumptions regarding the importance of a strategy for water loss control were clarified. From the perspective of operators, one of the basic issues to consider in developing this strategy consists of evaluating the potential gains from its implementation. In this case, the balance will be between the costs arising from water losses in the system and the benefits that will result from this strategy.

To proceed with the implementation of a strategy to combat losses, it is essential to take into account the specific circumstances of the utility. Thus, a prior diagnosis is necessary to determine the starting point, which should ensure information collection about the supply network, the way in which it is operated and definition of feasible solutions, given financial constraints, the type of existing infrastructure, levels of experience and degree of knowledge of available personnel, technology available as well as social, cultural and political influences.

Thus, before establishing a plan it is suggested that an initial diagnosis should be performed to characterize and detail the initial starting point.Utilities operating successful public services around the globe have adopted simple strategies based on four key actions (Figure 4.1).

Actions aimed at reducing overall operational costs, protect water resources and set priorities in investment requires the development of a proactive approach in detecting water losses. Any implementation of this strategy should be supported, managed and constantly reviewed by a dedicated team and any utility should take into consideration the following aspects:

- Identify internal stakeholders within the business you have interest in NRW, noting that the NRW team must not be a separate department in isolation, but should reflect the whole business's intent to economically conserve water;
- Establish policies to support water loss management;
- Develop an integrated policy for consumption monitoring;
- Calculate the Economic Level of Leakage (ELL), establish and monitor the set level;

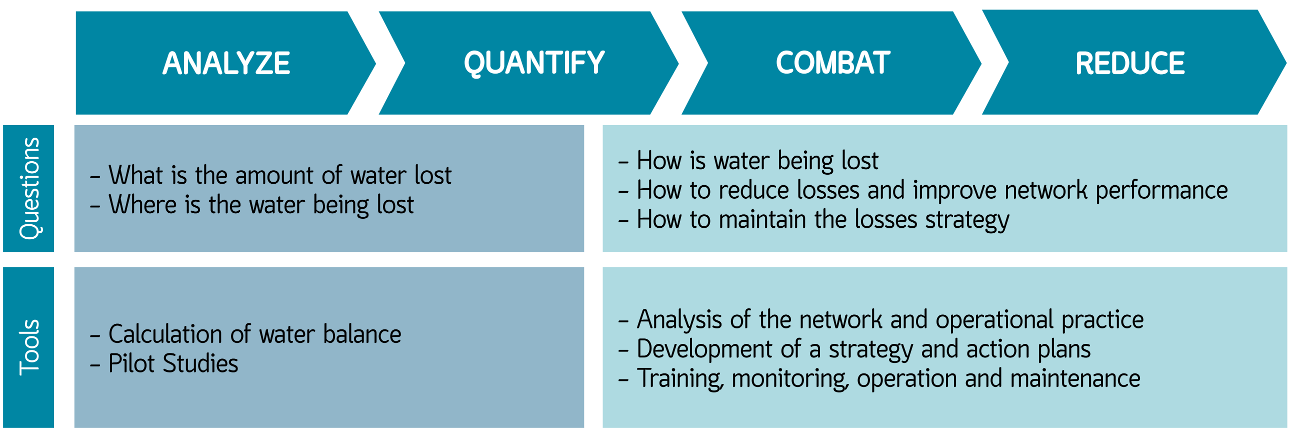


Figure 4.1 **Essential actions in a water loss reduction strategy**

- Provide estimates for loss detection targets, repairs and network renovation;
- Training technicians to perform detection work.

Adoption of a passive approach strategy can be considered as a limited action plan, provided only when solving actual problems, or on the other hand, an pro-active approach acts on a regular inspection or even continuous monitoring of system behaviour, allowing deployment of problem resolution actions at an early stage.

The choice of the approach to be taken by the utility depends intrinsically on their systems and financial capacity as well as determinants on service level aspects, including network pressure, burst frequency, level of background leakage, leak identification and location times plus the stipulated time for repair. A utility adopting a passive control approach to losses provides only a reaction to the reported bursts, usually by clients, or lack of supply capacity, identified by insufficient pressure in the network. Although this approach may have a significant impact given the potential waste of resource, it may be considered sufficient in systems in regions without major limitations of water resources, with adequate treatment capacity of water and low marginal costs. Other situations for which the passive approach can be justified relate to:

- Reduced operating costs, in particular as regards the purchase of water from external entities, either as a result of reduced quantity, or low unit price;
- Low operating costs plus capital costs deferred when water is saved being sufficient to defer capital investment, as in the case of works for new sources or pumping stations;
- Low price charged to client where water saved can be sold, being typical of systems with water shortages.

It must however be noted that a passive approach loss control cannot, in general, attain desirable levels of efficiency, particularly in terms of water losses, except for a limited period of time in new systems built from scratch using appropriate and quality projects and materials.

In any case, given the benefits it offers, it is recommended to adopt an active approach to control water losses, identifying two basic approaches for the same co-exist in the management of a supply system:

a) Regular inspection

With this method, leakage detection works applied progressively over the entire water supply system, may use one or more of the following techniques:

- Surveillance of network design so as to readily identify visible leaks and damaged caused by third parties that could conflict with the infrastructure;
- Systematically undertaken listening interventions on network accessories such as valves, discharge points and hydrants, in order to discover potentially leaks;
- Use mobile meters to temporarily measure flow in defined areas in order to locate high night flow rates;
- Use groups of fixed or temporary acoustic noise loggers.

b) Pro-Active network monitoring and control of losses

This method is preferably adopted by leading water utilities with high financial control and environmental liability, based on the network sectorisation in different supply areas and monitoring night flows normally associated with network losses. In these areas, DMAs, the rate of supply leakage is permanently measured, thus guaranteeing identification of potential leakage problems and allowing establishment of leak detection priorities.

A very important benefit arising from the introduction of a proactive approach to control water loss is the reduction of the average time for locating leaks, thus enabling rapid problem resolution, namely repair of unreported leaks. Thus, it is clear that a proactive approach in combating losses, which adopts a permanent monitoring strategy, may be more successful because it allows problem resolution at an earlier stage in its life cycle.

One of the main tasks of a water losses control plan is installation of new infrastructure, procedures and even new attitudes. The development of a strategy for NRW reduction implies the ability to assess the current situation accurately, being necessary to obtain precise level of flow measurement and client data. This strategy must be supported and have direct support from the highest levels in the utility through enabling policies and provision of adequate resources and training.

Alternatively, implementation of a water losses control strategy should be considered a long term goal, aimed at reaching the ELL as defined by the operator. When this loss level is reached, data related to the water balance must be constantly monitored to ensure that it is maintained.

4.2 Economic Level of Leakage (ELL)

4.2.1 Concept

A utility is considered to have reached the Economic Level of Leakage (ELL) when the sum of the cost of water lost in the supply system and the cost of active leakage control activities undertaken reaches a minimum. In this way, a limit on loss reduction investment is defined, after which it is no longer economically feasible to exceed the cost of water production. This notion applies to real and apparent losses, whilst ELL is achieved only when their economic levels occur simultaneously.

Figure 4.2 shows, in simplified form, the ELL concept in terms of total cost in relation to the level of losses. With increased level of losses, the cost of lost water increases linearly. Moreover, the cost of active leakage control decreases with increasing levels of allowed losses. There is an optimal level of total system operating costs where the marginal cost of leak detection activities is equal to the marginal cost of water. This point also allows identification of the economic level of resources to be allocated to leakage control.

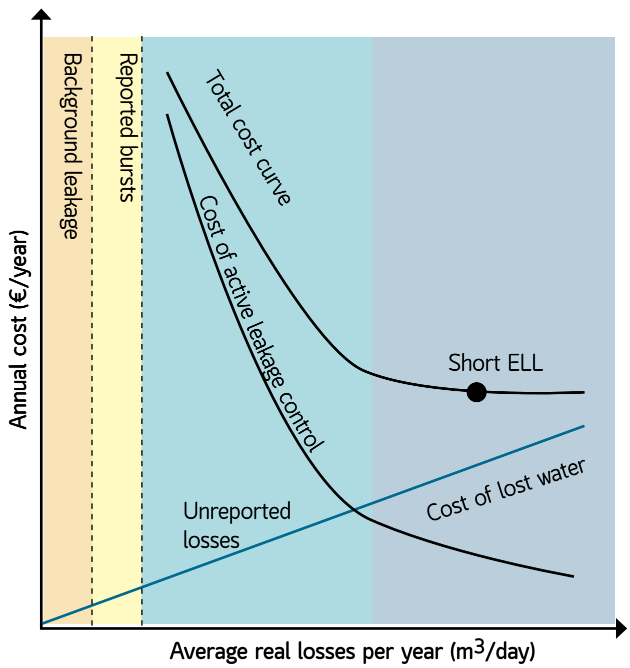


Figure 4.2 Principal factors of reducing losses

As mentioned above, water losses are impossible to eliminate completely so will always be a portion that must be tolerated, leading to the need for calculating a level of sustainable economic losses, thus being a key factor for determining the objectives of a water losses control strategy.

4.2.2 ELL Calculation Constraints

There is currently a lot of information about methods for ELL determination. The value of this indicator for a utility varies over time and depends on the burst rate, speed and quality of repairs, state of network assets and efforts made by the utility as regards active leakage control , particularly in investment in pressure management and implementing monitoring and control systems. It is therefore recommended that ELL calculation must be reassessed anually.

To ensure reliability in calculating and defining the basic goals for a water loss control strategy, an accurate characterization of the supply system, based on validated information and identification of all dynamic influences on the system is required. It is important to establish procedures for the collection of this base information, which is divided into three distinct categories: operational, tactical and strategic.

Operational information

- Level of losses;
- Network Pressure;
- Regulation of existing pressure reducing valves (PRV);
- Records of number, location and type of bursts found;
- Time utilised for active leakage control;
- Water consumption by industry.

Tactical Information

- Supply zones limits;
- Points of supply or transfer points of each system;
- Existing metering equipment for water balance assessment;
- PRV type installed in pressure controlled areas;
- Maintenance records;
- Existing assets.

Strategic Information

- Average flow rates for the distribution;
- Calculations for the water balance;
- Undertake and analyse results of pilot studies;
- Database of events in the network;
- Databases of clients and their measured or estimated consumption;
- Personnel and equipment involved in the active control of losses.

The ability to gather all this information in order to undertake a credible water balance calculation can imply a high level of development of the organization. Based on this information, practicable indicators can be calculated to define action priorities for setting desired losses levels and action or investment alternative scenarios, all of which fits within the ELL. In addition, these indicators are calculated by successive repetitions until they may be considered as reliable values.

4.2.3 Characterisation of Real Losses ELL

To be able to understand the estimated ELL value, it is necessary to examine how water is valued, this being a specific calculation for each region, or even being able to differentiate between different areas of the same supply system. ELL calculation can observe two distinct forms:

a) Short-term ELL (stELL)

This considers only the marginal cost of detection and repair of actual losses. For example, the cost of active leakage control, in relation to the marginal benefits of water which is no longer lost in leaks and overflows, establishing an optimal balance point. It may still be considered in analysing pressure management actions, mains condition or other operations not involving significant investments in the medium or long term. In the short term, it is stressed that the equilibrium between the marginal cost of active leakage control must be aligned with the marginal cost of water lost through leakage, noting that the value of water lost in the network will be higher than the marginal cost of production.

b) Long-Term ELL (ltELL)

This considers the impacts that certain investment needs have on the ELL calculation, such as expansion or construction of infrastructure (new extraction points or mains, etc.) or investments in creating permanent DMA. Thus, it is also possible to balance investment costs with those of increased work to reducing losses. Investments should consider the following questions:

- What is the current level of leakage?
- What is the short-term ELL?
- How ELL varies depending on short-term investments?
- How much lost water can be recovered, or a possible change in the active loss control policy, when compared with existing company policies?
- What is the cost of the proposed investment?
- What is the return on investment?

The answer to these questions will allow the utility manager to decide on its investment policy.

4.3 Factors to define water loss control strategy

The implementation of any water loss control strategy is conditioned from the outset by external and internal factors to the utility itself. Regulatory policies defined for the water sector in each country legally oblige organizations to achieve certain efficiency goals, or to include funds in their operating budgets earmarked for investments in combating water losses. Moreover, the organizational structure and utility culture, expertise of its professionals, but mostly, the financial balance of these organizations, unequivocally determines implementing policies and strategies to control losses.

No single standard solution exists, which is applicable to all utilities, hence each company must analyze the external and internal constraints to which it is subject, thus defining a suitable technical and economic level of leakage, position to achieve in the market, as well as strategies to be adopted to combat water losses. In this context, it is important that each entity undertakes a cost-benefit analysis of the financial burden associated with the implementation of various measures to combat losses before taking a decision to implement any strategy. The result of this analysis will influence identification of the level of losses to achieve and will directly dictate the level of investment made in a control strategy for combating water losses.

Given the above, it is apparent that water utilities that have a higher purchase or production cost per cubic metre of water are those that should adopt more proactive strategies to combat losses. These companies structure their operational plans in order to work actively and continuously to fully combat losses, through development of active leakage control measure, pressure management, application of high quality materials in distribution networks or through timely repair of detected bursts. The level of apparent losses can be controlled by use of higher standard meters, application of a rigorous plan for preventive meter replacement, control of supply points with zero consumption or service connections without clients associated. These companies can easily recover investments in combating water losses, including observing significant financial gains from the implementation of a proactive strategy.

There are, however, utilities where the cost-benefit ratio is not as advantageous, but where some investments in water loss control can still be justified. In such cases, more reactive water loss strategies should be adopted, simply intervening when problems occur. Although not taking active control measures, leakage detection teams have to intervene when required, particularly when there are leaks on private property and the source of the problem cannot be identified without resorting to these teams. In parallel, implementation of measures leading to preventative meter replacement but without major concerns with as regards to the rigorous execution of plans for preventive replacement of meters or use of higher quality meters.

At the opposite extreme are utilities with significant disadvantages and where investments in water loss control far exceed the benefit-cost ratios achieved by the implementation of these measures. These companies have no worries about the timely repair of visible leaks or leak detection teams in the organization. The utility itself does not have the implementation of policies to combat losses as a priority or even a strategy defined for this purpose. This type of loss control strategy or lack of one should not be objectionable and may even be admissible in very specific situations. Examples are utilities operating in world heritage cities, where a burst repair intervention can cost values far above average, or involve participation of numerous environmental and archaeological organizations. In these cases, water loss interventions are justified only in situations where the water supply to the population may be jeopardized or service quality is significantly affected.

Utilities may also exist where adoption of mixed strategies is undertaken, adapting their approach depending on the cost-benefit of each supply subsystem or on the influence imposed by their clients. In certain areas of the world there is commonly a scarcity of water in warmer periods of the year, forcing managers to restrict supply at certain times of day. In these periods clients impose greater pressure on utilities because they are more sensitive to efficient water use and less receptive to resource wastage. In order to convey an image of real concern, utilities tend to repair bursts faster, or even to place restrictions on water uses considered lower priority, such as irrigation of green spaces.

It is obvious that in the calculation of cost-effectiveness there are certain factors which are under-valued, yielding significant differences in results obtained by different operators, in particular, those relating to the impact on corporate image in the market, environmental issues or ecological footprint.

In parallel, the rules or goals imposed by regulators may also influence the choice of strategies to be adopted by utilities entities in controlling losses. Regulators with only recommended action do not introduce large pressure on companies but additionally they may have punitive powers to do so. In some countries in Europe, utilities may be punished financially if they do not reach certain efficiency goals or they do not invest a certain percentage of the annual budget in control measures to combat losses. However, in countries where regulation is more comprehensive, where it assumes a greater impact on business, the price of cubic metre of water is also higher, leading utilities to adopt measures based on cost-benefit analysis.

Each company must therefore adopt a strategy for water loss control that most suits their actual reality and bring a better quality of service to its clients. The optimal strategy should be that required to achieve the Suitable Level of Leakage and additionally, provide greater added value for all stakeholders and organizational value.

5. Monitoring and Control of Leakage

5.1 Minimum Requirements

The adoption of a supply system monitoring policy to control losses considers sectorisation into DMAs. To this end, it becomes imperative to consider a series of conditions and actions to be implemented in the network that require the prior profound network knowledge, namely on characteristics and operation. The implementation, without jeopardizing the quantity and quality of water supply, of a monitoring system aimed towards active leakage control, requires the existence of some basic tools, namely:

Geographic Information System (GIS) – computer application to visualise all infrastructure, which are geo-referenced and which must be updated regularly and also include terrain mapping representation;

Client Management Information System – IT system that compiles all client information and is interconnected with the GIS;

Digital Terrain Model – a set of numerical data support that associates any point with its elevation value;

Hydraulic System Model – a software tool that allows analysis and prediction of the system hydraulic behaviour, from the characteristics of its components, mode of operation and required inputs.

These tools, whilst not being essential to monitoring system implementation, are very important for the quality of results and overall optimization of the monitoring system and water losses control, maximizing their results and speed at which they can be obtained by enhancing process efficiency.

5.1.1 Geographic Information System (GIS)

A Geographic Information System (GIS) is a computer application for spatial information and computational procedures that enables and facilitates analysis, management and representation of an area and events which occur in it.

The GIS separates information on different thematic layers and stores them independently, allowing quick and easy manipulation. It thus provides the user with the ability to relate information from the existing position and topology of network features, in order to generate new information.

When applied to a water utility, GIS adds information (attributes) regarding the supply system infrastructure, including both its correct geographical location and physical/non-physical characteristics. This application requires constant maintenance for updating information.

In general, basic and essential information in the water utility registration includes the following attributes:

- **Mains** – year of installation, material, diameter, length and working order;
- **Pumping Groups** – year of installation, capacity curves and working order;
- **Valves** – year of installation, diameter, type and condition of operation;
- **Reservoirs** – year of installation, type and height, minimum and maximum level, maximum volume and working order;
- **Service connections** – association with clients, year of installation, material, diameter, length and operating status;
- **Flow meters** – year of installation, diameter, type and condition of operation;
- **Location and characterization of hydrants,** air vents, discharge valves and other network elements;

- **DMA boundaries** (virtual polygons that delimit DMAs, which should intercept flow meters and all boundary valves) – DMA Code and name and implementation date.

Indexed with all this information, it becomes possible to visualize the spatial scope of the network sectorisation project, including the DMA set-up master plan.

5.1.2 Client Information Management System

Client management and the relationship between those who serve and those who are served is one of the most strategic activities for any company. The definition of the core mission of a company is proof that it is usually focused on the client and service to them. In the case of operators, the mission must ensure that the water supply to the population is in sufficient quantity, quality and at the lowest cost. The relationship between the client and utility should therefore be regarded with the utmost importance and must be sustained and supported by an information system to help businesses better serve their clients.

A Client Information Management System (CIMS) must have the ability to be able to systematize a vast and diverse set of data, creating binding interfaces between them, so as to provide users with treated information, inherent in different areas of the utility. (Figure 5.1).

Figure 5.1 **CIMS Interfaces**

The CIMS must encompass four predominant for water loss areas, principally for apparent losses:

- the first relates to the physical register and correct association of service connections to existing clients – noting that it is important that managers have thorough knowledge of the location of its clients and service connections that supply them. This enables utilities to scale DMAs with greater accuracy, as well as enables the correct calculation of inevitable losses and authorized consumption, when seeking to determine volumes of recoverable losses in each of these areas. Additionally, proper registration of clients on CIMS allows illegal connections and theft of water to be identified with greater ease and speed, which will help increase the company's efficiency and loss reduction;

- the second area concerns meter management - the proper management of metering equipment used for charging clients for the correct volume of water supplied is a key element to control small values of apparent losses. The CIMS should manage the meter installation date, as well as the volume of water measured, prompting the need for preventive replacement of metering equipment, based on the criteria in Measurement Instrument Directive (MID) or the legal requirements for each country. The timely replacement of meters will significantly decrease the amount of water lost by under metering, increasing business efficiency. In parallel, information systems must also allow managers to identify the correct type of installation at each client meter location, facilitating association of consumption of each client to the correct meter profile curve;

- the third is related to reading and billing of amounts supplied where utilities should include the need for accurate billing of water volumes supplied in its business relationship, avoiding the use of estimates. Consumption estimates are, however, acceptable when associated with seasonally adjusted billing, based on actual meter readings when effected. Prior knowledge of the physical record of each consumption location and the use of appropriate meters, allows utilities to read all consumption points, avoiding even potential errors in meter readings or missing information. Alternatively, the existence of meter readings and billing modules in CIMS allows utilities to easily identify stopped meters and act accordingly to quickly resolve such occurrences;

- the fourth and final area concerns reporting and management indicators where the CIMS should make a set of reports and indicators available to managers as a basis for decision-making within each company. These reports should be structured based on the variables under analysis and can be customized by each user in order to allow more detailed analysis. For the management of such losses, reports of sites with zero consumption, without a client associated or reports of meters installed for over X years should be generated.

Use of a high performance CIMS can also enhance the company's image with its clients, conveying the appearance of organizational efficiency, which can lead to less unlawful behaviour by some clients as well as a decrease in water theft. It is thus evident that the use of an information system for client management is a leading tool for managing losses in a utility, including having a direct impact on the financial sustainability of the business and client service levels.

5.1.3 Digital Terrain Model

Digital Terrain Model (DTM) is a digital data support that, for a given area, allows the user to associate any point with its corresponding elevation value. Thus, a DTM can be represented in a two-dimensional or three-dimensional shape, in particular through a set of points or lines through an associated interpolation rule, or as is more commonly regarded, as a surface composed of cells arranged in a regular three-dimensional space .

Thus, it is possible to establish an association between existing entities in a GIS register and its digital terrain model, enabling spatial analysis on the altimetric information, with all the advantages in setting differentiated altimetric zones.

5.1.4 Water System Hydraulic Model

Water supply system hydraulic models are software tools which, with a margin of error, allow the analysis and prediction of the system hydraulic behaviour, from the characteristics of its components, mode of operation and required inputs. These models thus allow fast and efficient performance of sensitivity analysis and simulation of alternative scenarios, with sufficient approximation, without the need to intervene in the system concerned or risks associated with implementation of unknown modes of operation.

Typically, simulation models are computational tools used in the design and diagnosis of bulk water transport and water distribution systems at an operational level. However, they are increasingly being developed and applied by utilities with a view to making more informed decision on various less common operating situations.

The system behaviour simulation can be used to predict its response compared to extended operating ranges and environmental conditions, and thus anticipate a set of solutions before investments are undertaken.

Generally, a model for simulation of a hydraulic water supply system comprises of:

- a set of descriptive data on the system physical characteristics, their consumption and operating conditions;
- a set of mathematical equations that reproduce the hydraulic behaviour of individual components and the system as a whole, expressed in terms of key state variables, such as flow or pressure in the mains;
- numerical algorithms required for iterative solving of mathematical equations.

A model can be formulated and solved entirely manually, without recourse to computational applications. However, given the complexity and inherent slowness of calculations, it was with software implementation that models of this type have come to be a viable and useful tool for effective system simulation in a broad range of operating conditions.

Infrastructure description in the model is limited to topology and associated modelling parameters, but all information available in a GIS is not necessary. However, the existence of a GIS in a utility allows the creation of simulation models much faster, since a substantial part of the information required for modelling can be exported directly from the GIS.

In addition to describing the physical system, a simulation program enables the user to build a detailed description of water consumption and modes of operation, including any conditions imposed by reservoir levels and/or links to other systems.

Armed with this information, the software simulation offers the possibility to calculate the system hydraulic balance, expressing in numerical and graphical form, values of the state variables, such as:

- pressure and piezometric head at any points of the network, including water levels in reservoirs;
- flow rate, pressure drop and flow rate in pipes, valves and pumps;
- state of opening, closing of regulating valves and pumps.

Simulation models have multiple applications as regards planning, design, operation, maintenance and rehabilitation of bulk transport and water distribution systems, amongst can be highlighted:

- sizing of systems, by searching the best topology, diameters and materials selection for the pipes and other components and design of reservoirs and pumping facilities;

- supporting preparation of strategic development plans, using simulation of various options, essentially based on projections in time and especially consumption;

- simulation of problems and current operating scenarios, such as seasonal consumption variations, system management levels with multiple service reservoirs, or emergency situations such as failures in pumping groups, mains suspension or firefighting;

- operator training for complex operational systems, preventing incurring direct risks to the system and clients;

- managing rehabilitation of suspended systems and programming assistance with minimized client impact;

- reduction of energy consumption resulting from the operation of pumping stations;

- support for networks sectorisation, feasibility and impact of DMA creation;

- control of water losses, for example by service pressure reduction programs.

5.2 Flow Measurement

The monitoring and control of losses require rigorous flow measurement, hence the proper selection and installation of meters to be installed in each monitoring location is of great importance. In planning a water loss control strategy, the first premise to consider is the correct measurement, depending on which the tasks of qualification, identification and subsequent correction can be developed.

The most common scheme for monitoring any water system seeking to locate potential leakage is based on flow meters or water meters located throughout the system, from the source, through WTW outflows, reservoirs, DMA inputs and consumption by large clients.

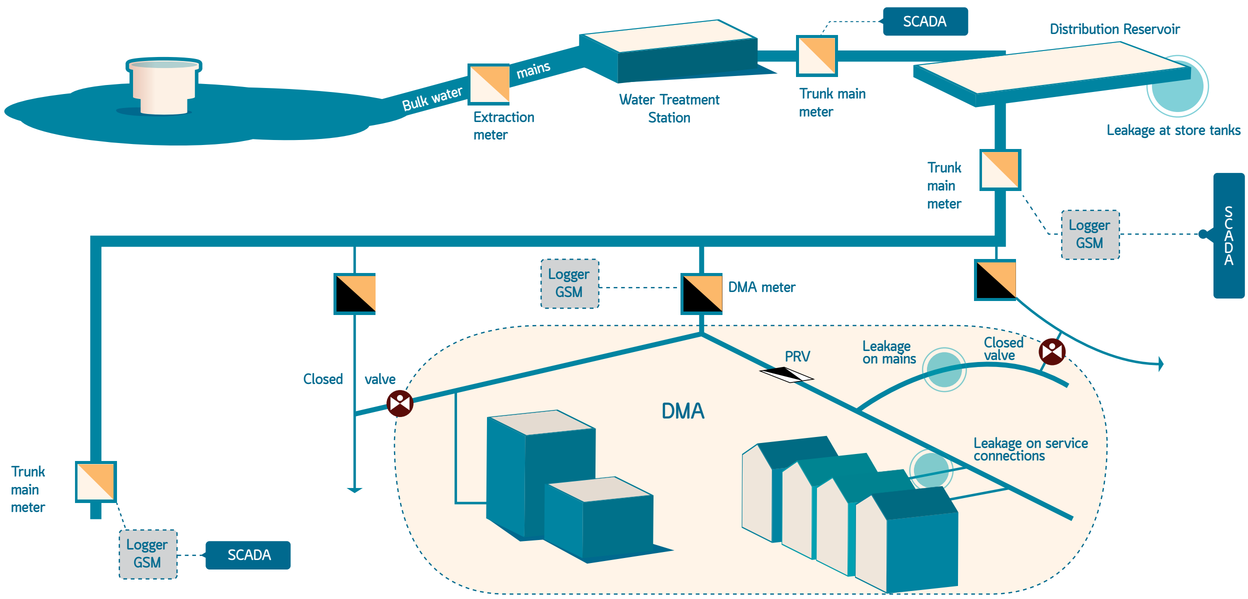


Figure 5.2 **Water supply system monitoring schematic**

Figure 5.2 presents a simplified diagram of water supply system monitoring, which are identified where water meters are typically installed.

High levels of meter accuracy and reliability is essential in supply systems, playing a key role in network management and the company's assets. Performed continuously, metering provides reliable information on the volumes of water entering, leaving and that are consumed in supply systems, being central to effective and efficient monitoring and evaluation of system losses. The availability of metered values and confidence in them are essential to the water balance calculation, allowing consideration of values actually read instead of resorting to estimates. This logic is fundamental:

a) At the DMA level

Accurate measurement of night flows in supply areas is essential to identify the emergence of new leaks, which can be quickly located and repaired, regardless of the existence of customer metering, as well as for the accurate detremination of the ELL for each DMA.

b) At the customer level

The main challenge faced by water distribution system managers is the ability to operate on a sound financial basis. As a significant part of turnover is based on customer consumption values, most businesses depend on their consumption metering to determine the amount to charge for water supplied. Therefore, it is essential that metering is the most accurate possible, within technically and economically feasible limits. In addition, it is common to find large clients that may represent significant influence on the mean DMA flow rate, so it is very important that they are specifically examined to allow consideration in the analysis and balance of these DMAs.

As such, it is clear that flow or water meter instrumentation is seen as a key piece for any utility, namely for its sustainability and self-confidence in the volumes of water that it reports at different process levels.

Flow meters are the basis for correct customer billing and for evaluation and monitoring of overall system performance, as well as a sectoring strategy, particularly when associated with DMA implementation. The correct selection and field application suitability, together with a proper installation are key conditions for good performance of the meters.

Equipment to be used in water measurement should be specified in accordance with the scope and level of rigor established either by legislation or by the company itself. Among the different equipment available, two types of solutions are frequently used in water measurement, which differ in technological terms and the principles underpinning its operation: namely mechanical, ultrasonic and electromagnetic flowmeters.

Consumption by domestic, commercial, industrial clients and public entities are measured, in general, for water meters whose operation is based on mechanical principles. Meters applied in network monitoring or DMA can also be based on these principles.

A mechanical water meter is a measuring instrument that incorporates a totalizer and allows continuous determination of the volume of water flowing inside. This measurement can be performed by direct mechanical means (volumetric meter) or indirect (speed meter).

The volumetric meter directly measures the volume of water passing through it, by counting the number of revolutions of the piston, moved by flow action passing through a chamber. The volume registered by the counter corresponds to the number of times the chamber with movable interior walls and whose volume is known, fills and empties of the water passing through the meter.

The velocity meter, as its name indicates, indirectly measures the volume of water that passes through it by relating it to the airflow velocity. It consists of a rotating element sensitive to this velocity, by mechanical or other means and converts the volume passing through in a given time interval. According to its construction, there are three types of velocity mechanic meters: single-jet turbine, multi-jet turbine and Woltmann. The primary element of the first meter type has flat turbine vanes mounted perpendicular to the flow direction, which is caused to rotate by being on the periphery of a single jet of water. The second type differs from the previous type, in the number of water jets which decomposes the flow passing the turbine with multiple contact points on its periphery. The last type of meter is equipped with a propeller driven by the flow. The propeller shaft may be arranged parallel or perpendicular to the axis of the main and the meter designated as a horizontal or vertical Woltmann type.

Figure 5.3 illustrates the differing elements of the various types of volumetric and velocity meters, previously describe.

Flowmeter Type		Differing elements	
VOLUMETRIC			
VELOCITY	TURBINE	SINGLE-JET	
		MULTI-JET	
	WOLTMANN	VERTICAL	
		HORIZONTAL	

Figure 5.3 Differing elements of the various types of volumetric and velocity meters

During the operation lifespans, volumetric meters present reasonable accuracy and very high sensitivity due to the type and design of the respective measuring element, which means that the volume of water passing through it is correctly counted, with the exception of a residual low level flow through the rotating and fixed elements which are necessary for clearance between the moving and stationary parts (Figure 5.4).

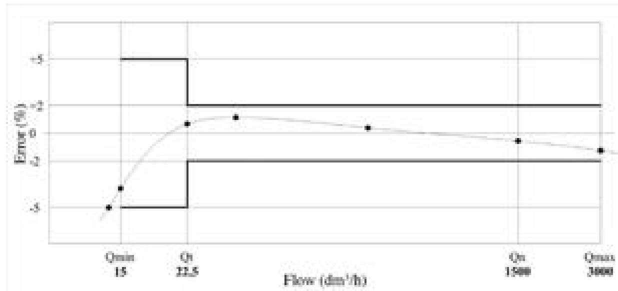


Figure 5.4 Error curve characteristics of a 1,5 m^3 nominal flow volumetric meter (DN15), Class C

Such meters are commonly applied in metering of domestic consumption or other small scale consumption, with more accuracy than velocity meters, since they directly measure the volume. However, the tight tolerance inherent in the design of the plunger makes them more susceptible to mechanical component wear and blocking due to the possible presence of sand and particles carried by the water.

The turbine velocity meters can be as accurate as the volumetric meters, but diverge rapidly throughout their use when compared with measuring quality parameters of their initial state. It is therefore generally admitted that the performance of this type of meter is less than the volumetric meters due to the lower sensitivity and high degradation of its components.

It is well known that impurities such as sand or air can enter the network and cause problems for the normal operation of mechanical water meters. Over many years, meter manufacturers have developed techniques to deal with damage caused by these impurities, but it has been proven that during the period of operation of these meters that they lose accuracy beyond acceptable limits, requiring a regular replacement cycle, usually of about seven years.

An additional problem that occurs with mechanical meters is converting the readings into electronic data signals required for automatic meter reading systems. Again, manufacturers have developed methods to do so, but they all require some form of electromechanical system which wears out with time and is subject to mechanical failure.

One of the most common limitations associated with mechanic meters originates from the fact that they are not compatible with the possibility of measuring bi-directional flow when installed on the network to control DMA inputs and outputs, implying consideration of the use of other types of meters, usually electromagnetic meters.

Electromagnetic flowmeters measure the quantity of water flowing per unit of time inside the chamber, using a working principle based on Faraday's Law. This law relates flow with the electromotive force induced by the flow of water in a perpendicular magnetic field, created from an electrically powered coil (Figure 5.5).

This instrument consists of a primary element or sensor and a secondary element or converter, which converts the instantaneous flow rate of the total volume passing through during the integration time. It is used in clients with large consumption values, such as industrial or municipal clients, whilst its application in monitoring distribution networks is increasingly common. Such meters can be powered by a direct electric supply or through a battery, whose life has been progressively increased with technological developments.

These meters operate within a finite range of flow rates over which the measurement error is made, which although variable should not exceed values considered acceptable for the level of accuracy required. The main source of errors comes from performance featuring the equipment itself. Such errors, after being determined in a calibration laboratory, can be minimized by adjusting the meter. The conditions under which the meter is installed and in operation is another important factor that can significantly affect measurement accuracy, in cases where their installation has not been implemented to recommended standards and reference guides or in compliance with the manufacturer's instructions. In such documentation, the mechanical, hydraulic and electric requirements to be respected for the proper installation of the equipment are defined, as well as the appropriate environmental conditions for operation, particularly with regard to the need to limit climatic, electrical, electromagnetic or mechanical influences.

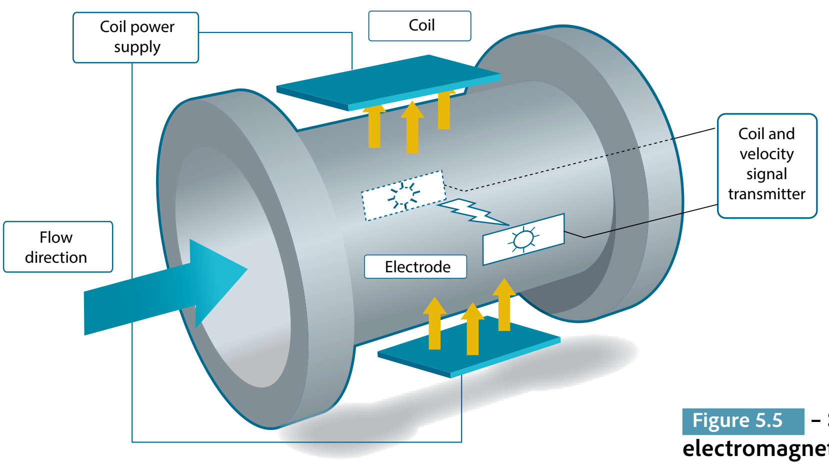


Figure 5.5 – Schematic representation of an electromagnetic flowmeter

Sizing in relation to flow measuring	Choice of technology according to application	Installation according to manufacturer's instructions	Metrological verification plan
Measuring range	Flow direction	Installation position	Determined by law - legal metrology
Permanent or nominal flow	Telemetry	Stabilization Sections	According to the manufacturer's instructions
Permissible measurement errors	Resolution reading		
Maximum discharge or overloading	Water Quality		

Table 5.1 **Relevant aspects for flowmeter selection and installation**

In the meter selection process, each case must be considered, beyond the normal level of accuracy of the consumption profile whose range of flow rates to be measured, installation location constraints, flow direction, suitability of the equipment for telemetry signal broadcast, water quality, construction and metrological equipment characteristics and costs involved.

So for the selection of the most appropriate measurement of certain flows in the supply network instrument, the range of flow rates and the consumption profile to be measured at the installation site must first be diagnosed and according to the hydraulic characteristics of these, the most appropriate technology should be chosen (Table 5.1).

One of the most important stages in meter selection corresponds to the instrument design for measurement over a given range of flow rates of consumption characteristic profile which is to be monitored. In this case it is important that the measurement interval associated with the equipment, characterized by a minimum flow and maximum flow, cover the expected amplitude, especially with regard to the most significant for this type of flow profile, which in systems where the flow rate to be measured can vary significantly and which may require further analysis.

A meter scaled to accurately measure up to a certain minimum flow, can be at risk of under-metering, thus introducing a significant potential apparent loss in flow rates.

Occasionally, installed meters are unnecessarily oversized, as a meter of larger size allows for a higher flow rate of flow without significant pressure loss. This will tend to give rise to meter under-registration, since the meter operates outside its optimal range of lower and upper limits of flow measurement.

These notes highlight the importance of correctly measuring water volumes and flow rates within a strategy of network monitoring and losses control. Thus, utilities who wish to practice this type of strategy should have a consistent policy of water metering to ensure measurement accuracy and performance consistency throughout the different phases of strategy implementation.

5.3 Network Sectorisation and Monitoring

Although the practice of sub-dividing water networks to measure losses has been noted from Roman times, the early years of the 1980s saw the first reported consistent approach to defining District Meter Areas (DMAs), applied in the UK. The idea of network sectorisation for leakage monitoring is based on the implementation of a fully sectored distribution network. In this sense, flow meter installation at strategic points is required, in order to measure flow that entering or exiting a particular area bounded by a permanent border, guaranteed by closing valves. DMA creation permits analysis of measured flow rates, in particular night flow, enabling calculation of leakage level, as well as obtaining the necessary indicators for decision support regarding network interventions. Advances in data transmission technologies associated with flow metering equipment now allow effective monitoring, so justifying the name change from Metering to Monitoring, keeping the acronym DMA.

Therefore, DMAs are a support tool for network management and efficiency improvement as well as water losses from bursts and leaks. Thus early in the DMA sectorisation process, their existence allows utilities to define intervention order according to the worst performance indicators, which with project progress and potential increasing complexity, begin to play a key role for network performance maintenance through the early identification of new leaks and consequent triggering of response actions necessary for their detection and repairs.

This approach is particularly successful when implemented in conjunction with more sophisticated data model analysis, allowing rapid analysis of DMA data, as well as guiding field team activities. This analysis will normally utilise night flow values, and recorded daily flow, being available for future comparisons.

At EPAL, under the distribution network DMA project, a total of 179 electromagnetic flow meters were installed, along with associated with telemetry or SCADA equipment, thus continuously monitoring 152 DMAs in the network

The implementation of a plan for network sectoring, with the aim of leakage monitoring will also result in major improvements in the management and knowledge of the network, in particular regarding:

- **Quantity and quality of information available about the network and its operation**

  Monitoring systems of water supply networks which are not sectorised aim to control the network, to ensure a regular supply to clients and reservoir levels, with an analysis on an overall scale, based on the total area under analysis. The information available, usually through the SCADA system, aims at continuous improvement of processes operating within the distribution system.

  Network sectorisation into smaller monitoring and control areas can increase the amount of information available, given the much broader scope of measurement, making it possible to make a detailed analysis of the network functioning, particularly as regards pressure management, location of hidden faults and their causes and obviously, monitoring of night flows from each DMA.

- **Identification of each DMA client and abnormal nocturnal consumption**

  DMA implementation in a distribution network, bounded by a continuous, well-defined boundary line, enables continuous monitoring of flow entering and leaving the zone and leakage indicators obtained based on flow night. The daily reception of DMA consumption data also allows validation of changes in consumption and macro-location, at a DMA level, of bursts or any valving operations in the network.

- **Evaluation of trunk main DMAs**

  The sectoring of metering zones in bulk transport pipelines on the supply network is usually referred to as Trunk main DMA set-up. These areas differ from distribution network DMAs as they normally feature larger diameter pipes usually above

300 mm and are substantially free of service connections. The water loss evaluation methods and measurement equipment to consider are generally the same as normal DMAs but may however see analysis hampered by the existence of a greater number of measurement points, including either imports or exports to DMAs

- **Management and control of pressure in the water distribution network**

Access to data, both flow and pressure at DMA entrance points in each zone or group of zones monitored, beings an additional level of network knowledge, thus it becomes possible to adjust pressures managed sections of the network and optimize operations. The network pressure level must comply with regulatory requirements for clients, whilst also contributing to burst prevention and minimizing of water losses. This type of analysis may lead to active pressure control in the network, by Pressure Control Valves (PRV) at DMA entrance points or to create smaller DMA sub-sectors (e.g. Trow and Tooms, 2014).

5.4 District Monitoring Areas

5.4.1 Definition of District Monitoring Areas

A District Monitoring Area is defined as a discrete sector of the distribution network, either formed naturally or imposed, which can effectively evaluate the continuous in-flow of supply through flow meters installed at their input and output metering points.

The DMA behaves as a virtual polygon, implemented in the network with its shape and size dependent on the characteristics and design of the network and its topography. Generally, a DMA should meet the following conditions:

- Make use of known point(s) of water in-flow and out-flow, provided with reliable flow measurement;
- Be discrete areas, with perfectly defined and fixed boundaries, not allowing unknown inter-connections or interchange flows with adjacent areas;
- Permit metering interface points with neighbouring DMA, creating bi-directional exchanges or unidirectional cascades to neighbouring zones, provided that the same measurement equipment is installed.

The DMA boundary line is physically defined by closed section valves closed, known as DMA boundary valves in the case of boundaries with adjacent network of the same pressure level or pressure zone boundary valves in the case of the adjacent network being of a differing pressure zone or sub-system. Where no network exists adjacent to the DMA to be implemented and the process does not imply the closing of any valve, this will be referred to as a naturally closed DMA. In addition the flow and pressure is also continuously monitored at the DMA entrance. In cases with active pressure control, in addition to flow meters, pressure-reducing valves (PRV) may also be installed creating pressure controlled zones.

Taking the opportunity to install or replace meters or PRV equipment, the implementation of improvements in the network or other equipment, is advisable:

- Analysis and definition of installation locations for new flowmeters and other equipment (eg PRV, instruments, telemetry) and preparation for telemetry installation;
- Location, diameter and type of flow meters to install, after consultation with technical operation of the network and equipment, taking into account possible future developments;
- Definition of intervention proposals for improving the network and other equipment in order to increase or decrease DMA pressure.

Figure 5.6 illustrates a schematic representation of two contiguous DMA, whose design allowed the possibility of being able to work with the DMA segmented into smaller sub-zones temporarily, which may prove to be very useful for network operations, in particular as regards the effectiveness and speed of identifying problems in the DMA.

5.4.2 DMA Dimension and Size

There are a number of factors that should be considered for the correct sizing of a DMA in a distribution network, including the size and physical characteristics of the area, economic considerations, improved customer service and water quality. In more detail, the design of a DMA should take into account the following areas:

- **Area and geographical density of clients**

  The size of a DMA is expressed by the number of associated clients. It is recommended that a typical DMA, implemented in an urban area should comprise between 1.000-3.000 clients, according to the population density in the supply network, the existence of large clients and constraints imposed by existing supply zones.

Interestingly, despite the IWA advocating the expression of losses in terms of the number of service connections, when it comes to defining water loss minimisation through proper DMA sizing, the IWA advocates use of the number of customer meters instead of the number of service connections. Through the experience gained in managing the Lisbon network, it is considered that the use of the number of customers is appropriate, with recommended good practice indicating that DMAs encompass between 1.500 and 2.500 customers.

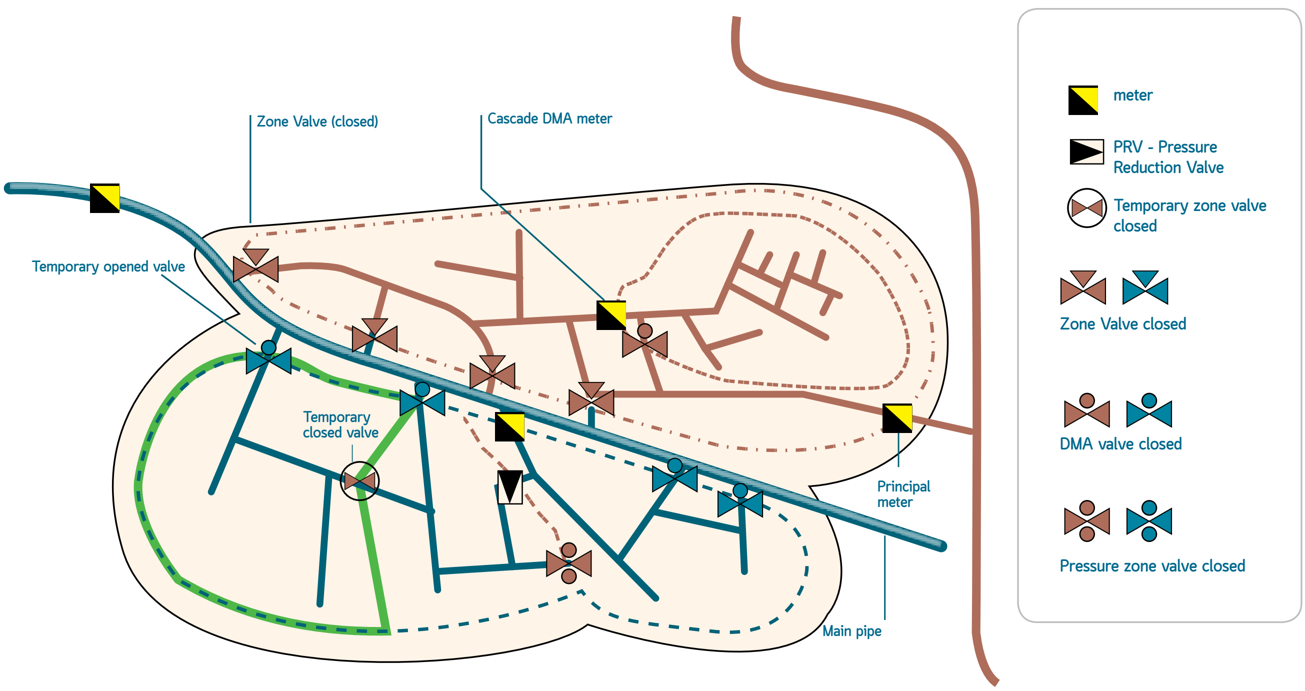


Figure 5.6 **Schematic representation of two contiguous DMAs**

Note that this assists with comparison of DMA performance, given that if the DMAs are of roughly equal size, then it avoids or reduces issues when comparing nightlines, as they should be in the same range.

It should be noted that the term "customer" or "client" refers to an individual entity, business, or public entity that has a water supply agreement or contract with the managing utility. In the case of Lisbon and the overall Portuguese situation in general, with universal metering, each customer has a specific meter, a situation that has no direct correspondence to other cities and countries without universal metering.

In addition to the previously referred to criteria, there are other important factors for defining DMA sizing, such as the total network length - noting that this should not exceed values of the order of 5 to 10 km, with the smaller the extension, then the faster leak detection tends to be - and average daily total DMA consumption, which as a reference should encompass net values of values of the order 1.000 to 1.200 m^3/day.

- **Change the topographical design of the network and supply points**

The DMA should cover areas belonging to the same pressure supply zone, always respecting the maximum and minimum regulatory pressure. In the case of this impossibility, sub-areas with pressure control should be analysed within the DMA, by installing pressure-reducing valves.

For easiness and to gain experience, it is advisable that the network sectorisation process starts by implementing "Natural DMAs", namely those areas of the network that were already naturally closed. Only after building knowledge and understanding of these areas provided by these first network interventions, should attention be focused on more complex areas, where the closing of boundary valves requires more careful planning and specific knowledge.

- **Economic Level of leakage (ELL)**

Based on the given range for the ELL associated with the network, the sectorisation process implies a greater or lesser investment effort in terms of network monitoring and consequent active leakage control work. The interest of utility in achieving ELL will also condition the human and financial resources that will be directed to these active leakage control activities. It should be emphasized that the degree of monitoring is closely dependent on the size and amount of DMA to implement in the network, as well as control of key clients.

DMAs should established on a cost-benefit basis, from managing a complete network however, DMAs should be considered for a system-wide approach. Hence, a whole sub-zone or supply zone should be subject to DMA implementation, even if some are larger than others and according to the economics of implementation.

- **Existence of sensitive or critical areas for correct supply**

Defining DMA limits should take into account existing records, including experience or local knowledge, especially in areas close to the lower limit of regulatory supply pressure. Sizing the DMA requires special care, since a small increase in pressure head loss can harm regular client supply.

They must also preserve main supply loops (for example trunk mains with higher than average diameters), in which the flow rate must be maintained, that is, the DMA boundary line should follow the path of least flow resistance and these mains must be as far as possible, excluded from within the DMA. The impossibility of exclusion involves installing larger diameter flowmeters, raising the costs of implementation.

Other factors that may influence the design of DMA are:

- Geographic or demographic factors such as urban, industrial or rural areas;

- Techniques available or applicable for leakage control in certain areas;
- Specific options for each utility, such as identifying service connection bursts and ease of access to the burst;
- Variability of hydraulic conditions, such as availability or limitation of valves for implementation of physical boundaries or limits of the DMA;
- Type of pipe material and age
- Maintaining service levels and water quality.

DMAs implemented in urban areas with high population density, such as in the center of Lisbon, may include more than 3.000 clients, with an upper maximum limit of 5.000. This limitation is imposed, since higher density housing implies increased in the analysis of night flow rates, by the limits of being able to identify bursts and consequent difficulty in leakage location detection.

For reasons relating to the analysis of night flows, optimization of the time associated with the identification of the existence of bursts and consequent speed of detection and location, it is considered that DMA size should correspond to a dimension of the network where there are no more than 3.000 and 5.000 clients. However, if restrictions on DMA creation imply they are larger, then can be subdivided temporarily by closing valves inside in DMA for study or leakage detection campaigns purposes. In this case, it is important to ensure the existence of potential temporary limit valves and the possibility of that each sub-area is supplied independently from the main flow meter, thus allowing evaluation night flows.

Despite the diversity of possible situations and conditions set out above, DMAs can be split relative to their size, in the following categories:

SMALL: less than 1.000 clients;

AVERAGE: 1.000-3.500 clients;

LARGE: over 3.500 clients.

These values relate to the average indicators for DMA sizing in urban areas, having been tested and validated in the case of Lisbon. However, the ranges of values noted are not universal and absolute, assuming that they may be difficult to meet due to the individual nature of each DMA, which may necessitate adjustments depending on the topography and topology of a city and thus distribution network operating pressure, the predominant type of properties such as houses, buildings, social housing for example, the existence of large customers including hospitals and shopping centres amongst others.

It should be stressed that in situations of implementing DMA in rural areas, that it is more difficult to set a limit on their spatial dimension. Indeed, from a low concentration of housing and clients, the DMA may have to cover a large geographical area, which may correspond to the whole of a town or village.

5.4.3 Considerations for Water Quality and DMA boundaries

The creation of a new DMA, which is not defined naturally by the layout of the network in a particular area of the distribution system, usually involves the effective closing of valves, thus setting up its boundary with adjacent DMA. This procedure invariably involves the formation of new network extremes, namely sections of mains with no exit and no consumption where water tends to stagnate, which normally does not happen in a completely open system.

The existence of extremes or dead sections without consumption, which can be much more problematic with greater specific lengths of the dead sections, may increase the likelihood of degradation of water quality, with consequent complaints from clients. This may occur on short or medium terms, from the moment when the DMA boundary valve was closed until whenever it is necessary to operate them to ease network interventions. Thus, the larger the number of extremes created with DMA boundary implementation, the larger the probability of these potential problems.

This is not however an insurmountable problem and consideration should be given on how best to reduce the number of extremes in the DMA design and implementation phases, balancing the need to install new valves in the network in more favourable areas. If there are no alternatives to these extremes, then this may lead to water quality degradation, hence regular and systematic programs for water discharges or flushing must be provided in such cases, thus minimizing the problem.

It should be also stressed that the creation of extreme is not necessarily bad for the network. Indeed, analysis associated with their existence in DMA and the consequent greater knowledge, can create opportunities for re-directing flow direction, decreasing flow resistance and pressure head loss, improving pressures in critical areas and correcting existing poor water quality issues. This can also be achieved by increasing flow velocity in critical areas, particularly in large-diameter pipes. Ultimately, such situations can be resolved through proper DMA reconfiguration, passing part of it to an adjacent DMA.

In the case of the DMA implementation project in the city of Lisbon, there are several examples where alteration of DMA limits was necessary after their initial clock-in, following identification of solutions to address certain network problems.

In this context, there situations where adjustments were undertaken to DMA limits due to the closure or change of use of premises or establishments located at the network extremes and with relatively high consumption, ensuring that flow circulation in these areas of the network occurs at an adequate velocities. With a change of circumstances it was often necessary to reconfigure DMA boundaries, usually with small interventions in

the network to create new water circulation routes and creating conditions for appropriate flow velocities. This is where model predictions and real-life testing sometimes differ.

Another particularly interesting situation occurred in an area with recurrent problems in terms of guaranteeing the minimum working pressure, due to the topography and height of some buildings. With the implementation of two DMAs in the area in question, there was a worsening supply conditions but only in one of these DMAs, thus indicating that the source of the problem was that particular DMA. Following a more detailed investigation, which included a pressure mapping exercise along the DMA, a review and analysis of key customers consumption was undertaken, through which it was found that the cause was related to a specific customer whose consumption profile included highly irregular, large peaks in consumption. Having identified the source of the problem, a change in the DMA boundaries between the two zones was undertaken with the 'disruptive' client being included in the DMA with a higher supply capacity, an intervention that allowed complete resolution of pressure problems in the area. Reconfiguration had no adverse effects on the supply to other customers despite leading to an increase in the number of customers in one of the DMAs, as consumption was essentially by domestic customers. In contrast, the other DMA encompassed fewer, but primarily non-household customers and therefore with higher consumption and greater profile variation. Figure 5.7 illustrates the changes made within the limits of the two mentioned DMAs.

The examples highlight that network sectorization, with the consequent restriction of consumption in specific areas, may create new, known and controllable risks and challenges for network management, can also contribute to solving existing problems or arising out of the urban area dynamics. Thus, the possibility of changing DMA boundaries is seen as a flexible network measure, since it allows service quality problems to be overcome, whilst minimizing the effects of changes on customers. In this context, mathematical modeling can be a very important support tool to optimize DMA adjustments and reconfiguration.

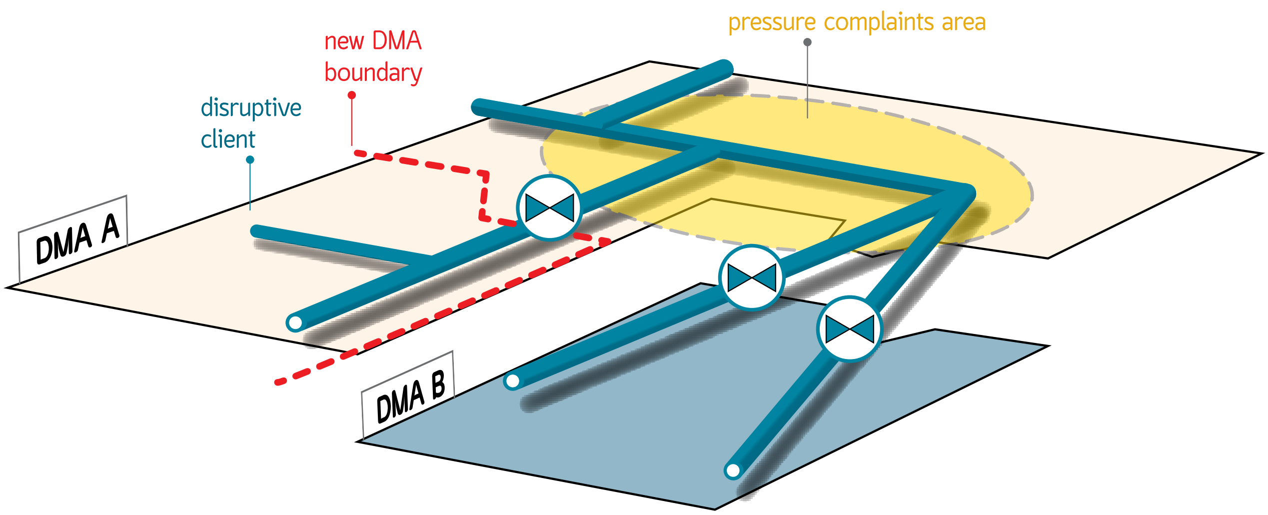


Figure 5.7 **DMA boundary limit alterations in the Lisbon distribution network**

5.4.4 DMA Planning Projects

The process of planning and design of a DMA can be described as performing a series of interrelated tasks, where the overall shape is iterative, corresponding to their development resulting from the integration of information obtained in the surveys and field investigations throughout the process.

In the first phase the provisional drawing of the DMA border should be prepared, using GIS, with the aim of characterizing the DMA and establishing procedures for continuous implementation, while ensuring the supply quality and pressure during periods of higher consumption. For DMA preparation, the following must be identified:

- Pressure zone supply source, the influencing reservoir, as well as DMA inputs and outputs, including characterization of respective flowmeters;
- Clients supplied in the DMA, identified by the GIS and client management system, including the total volume of water billed. Should large volume clients be identified, particularly those with a significant impact on total DMA consumption or high night consumption, then the installation of telemetry should be applied;
- Total length of pipes of the DMA and the average number and length of service connections;
- Boundary valve limits, section valves of the main supply mains within the DMA and identifying the type of valve operations to perform;
- Pressure controlled zones and characterization of any pressure reducing valves or pumps;
- Equipment associated with pressure monitoring points and estimated pressure as the points raised, namely: EP - Entry Point (next to the flowmeter), PMAX - Point of Maximum Pressure, PAvg – Average Pressure point, CPP – Critical Pressure Point, CCPP - Critical Client Pressure Point (client with the highest elevation supply point);
- Problematic areas of the network, defining their current status and existence of previous historical campaigns undertaken in the DMA. If necessary, hydraulic models should be applied to validate the proposed DMA;
- Extremes and dead sections without consumption created by closing DMA valves;
- Discharge valves which allow periodic cleaning of these sections or, if none exist, to propose installation of new discharge valves;
- Type of telemetry equipment to install in the input and output DMA flowmeters and other points of interest in the network, such as PRV upstream and downstream points, for continuous monitoring of flow-rates and pressures.

Based on the actions described, inspections should be conducted on-site, which include the following actions:

- Auditing of existing facilities - flowmeters, PRV, DMA, subsystem/supply zone or pressure controlled zone boundary valves - and verification of normal functioning;
- Checking of the operational status of section valves of the main supply mains within the DMA and audit the status (open/closed) of DMA and subsystem/supply zone limit valves, including validation of their accessibility, condition and manoeuvrability;
- Location, accessibility and operational check of the network elements such as hydrants, where pressure loggers equipment may be required to control DMA implementation operations and subsequent tests;
- Survey of new works and buildings not registered that have impact on network hydraulic performance;

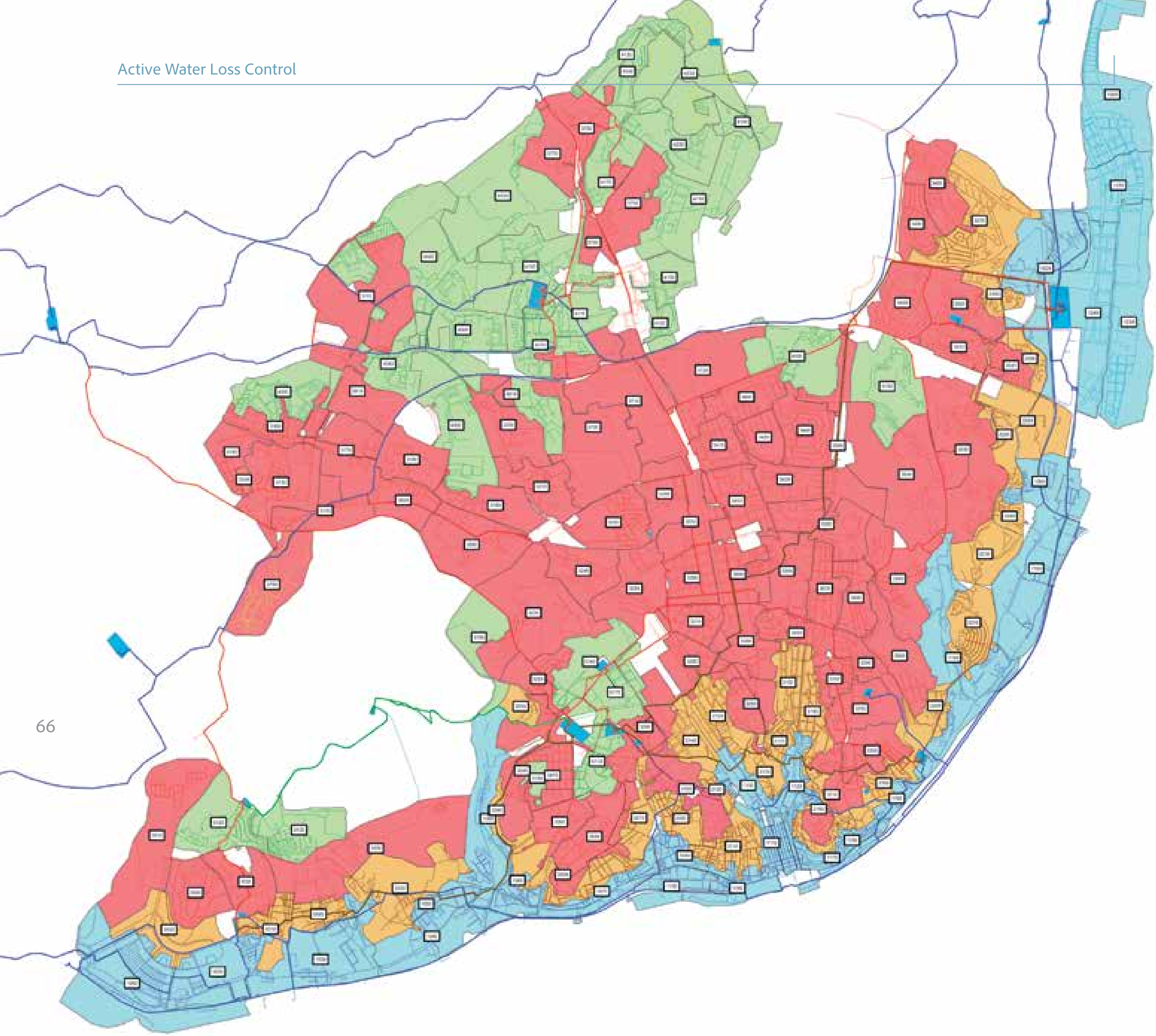


Figure 5.8 **DMA boundaries within the city of Lisbon distribution network**

- Pumping accessories and equipment not included in the GIS, along with respective correction and update.

After collecting and organizing all data and taking into account the information collection actions undertaken in the field, the next step is validation of DMA project. This is an iterative process which may require revisions to the design of the DMA polygon and hence identification of new valves or boundary locations for pressure monitoring points. In some cases the DMA design may be conditioned to require works on the network, so it may be necessary to implement a temporary polygon until completion of the intended works.

The draft DMA proposal should always be validated by other operational areas in the utility, namely operations, maintenance, construction and water network quality control areas, being subsequently distributed to the field team for eventual implementation of DMA. For its part, the implementation process should be acceptable to those areas of the company noted, as it will imply changes in the daily work of many teams. Thus, to test new ways of working resulting from DMA implementation, it is recommended that small pilot areas are initiated to start the process of DMA set-up.

Figure 5.8 illustrates the existing Lisbon distribution network, grouped by altimetric zones and DMAs.

5.4.5 DMA Implementation and Integrity Confirmation

After approval of the draft DMA proposal and termination of any network interventions, the DMA is ready to be implemented and tested. As already mentioned, the implementation process should be implemented during a period of high consumption, verifying that the mean network pressure values registered and those at the critical point are consistent with the estimates, thus guaranteeing the correct supply to clients according to the regulations.

After the DMA implementation phase, follows the validation phase, involving testing its integrity, the most common method of which is the Pressure Zero Test (PZT). This test, in addition to ensuring the effective closure of boundary valves and thus the DMA independence, ensures effective metering of DMA consumption through the monitoring points installed for this purpose. It should be emphasized that this test requires the suspension of supply throughout the DMA and is therefore undertaken during periods of lower consumption, usually at night.

To proceed with DMA implementation and Pressure Zero Tests, the following steps should be considered:

- Installing pressure loggers at the critical pressure point (CPP) of the network, namely at the point of highest elevation within the DMA in order to obtain pressure every minute for seven days before locking-in the DMA. With the records obtained, analysis will be undertaken, in conjunction with telemetry data from the DMA entry point, to verify and validate the estimated pressure;

- Validate DMA implementation by consensus with the other areas involved in the process - operation, maintenance, water quality and leak detection - to provide for the effective closure of the DMA, or conduct a review and revision of the DMA design, if the estimated pressure is not validated;

- Confirm accessibility of future DMA boundary valves, which will be operated at the time of implementation and check the status (if open) of isolating valves belonging to major mains supplying the DMA;

- Inform in advance the Operational Command Centre regarding closing of boundary valves in the network in order to prevent the possible impacts on network service or interference with other work in progress. Sensitive consumers, such as hospitals and the Fire Service, should also be informed of these operations, if required;

- Closing of DMA boundary valves must be made at the time of greatest consumption, with analysis of the impact on pressure values recorded at the

Critical Pressure point. Utility call centre teams should be informed in order to prepare the most appropriate response to any complaints. If there is a significantly negative impact on network pressure, in addition to the estimated values, the rapid opening of the DMA boundary valves should be undertaken and its design subsequently revised, with the definition of new borders, installation of an additional input or total DMA redefinition. If there is no negative impact on supply, the DMA is considered to be implemented;

- Undertake the sealing and labelling of DMA boundary valves, so they can be easily identified on the ground by the operational and maintenance staff. Any action involving DMA boundary valves should be reported immediately to the person responsible for network monitoring so that false alarms are not generated by the DMA monitoring system. The valves must be catalogued in a database and annual programs to validate their operational status;

- Undertaken Pressure Zero Test using the Critical Pressure monitoring point to confirm the integrity of the new DMA and ensure the tightness of its boundary valves. This test will be applied preferably in the morning following DMA implementation during hours when less water is being consumed so as to minimize the impact on supply. A successful PZT will confirm the actual closing all DMA boundary valves, as well as the lack of unknown connections as inputs or outputs. Checks on the difference between input and output flow values should be conducted only for the supply within the DMA. The PZT requires analysis of the pressure curve at the logger installed at the critical pressure point of the DMA when the supply is stopped by closing the isolation valve at the single input DMA. If closing of boundary valves has been properly achieved during DMA closure, then the pressure values should approach zero over a short time interval, confirming the actual DMA closing and consequently, its correct implementation. For subsequent data analysis, pressure should continue to be registered at the datalogger installed at the Critical Pressure point for nine days, to include a weekend record;

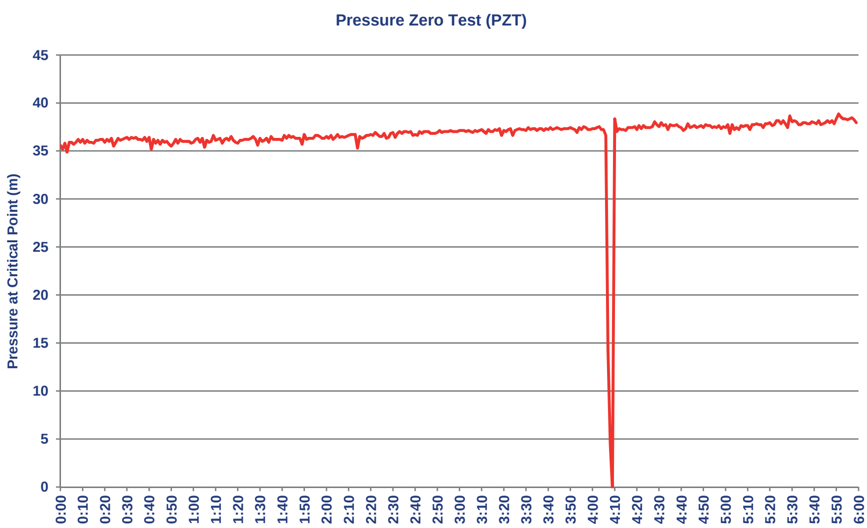


Figure 5.9 **Illustration of a Pressure Zero Test**

- Following completion of the PZT, dataloggers must be installed in the remaining pressure monitoring points – namely minimum elevation point (PMax) and average point (PAvg) - also for nine days. The observed records should demonstrate the correct DMA operation and supply to clients within regulatory conditions.

After stabilization of the process of continuous DMA monitoring and ensuring the existence of a reasonable historical record, then flow and pressure data will be collected and analysed. These records will allow calculation of the DMA water balance to identify levels of losses. The purpose of this calculation is the establishment of priorities for leak detection action within the network.

Figure 5.9 illustrates the undertaking of Pressure Zero Pressure, in which the DMA entrance is closed and the zero pressure can be observed 15 minutes later. At this later point, the inlet DMA valve was opened and pressure normalized within three minutes.

5.5 Collection, Management and Treatment of Information and Data

The use of a reliable system of recording and reporting of data is essential for proper understanding and management of a water distribution network. Given the multiplicity of existing equipment on the market and diversity of its characteristics, the choice of particular technical solution can determine the achievement of monitoring objectives of the water supply network.

For control and monitoring of water supply systems, different registration and data transmission systems have been implemented, notably the use of data-logging equipment that allow automatic collection of consumption data, pressure or other variables, from flowmeters or probes such as pressure sensors, pH, chlorine, installed in the network. These devices also have the ability to remotely download and store this data in a central, internal or external server, which can be made available to different users and for varying purposes. Implementation of such systems using telemetry enables more frequent

Figure 5.10 Dataloggers and Telemetry Equipment

readings and reliable records, thus eliminating the need to estimate whilst reducing uncertainty attributable to human factors.

Figure 5.10 illustrates various types of telemetry equipment.

All pressure and flow data provided by telemetry, associated with DMA and pressure monitoring points during the implementation process as well as large customers, provide valuable information on the supply system in question. It is up to the utility managing this information to make it available to various areas of the company, according to their needs, supporting their decisions to intervene. This phase will be implemented in a real-time monitoring system, allowing the next stage of capacity development to organize and analyse data. In most utilities the volume of information is very large and it is fundamental to aggregate and ensure the proper handling of data available on a single software platform that allows storage and provision in clear and structured way, in accordance with the objectives defined.

There are numerous gains for utilities arising from the availability of these properly treated pressure and flow records, can be divided according to the type of information collected. Pressure data allows the creation of alarms in different network zones and DMA entry points.

These alarms when activated, allow rapid intervention in case of sudden changes, anticipating complaints, or more serious situations, including major disruptions or service interruptions. They also allow the diagnosis of the source of problems in pressure sensitive areas, providing the basis for definition of new pressure controlled areas, in order to enable active management of network pressures, a situation that is considered one of the most effective solutions for the reduction of real losses in a distribution network.

Flow data, in addition to allowing calculation of the water balance can also, by direct analysis of any variations noted, give warnings about consumption

Figure 5.11 **WONE Monitoring Dashboard**

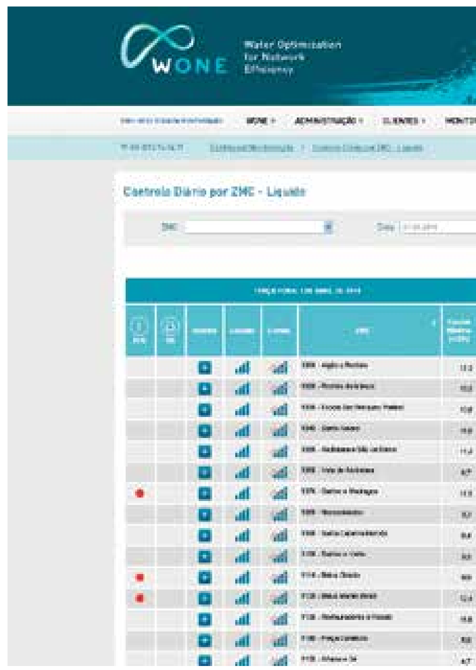


Figure 5.12 **DMA Daily Control page**

values. In addition, it allows calculation of various DMA performance indicators, enabling the identification of DMAs which are potentially recording excessive water losses and which should be the priority objective of active water loss control interventions.

Figures 5.11 and 5.12 illustrate information made available by a dedicated application for monitoring and control of water losses in supply networks (WONE - Water Optimization for Network eficiency), in which it is possible to verifiy which DMAs have the worst performance at any given time, from which it is possible to prioritize attention of leak detection teams.

The WONE application produces statistical analysis of DMA performance indicators including minimum and maximum daily flow, night flow, total daily volume and recoverable losses and pressure variation alarms. A set of performance indicators is calculated, including for example, the percentage of minimum flow to the average daily flow rate of each DMA, an indicator that has proven to reliably reflect the greater or lesser likelihood of leaks in the monitored area, as well as the daily total and night flow per 1.000 clients or per km of network, with the aim of organizing performance ranking, comparing and prioritizing intervention between the DMA volumes.

This information is systematized in a table which lists all DMAs and identifies performance levels within a set of predefined colour codes. In addition, alerts are generated to include DMA monitoring points without data communication, pressure anomalies or zero total consumption alarms and measured values outside the defined limits. From this page, the user can still navigate all DMA data, consulting more detailed information about each area, their monitoring points and clients.

The WONE application provides an additional set of performance indicators for each DMA that allows automatic DMA performance ranking, based on various indicators, including the minimum flow rate per 1.000 clients per km of network, the authorized night

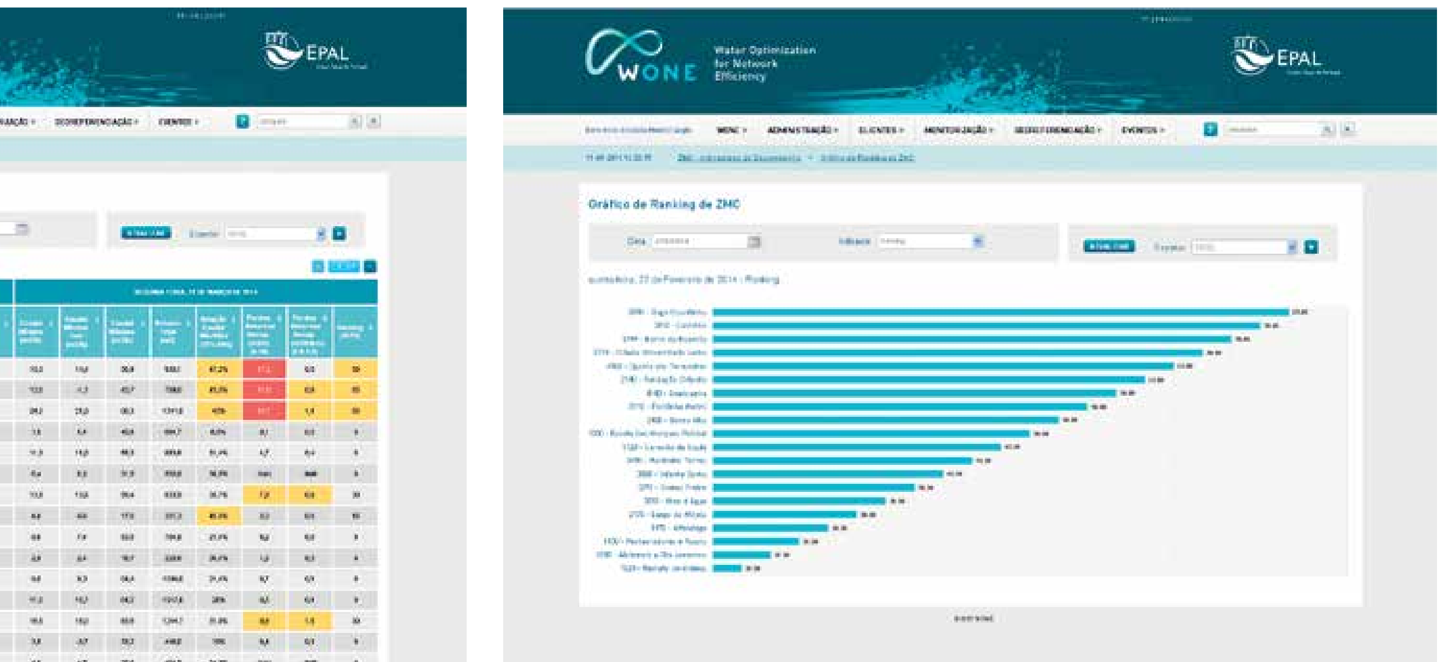


Figure 5.13 DMA Ranking

flow, mean pressure in the last seven days, inevitable infrastructure losses and recoverable losses. (Figure 5.13).

The WONE application has proved an essential tool for network optimization and active leakage control , which contribute directly to NRW reduction in the Lisbon distribution network. DMA data integration into existing management systems and DMA performance ranking has produced systems which are used not only to support active leakage control intervention), but also to support Network rehabilitation interventions planning as an aid to operational problem diagnosis and the distribution network management under normal operating regimes as well as alternative operational scenarios.

The flow data and validation of flow directions in the network, including the input and output flow directions of the DMA and how they vary during the day according to the mode of operation of the network, allow better understanding of network functioning. Knowledge regarding flow directions, resulting from DMA implementation , may prove to be very useful in cases of poor water quality, since the closing of the DMA may contribute to flow velocity increase. This information provides a more rapid identification of the greater or lesser requirement of each area in terms of water supply and can be used for medium or long term planning, redefining DMA limits and targeting a more balanced size and operation.

Given the theme discussed, the initial objective of network sectorisation and consequent obtaining data via continuous monitoring, is the development of a strategy for managing water losses. Thus, the information will be collected from flow meters installed at the entrances and exits of the DMA will enable the calculation of the water balance of the DMA, verification of night flow rates and mean pressures that occur in the areas under review. From this information you can create rankings to make the intervention in DMA according to their performance. The integration and linking this information with data on the invoicing of clients supported and joined with the GIS tools, will enable greater efficiency in detecting the level of leakage results. Moreover, the treatment and organization of data and its availability throughout the

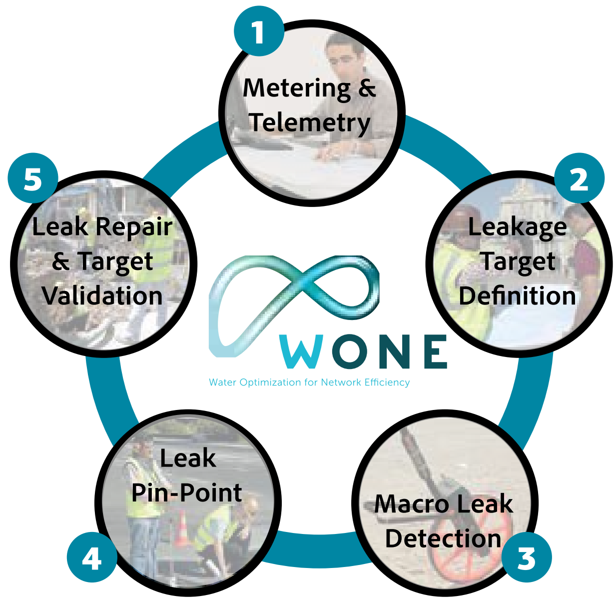


Figure 5.14 **Optimized DMA analysis and control process**

company in the form of useful information will allow making correct decisions and sustainability relating to the operation and optimization of the network, as well as a more strategic planning of future interventions.

In this context, it is recommended that utilities balance the setting up of DMAs with the primary objective of NRW management, ensuring the collection and consolidation of all available information, with a view to managing water losses efficiently and its connection with operational and maintenance activities on the network.

The existence of this type of structure also allows the utility, even in situations of lack of reliable flow measurement or inability to undertake sectorisation of the total system, to identify which areas are most critical in terms of network losses. This process can be done through the construction and implementation an array of risk assessment in accordance with a set of criteria that will characterize each network area, amongst which can be noted the following:

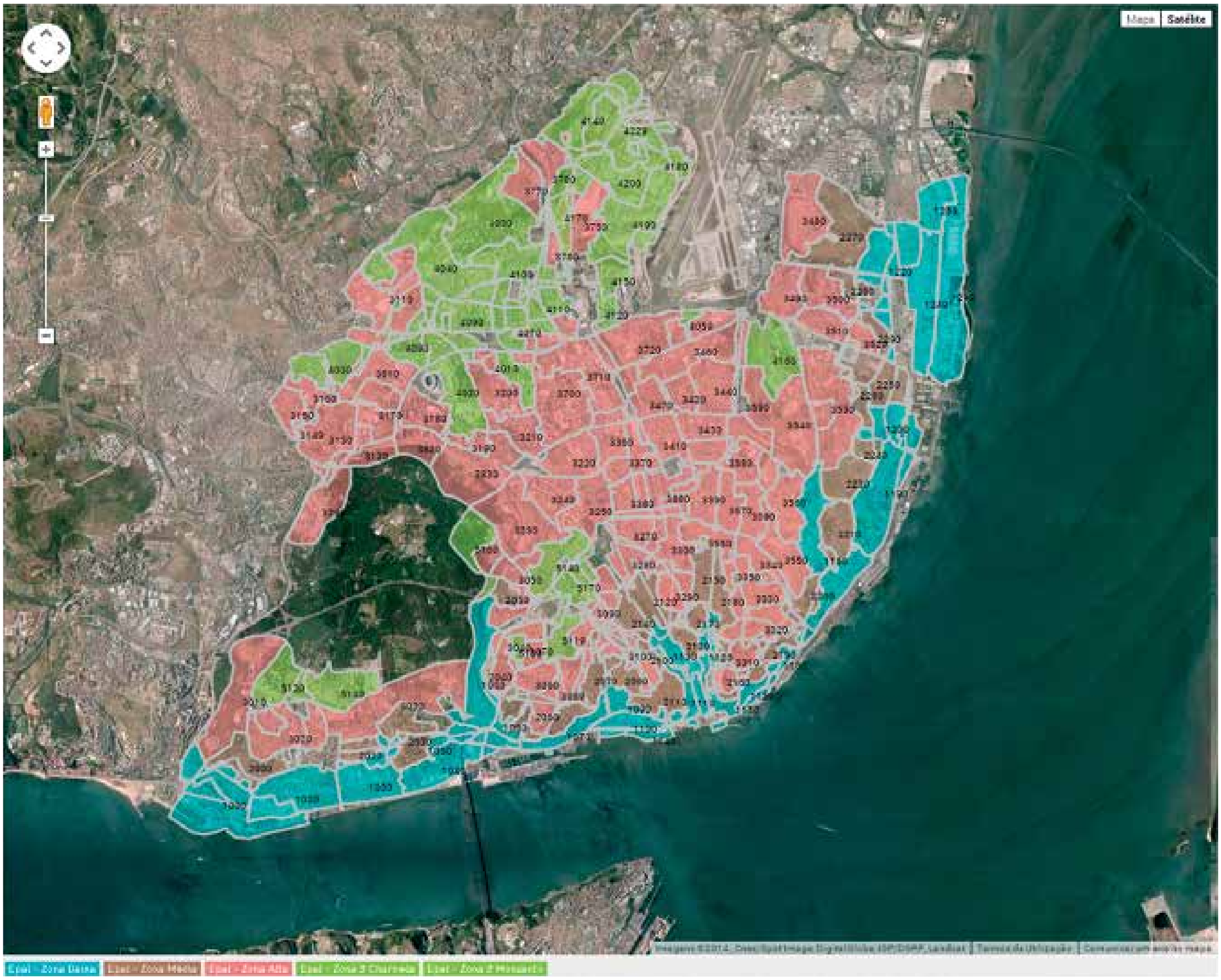


Figure 5.15 **Geolocalisation map of Lisbon DMAs**

- Network age and materials;
- Network pressure and daily variation;
- Annual burst frequency;
- Soil characteristics;
- Groundwater level;
- Type of socio-demographic occupation.

This methodology will, without great risk, establish the first ranking the potentially most problematic areas of network and in need of most urgent intervention. Thus, a start can be made to locate and resolve existing problems, whilst simultaneously developing the process for sub-metering and monitoring problems as well as gaining experience and mastery of the techniques involved, to progressively adopt a more structured approach, supported by properly treated monitoring data.

In this context, it is considered important to have geolocalisation module that allows spatial visualization of DMAs. This module allows for quick consultation of relevant DMA performance indicators and associated monitoring points, as ilustrated in Figure 5.15.

6. Leak Detection and Localisation

6.1 General Considerations

A significant proportion of existing leaks in a water distribution network are not easily detectable because their occurrence is not evident in decreases in customer service levels such as lack of supply pressure or the appearance of water in the street or network infrastructure. These leaks are usually caused by mains bursts or in the associated elements, with the water being absorbed by the adjacent soils, infrastructure or draining into aquifers, subterranean streams or in other existing underground infrastructure. This requires that utilities establish effective mechanisms to locate these invisible leaks, using equipment and techniques for monitoring and leak detection.

This problem, which is common to all distribution networks, requires operators to adopt measures to combat invisible water losses, which should be based on analysis of ongoing diagnostic of network efficiency, supported by monitoring and sectorisation strategies (see Figure 6.1).

The application of water leak detection techniques without any prior analysis to identify priority intervention areas cannot produce practical effects in reducing inefficiencies within a distribution network. Imagine a person with disease that consults a doctor to try and resolve the problem, from which the doctor decides to prescribe a drug judging the solution only on the situation presented without any process of diagnosis. Only by luck or great experience is the doctor able to effectively cure this disease. The same can be said to happen with leak detection and application of related techniques.

Interventions must be preceded by an analysis process to identify areas of the distribution network where more water is lost, or if possible, to quantify water losses for the given network length. The application of leak detection should be used only in cases where there are already clear signs of the occurrence of bursts and difficulties in determining the exact location of the leak. Thus, the application of leak detection techniques should be applied in priority areas, confirmed using detailed analysis and in particularly in DMAs diagnosed as under-performing in terms of efficiency. The surveillance gained by continuous monitoring of network activities allow for leakage detection to be possible early in the life cycle of a burst, preventing an increase of the DMA minimum flows and consequently the volume of water lost.

As can be seen in Figure 6.2, the lifecycle of a leak can be extremely long and may even occur for years, thus

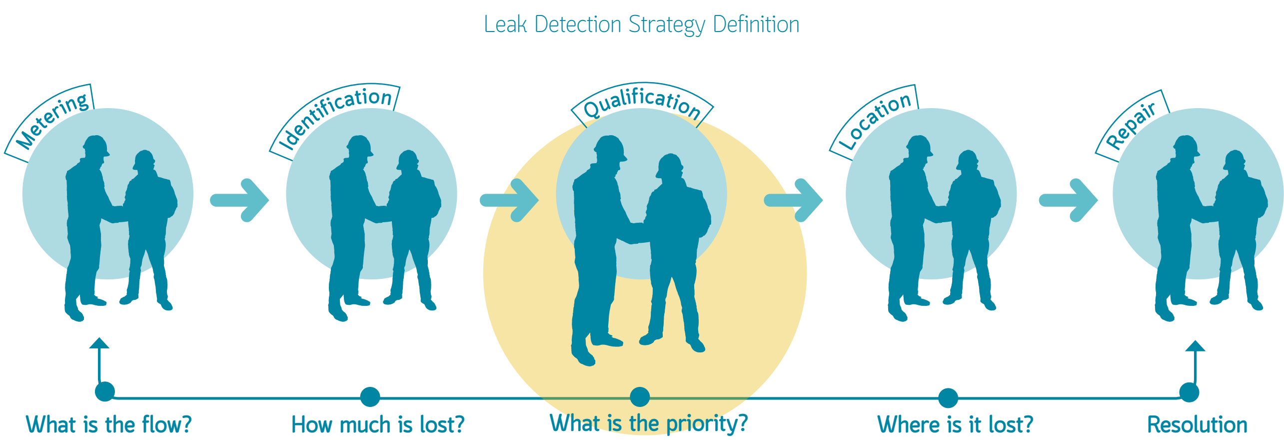


Figure 6.1 **Leak Detection Strategy Definition**

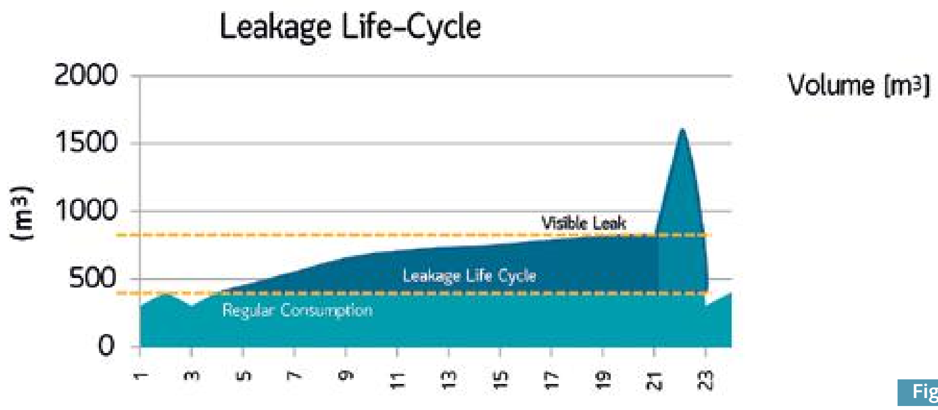


Figure 6.2 **Life cycle of a leak**

representing a huge waste of water to utilities. In addition, it is apparent that their occurrence cannot imply immediate appearance of visible evidence that allow its rapid detection. Therefore it appears that the great advantage inherent in the association with a leak detection monitoring strategy is the possibility that utilities can act much more quickly and effectively when the leaks occur or grow to a considerable size and may even set specific targets for leak detection teams once it is possible to measure the problem and evaluate the effectiveness of their intervention (see Figure 6.3).

During interventions to eliminate leakage process, there is a clear distinction between the procedures for leak detection and location of leaks.

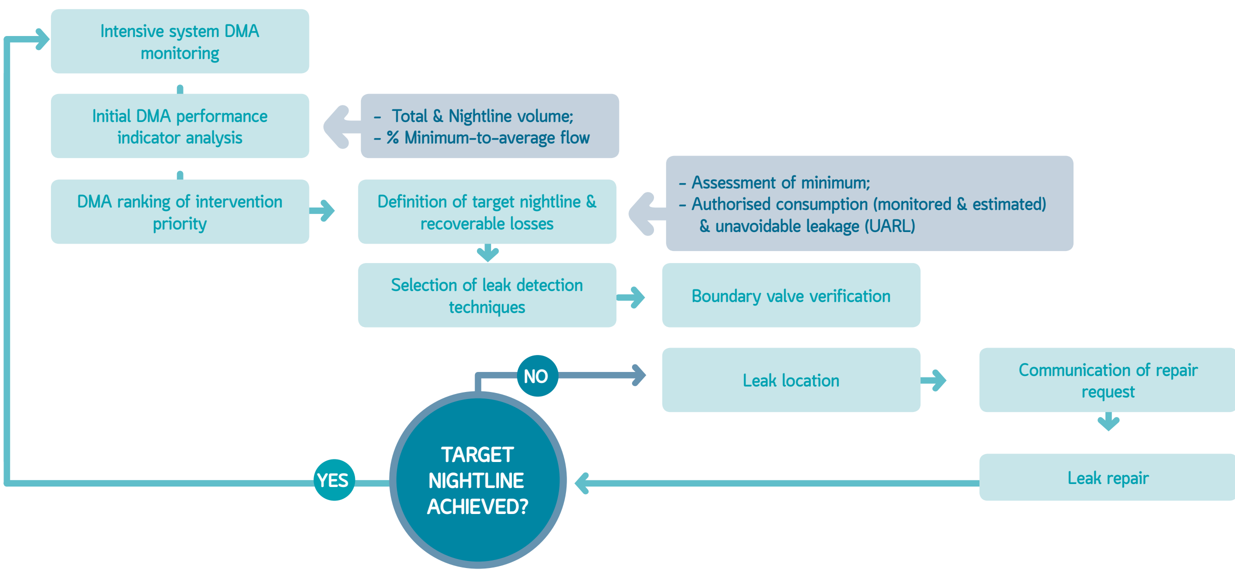


Figure 6.3 **Integration of network monitoring with leak detection**

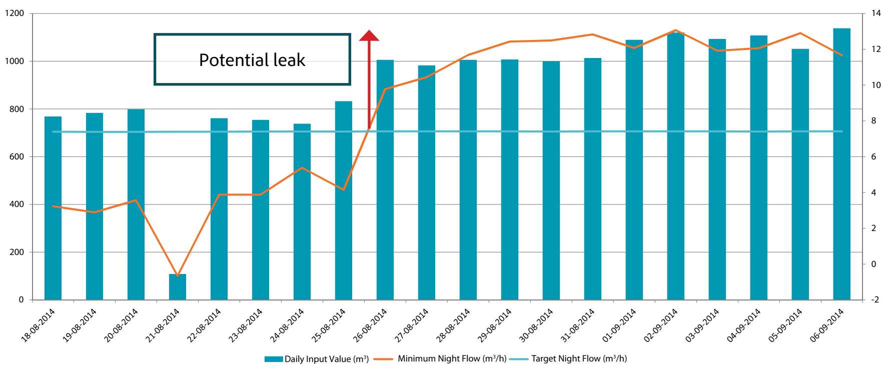


Figure 6.4 **Flow profile alteration identified in a monitoring system**

Leak detection aims to identify the onset of one or more leaks in a certain area of the network, which can be supported by evidence from the monitoring processes or simply the inability to maintain sufficient water supply, thus initiating the leak detection process. In the case of a sectorised and monitored network this process is facilitated by the possibility of identifying a poor performing DMA through a higher than expected flow rate.

The actual locating of a leak may be approximate or exact and is the process of any activity which allows for more precise and correct identification of the positioning of the leak until excavation and repair. This activity should enable the macro-location of leakage in monitored sub-areas, followed by remaining methodologies to focus on the exact location of the problem. Thus, it is understood that the leak location process is one that leads to decision making for conducting a survey on the ground.

As can be seen in Figure 6.4, the existence of systems for monitoring and observation of information generated facilitates diagnose of problem occurrence.

Where the monitoring systems identify a deviation

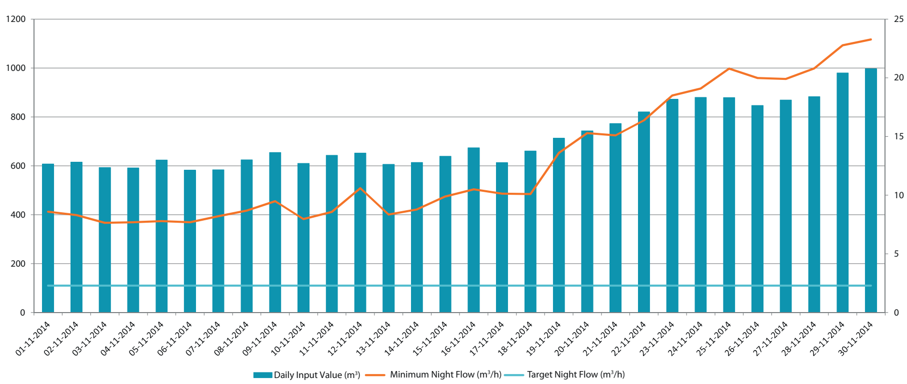


Figure 6.5 **Flow profile alteration due to a progressively larger leak occurance**

from the normal or accepted consumption profile, thus detecting a potential leak, a process of investigation to locate the origin should be initiated.

Although the situation illustrated in the previous figure corresponds to a sudden leak, where in the effect on consumption profile is relatively clear, there are instances where leaks have a progressive nature, with a gradual increase in consumption, which is more difficult to detect without the use of support monitoring systems, highlighting the importance of these support tools. Figure 6.5 illustrates a situation of this nature.

Another essential aspect in the analysis of the DMA performance involves daily determining of the minimum night flow rate and the total daily volume of each monitored zone (Figure 6.6). This information, which can be combined between different DMAs, highlights the evolution of these indicators and allows comparison of the minimum night flow with theoretical target flow rates for each DMA, based on the methodology adapted from IWA proposals. This information can be exported in the form of chart or table to other computer applications and is the basis of DMA Analysis Projects, in which are the gains quantified in terms of minimum night flows, prior to and following active leakage control interventions.

Note that the minimum nightline may use the absolute minimum, the hourly rolling hour minimum or avarage between fixed night hours, depending on consumption patterns or consumer charateristics.

6.2 Leak Localisation Techniques

Network leak location requires specific techniques and equipment, hence as mentioned above, utilities are strongly advised to have adequate software systems which can automatically detect the existence of a potential water leak, immediately alerting monitoring teams.

Once a potential water leak problem in the network has been detected, the utility must instigate an investigation of the causes of the problem, considering a two-phase intervention approach, the first approaching aiming for approximate, based on a process of narrowing down intervention areas, with the second aiming for the exact leak location, based on the application of acoustic survey or other appropriate techniques. These two approaches should be complementary, accelerating the whole process of identification of the problem without unnecessary waste of effort, time and resources.

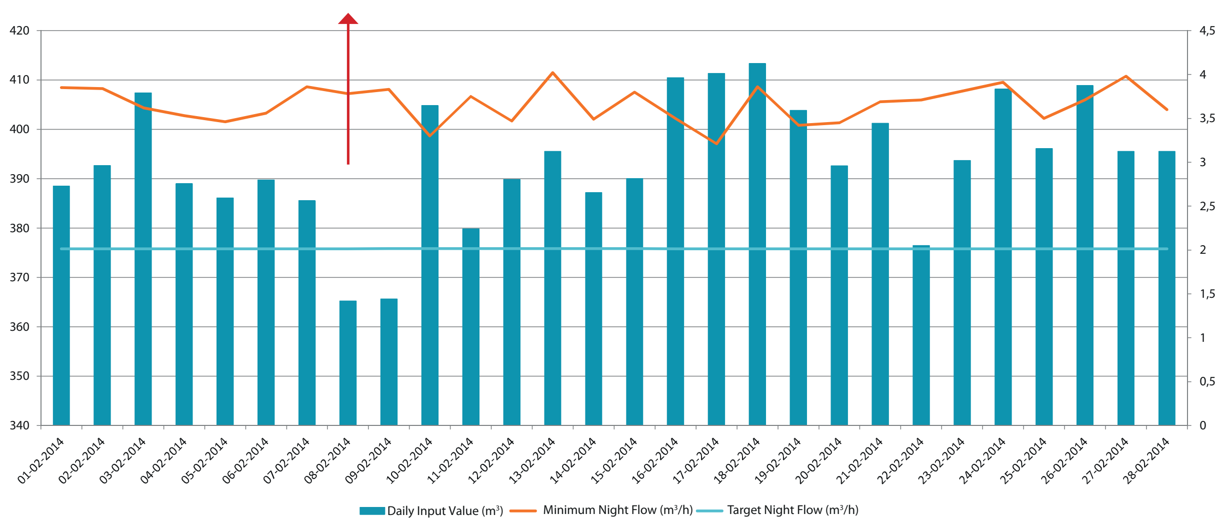


Figure 6.6 **Daily Total and Minimum Nightline Flow Graph**

Depending on the size and characteristics of the area under investigation, in particular by ensuring the existence of section valves or access points to the network should be adjusted to apply the following techniques or methodologies including:

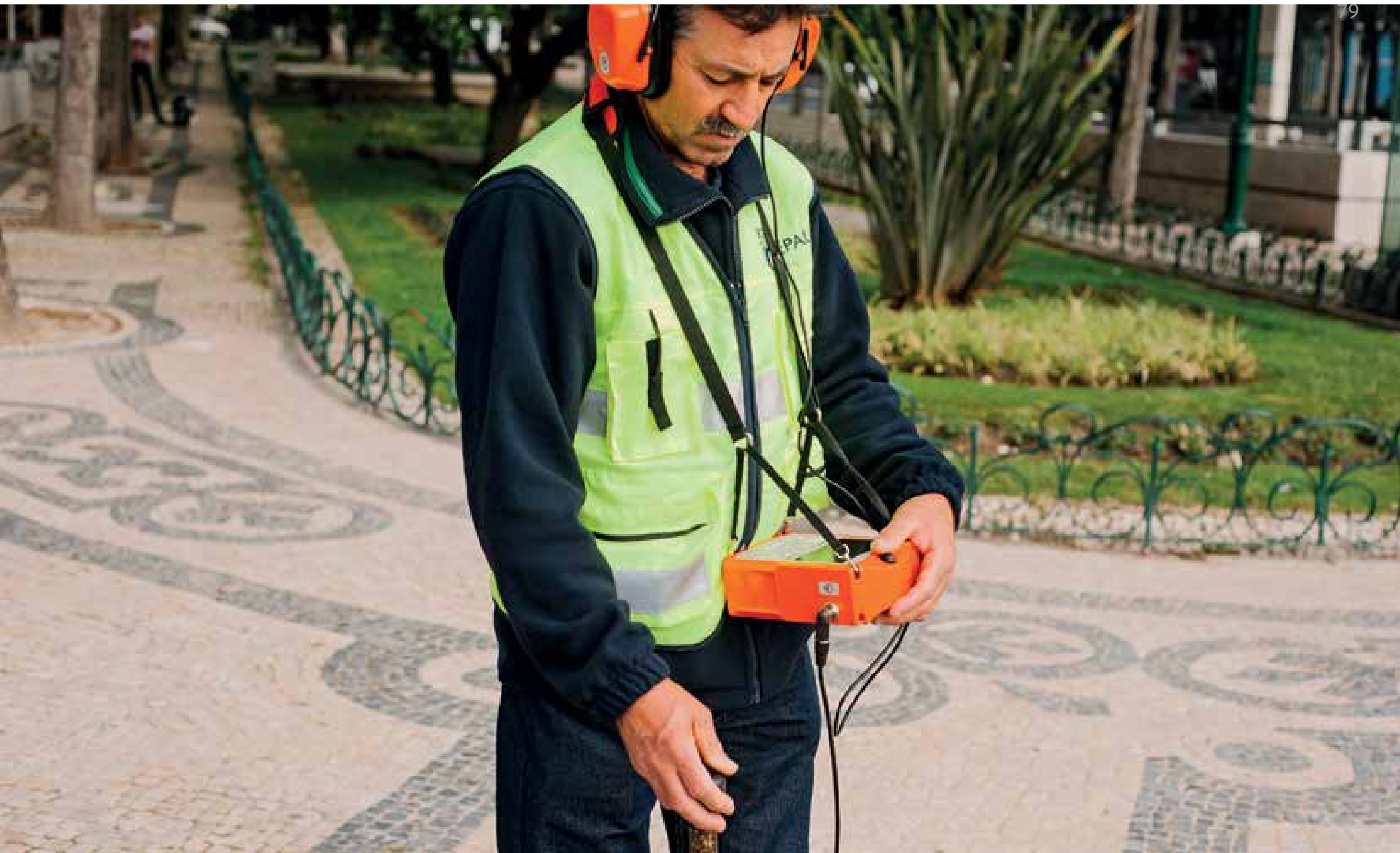
a) Technical Approach to Leak Location:

- Sub-zoning or internal subdivision of the DMA without supply suspension;
- Sequential Step-testing and supply closure;
- Pressure mapping along supply mains;

b) Techniques for Exact Leak Location:

- Acoustic Sounding - Acoustic Loggers, listening sticks and geophones;
- Acoustic Correlation - mathematical noise correlators;
- Tracer Gas Injection - Hydrogen or Helium Detectors;
- Drop test applied to reservoirs and mains.

It may be noted that in situations of an absence of monitoring systems or of a preliminary DMA implementation stage, it should be possible to adopt a strategy of detailed inspection and regular network directed to areas where there is a greater rate of burst occurrences in customer service connections or in older sections of the networks. In such cases, detection teams should be directed to a process of overall coverage or leakage sweeping of these supply networks, defining a maximum interval between detection cycles.



6.2.1 DMA Sub-zoning

The technique of sub-zoning is applied when identification of excessive consumption in a DMA is considered. The aim is to reduce requirements for application of precise leak location techniques by considerably shortening the length of the network requiring leak detection interventions. To this end, the opening valves DMA boundary valves and closure of internal DMA valves, which creates a change in the design of the DMA boundary, implying the consequent "transfer" of subzones to neighbouring DMA(s).

Ideally, this transfer must be undertaken in monitored neighbouring areas, enabling analysis of correlation between the drop in flow of the study DMA and corresponding increase in the neighbouring area. If there is no monitoring, the utility may choose to temporarily install flow measurement in the transferred areas or simply choose not to have that information, only analysing the drop in flow within the study DMA.

In either case, a procedure for checking conditions prior to implementation of this type of test should be created, namely the existence and operability of section valves or the presence of possible network restrictions. The number of sub-areas designed should be adjusted depending on the size of the study system and flow rate profile, in order to enhance test results and alignment with the potential leak location. After the test, the impact of valve operations and internal DMA boundary changes should be correlated with the flows recorded at the different monitoring points, which will identify the most critical area in terms of leaks. Figure 6.7 illustrates this process of sub-zoning.

This type of test can be performed in just a few hours or over several days. In the first case, an analysis of flow variation can be undertaken by direct meter observation, though use of a monitoring device, in particular a logger, is not necessary. In the second case, it is essential that flow rate data registering and monitoring equipment is used, since it is impractical to have a technician to

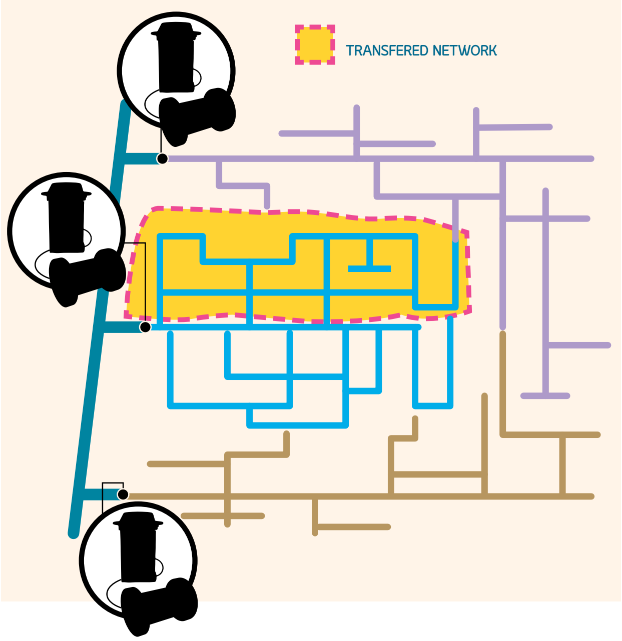


Figure 6.7 Process of DMA sub-zoning

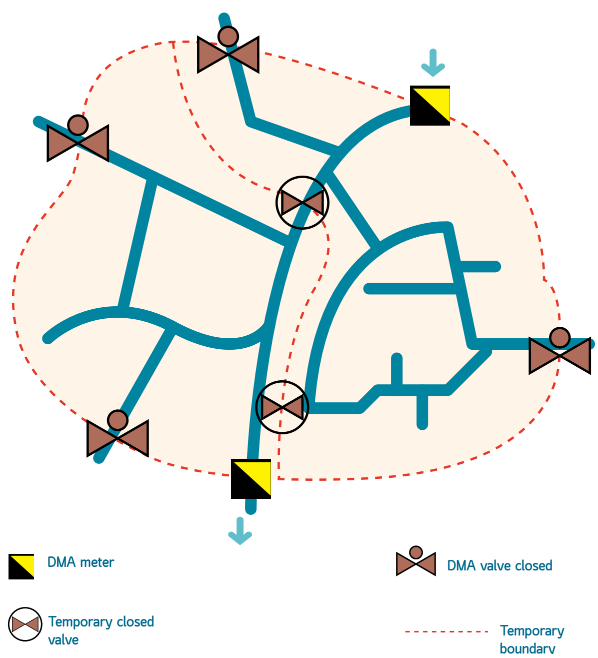


Figure 6.8 DMA Sub-zoning schematic with provisional meter installation

manually register flows at monitoring points throughout the test period.

In DMAs where subareas are transferred to neighbouring DMA and where this may cause disruptions to supply, it may be required to resort to the installation of one or more meters at certain boundary points, creating small temporary DMAs. Thus, the initial DMA will be monitored subdivided into two distinct zones, one of which may be supplied from a neighbouring DMA via a cascade (Figure 6.8). To ensure complete sectioning and independence of each of these small DMAs, it may be necessary to verify all section valves operated and closed to create the temporary boundary, as well as applying a Pressure Zero Test. With monitoring of each of the different area entrance points, it should be possible to know the losses associated with each sub-zone.

It is important to note that the opening of DMA boundary valves can cause changes in water quality, if there is a length of pipe without considerable regular consumption upstream of these valves. In these cases a discharge using a specific valve or fire hydrant must be performed beforehand in order to mitigate potential problems with water quality.

6.2.2 Step Testing

The principle application of this technique is to reduce the size of the area being studied by closing internal valves and consequent suspension of water supply (see Figure 6.9).

Assessment of the impact of these operations is made upon observation of the measured flow at the monitoring point, where monitoring equipment can be used for permanent recording of flow rates (see Figure 6.10). Observation of a significant reduction in flow rate profile during a valve operation indicates the presence of one or more leaks in the suspended area or a potential illegal connection with leakage or consumption.

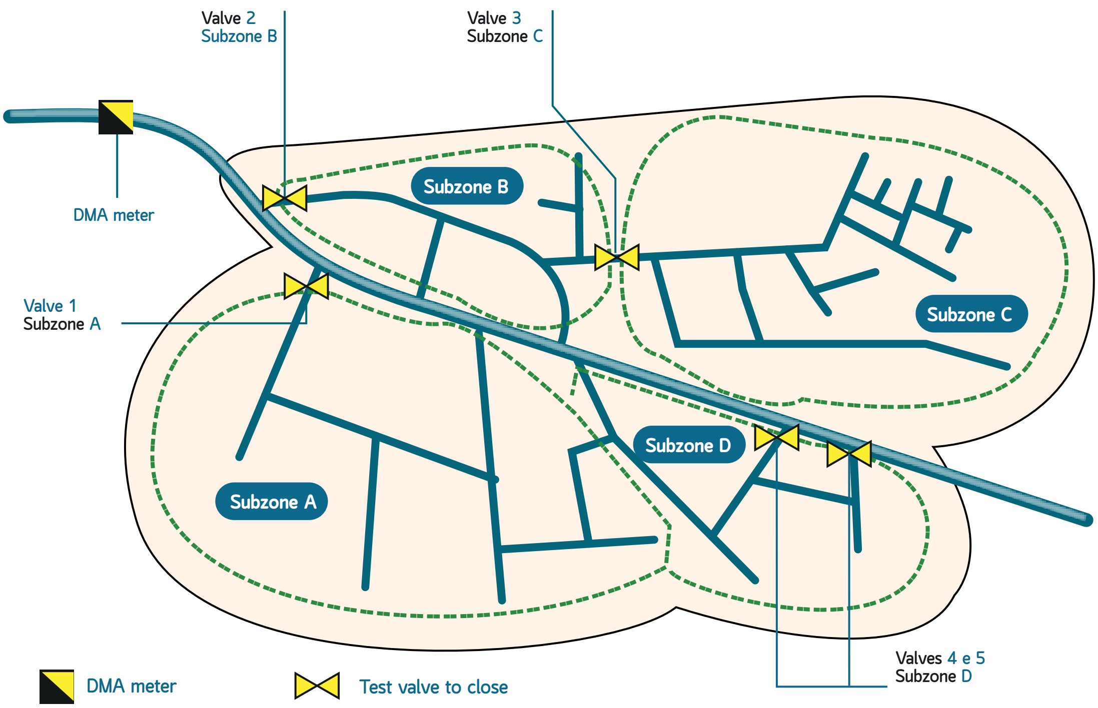


Figure 6.9 **Step Testing Schematic**

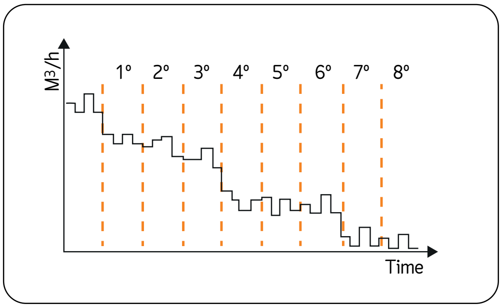


Figure 6.10 **Effect of Step Test on DMA flow profile**

It should, however, be remembered that there are some critical aspects that may hinder or prevent the application of this methodology, namely:

- Requirement to ensure the watertight integrity of internal section valves, which involves undertaking of Pressure Zero Tests (PZT) in each sub-area;
- May involve prior warning to customers affected by the supply suspension, in accordance with the internal utility rules or legal obligation by regulatory notices;
- The reduction of the supply suspension impact and avoidance of potential influences on the test results, originating from authorized consumption, requires the test itself to be undertaken at night time, which in turn may require the payment of staff overtime hours;
- A feeling of insecurity may be created for the technical teams, because of the depressurization and subsequent re-pressurization of the infrastructure, which can potentially cause disruptions in the distribution network;
- The risk of causing changes in water quality or blocking of building networks and residential meters as a result of service reinstatement after supply suspension may increases the flow velocity, thus releasing debris or particles deposited inside the mains.

To apply this technique, as well as to optimise results, it is advisable to collect the following information prior to application:

A. To define and characterize the step test area it is necessary to determine:

i. The number of properties in the area;

ii. The number of metered clients with water consumption during the night;

iii. The number of unmetered non-household customers, noting any customers with night consumption, such as hospitals or hotels;

iv. Checking the status of valves to be operated during the test.

B. Develop a plan of the Step-Test area with indication of :

i. Street names and mains layout;

ii. Boundary valves (closed to isolate the DMA area);

iii. Surrounding valves (Completed for removing by-passes and to create a root and branch-style network);

iv. Sequential valve (operated during the step- test);

v. All other valves are not used during the testing, to avoid mistakenly opening them;

vi. Verify positions and details of commercial customers with an estimate of their night consumption to assist in further analysis of test data;

vii. Numbers of valves, position (open or closed) and direction of closure.

C. Preparation for the test:

i. A discharge program plan for reducing potential water quality issues;

ii. Close valves that do not interrupt client supply during the day;

iii. Close remaining valves in the evening before starting the test;

iv. Take the initial night flow reading;

v. Whenever possible, suspend supply to major night consumers or premises with overnight tank refilling;

vi. Verify meters of users that cannot be suspended and subtract their night flow or if feasible, loggers should be installed;

vii. Check if the supply is not interrupted for customers at risk or those with special needs.

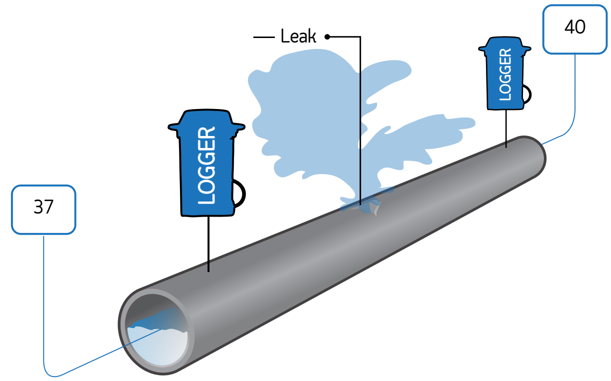


Figure 6.11 **Pressure Mapping Schematic**

6.2.3 Mains Pressure Mapping

The technique of mapping the pressures along supply mains may be applied when excessive DMA consumption is identified and involves a substantial increase in flow velocities. For this purpose various pressure monitoring loggers may be installed, synchronized with each other so as to allow for a comparative analysis between them. Note that this technique is far more reliable in cases of high flow rates created by excessive consumption, since the losses are directly influenced by velocity. This requirement also makes it difficult to apply in DMA with a high level of inter-connections, as there is a large flow distribution and reduced influence on flow velocity. To minimize this situation, the closing operation of valves within the DMA may be considered, thus ensuring a more direct flow.

Analysis of this mapping exercise encompasses verification of piezometric elevations (ground elevation plus instantaneous pressure) at each pressure monitoring point installed and systematic comparison of the values calculated along each profile. When the decay of piezometric levels between two successive points is relevant, it is expected that excessive consumption can be located in the section of mains or network between them. Otherwise, if there are no changes to the piezometric elevation profiles between two successive points, then this zone is likely not to be considered critical.

This technique can be further improved by using a calibrated distribution network hydraulic model, as this can contribute to a better understanding of flow distribution and thus support selection of the preferred locations to install pressure monitoring and also for greater confidence in interpreting results. In addition, model calibration routines can be included in order to locate, computationally, the most likely places of excessive consumption.

There are many aspects that differentiate and influence the application of the varying techniques noted. The choice of the test type to the detriment of another must take into account the characteristics of network analysis, monitoring equipment available, technical capacity of existing human resources, legal or regulatory requirements and especially customer service quality impacts. Step-testing is the technique which has the greatest impact on customer service, because it implies supply suspension and can cause problems in terms of water quality or bursts in the network, which in turn, creates the potential for increased suspension periods in order to repair these bursts. Thus, this type of test should possibly be considered as a last resort and only after previous efforts using other techniques have been applied to locate water leaks. A key point to highlight when step-testing is that of carefull valve operation. Network pressure will be at its highest at night, often much greater than during the day, hence the change from zero to maximum pressure can lead to bursts if valves are not operated sufficiently slowly.

6.2.4 Techniques for precise leak location

There are various techniques applicable for the exact location of leaks, the most common being based on acoustic methodologies, detecting the noise caused by a leak which propagates through the mains and accessories. However, the diversity of new materials used in networks, especially with plastic mains, combined with low operating pressure and lack of access points, have conditioned the application of acoustic techniques to most distribution networks. This reality has challenged utilities and leak detection equipment suppliers to invent new technical solutions to enable leak detecting and locating interventions in all areas of a distribution network. Example solutions include the injection of a tracer gas inside the mains or non-intrusive acoustic inspection with a hydrophone, in order to aim to overcome the constraints mentioned above.

The market has presented innovative solutions acoustic survey aimed at locating leaks in harsh conditions, in particular larger diameter mains or softer plastic pipes. These are generally more intrusive and require the prior creation of specific conditions that permit their use, such as access points to the interior of the mains. These techniques include a combination of ground radar, sound or video inspection technology, functioning as true detection systems, such examples are the Sahara developed by WRC, Smart Ball or JD7 Bullet.

6.2.4.1 Acoustic Surveying

The application of acoustic survey techniques must follow a methodology of successive approximation to the origin of permanent noise caused by a leak, using specific equipment, including acoustic loggers, correlators, ground microphone or listening stick.

Acoustic survey involves listening for leak noise directly on the network accessories or on the ground surface, along the alignment of supply infrastructure. The results produced with this type of surveying are more effective

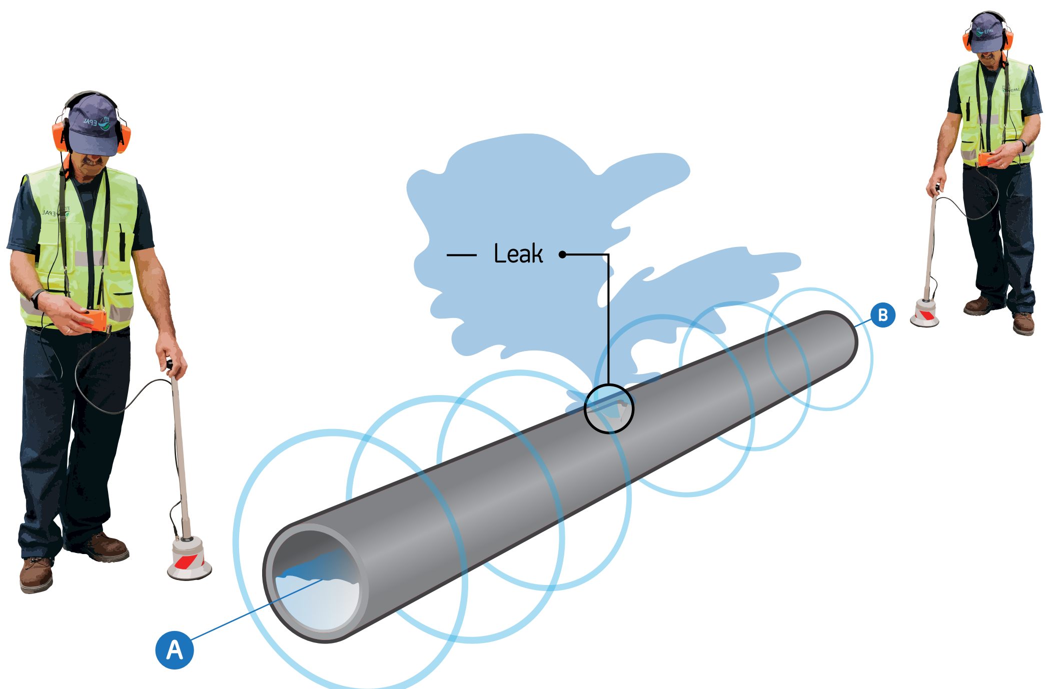


Figure 6.12 Leak Noise Propagation

if they are applied directly on to mains network access points, thus allowing analysis of the intensity of the leak noise in different accessories of the network. However, the time allocated to such activities of exact leak location will be greater when the number of listening points to be sounded is highest, hence utilities must make a balance between available resources and expected results.

Acoustic methods are based on the fact that a leak in a pipeline under pressure emits a permanent specific noise, defined by a particular range of frequencies (see Figure 6.12).

The distribution of noise frequencies generated by a leak is specific to that leak and dependent upon such factors as the type and size of the orifice, pressure, material and mains diameters or soil type. The noise is distributed along the pipe at a speed dependent on the particular characteristics of the material with a smaller noise trail dissipating with the greater the distance between the leak and the listening point.

One of the main advantages of the application of this technique is the possibility of undertaking the detection work without the need for supply suspension. Moreover, the existence of a minimum possible supply pressure is significant for leakage noise detection. This premise assumes utmost importance in systems without continuous supply because at certain times of the day the minimum conditions necessary for the application of acoustic techniques are not available. In these cases, other techniques can be applied such as the injection of a tracer gas, noting that all of these new techniques have specific limitations on their potential application.

Alongside the inherent supply conditions, utilities should also examine network characteristics and the experience and ability of each operator, adapting the use of different acoustic detection equipment to analyse each case.

Amongst the equipment most commonly used for acoustic surveying, the following may be highlighted:

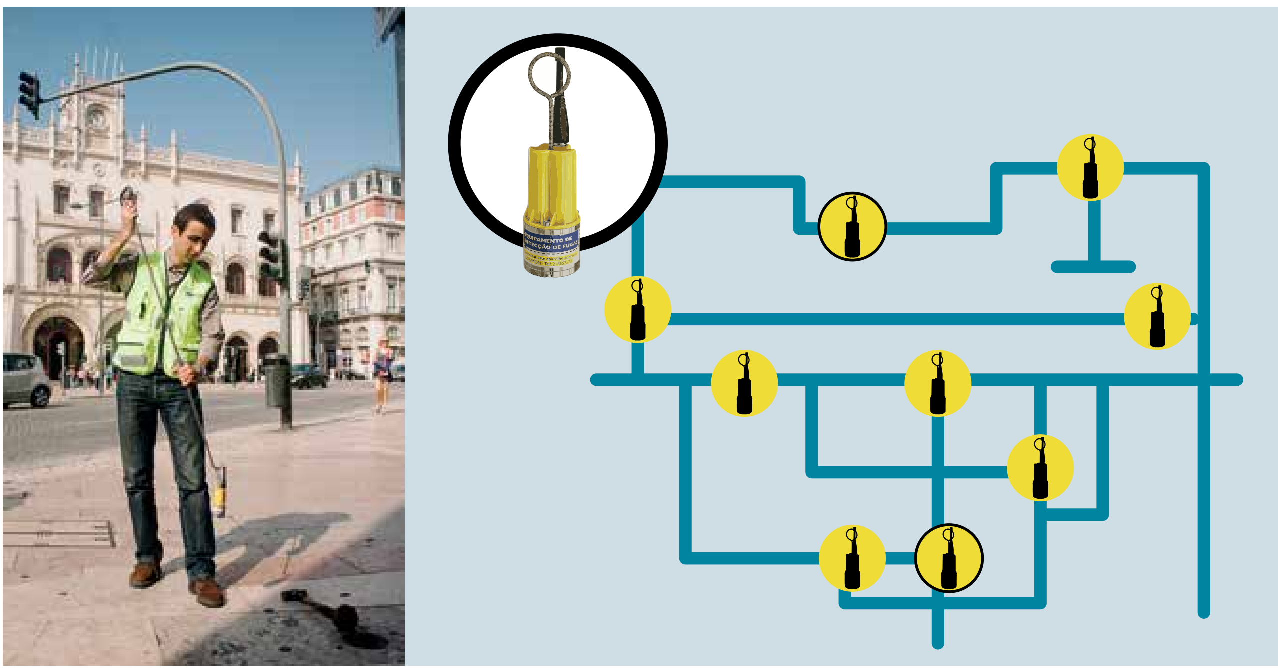


Figure 6.13 **Installation of acoustic noise loggers**

a) Acoustic Loggers

An acoustic logger is a compact unit comprising an acoustic sensor (accelerometer) and a programmable datalogger, which has a magnet for ensuring contact between the sensor and valves, fire hydrants or metal pipe section itself. Its size and configuration allow this type of equipment to be installed in tight spaces, so as to be able to use all available points of contact in the water supply network. Acoustic loggers achieved a great popularity amongst operators, as they can operate autonomously after its programming, not requiring the presence of a technician to make noise recordings. The equipment is installed during the day, with a schedule to monitor noise leakage at night time, usually between 2:00 and 4:00a.m., when the best conditions for leak detection works are met, given that there is only minor interference from ambient noise and consumption is minimal. This unique feature negates the need for leak detection teams on permanent night work, reducing costs associated with water loss control.

The loggers should be programmed correctly and installed during the day, recording the noise propagated along infrastructure during the night, with data collected the next day by technicians and subsequently analyzed in the field or in the office environment (see Figure 6.13).

The results of acoustic measurements are collected through a patrol unit, which connects with each logger via radio or via GSM / GPRS, in the case of permanently installed units (usually installed in places with frequent reappearance of leakage). In the case of non-resident equipment, patrols may be conducted, using a patrol car, or on foot when performed in dense or complicated urban and therefore greater difficulty with communication (see Figure 6.14).

When scanning large areas, equipment can be transferred successively between locations, until all the network is inspected for leakage in an operation frequently referred to as “Lift & Shift”. Installation of this equipment in the supply network enables a "sweep" of large areas with little effort and effective inspection of areas where there may be noise during the daytime, caused by traffic or movement of people. In parallel, this type of equipment also allows that problematic leak detection intervention areas can be inspected during the night, without risking staff safety and security.

Figure 6.14 Acoustic Patrol Loggers

In the planning the installation process, two important aspects must be considered, including the distribution network mains material and existing pressure service, as noise propagation is greatly influenced by these two factors. The distance between units installed may be up to 200 meters, if they are installed in metal mains with a high service pressure, reducing to less than 80 meters distances if they are placed in plastic pipes such as HDPE and PVC. In general current devices on the market, require a minimum allowable pressure for use of 1.5 bar, regardless of the mains material.

A leak detected by a set of noise loggers is closest to the unit which has registered the highest noise intensity over a regular sampling period. The proximity to a leak is usually identified by a high decibel level and little scatter in the respective frequency range observed.

The exact leak location is not usually detected by this type of equipment, as this is not its function. This indicates the existence of leakage in the vicinity around the installation site which is considered to be suspect and thus subject to a more detailed inspection, by use of another type of leak detection equipment.

b) Listening sticks and Geophone/Ground Microphones

Once the search area for a leak has been reduced, approximation techniques to pin-point the exact leak location should be applied with an approximate error of one metre, in order to reduce effort and investment associated with excavations.

It should be emphasized that the pressure caused by water leakage causes vibration in the pipe and surrounding ground, which can be perceived at different frequencies and heard through a device similar in operation to an amplified stethoscope. These vibrations are usually detected on the ground surface in the 200 to 600 Hz frequency range and directly on the distribution network mains between 600 and 2.000 Hz.

In applying acoustic survey inspection methods, interventions are undertaken by listening to the noise leakage by direct contact with valves, hydrants, service connections or other network accessories, through a listening stick with an amplified electro-acoustic signal. Having identified the peak noise leakage in a section of pipe between two points, the leak can be virtually located (see Figure 6.15).

When this method is applied to listen to the ground surface above the main, a geophone or ground microphone is utilized, with this equipment following the same principle of detection using an amplified electro-acoustic signal (see Figure 6.16).

In this context, the ground microphone or geophone, which must be protected with filters against noise from vehicle traffic and wind, is placed in the soil above the main at regular intervals of one or two metres, in order to detect the exact leak location.

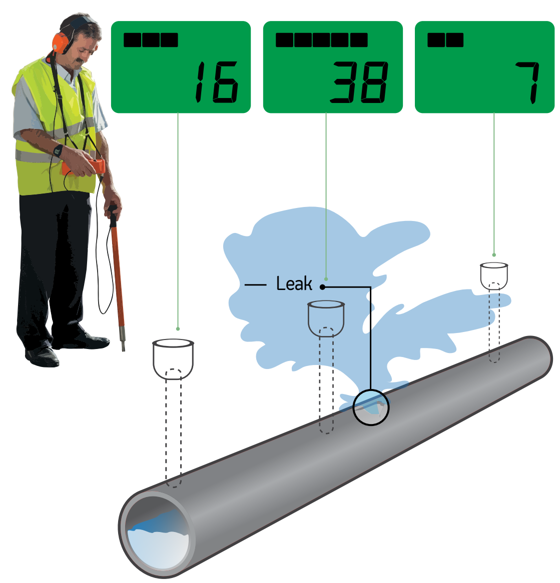


Figure 6.15 **Use of Listening Stick**

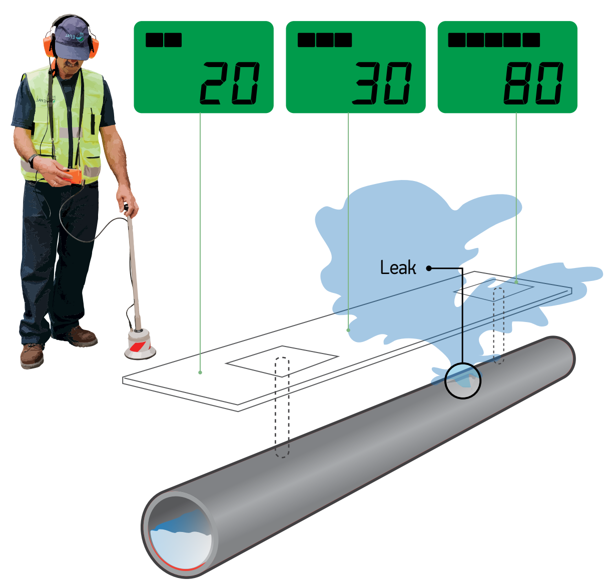


Figure 6.16 **Use of Geophone or Ground Microphone**

c) Acoustic Correlation

The acoustic correlator is one of the most effective tools for locating water leaks. The method of operation allows determination of the exact leak location, functioning by using mathematic calculation of the time delay between two signals (frequency curves) from the same noise source – namely, the potential leak (see Figure 6.17).

Therefore, the instrument does not seek the point of greatest noise, but instead proceeds to listen using two different points on buried mains and determine the relative leak position, by cross-correlation for each of these points. The latest versions of this type of instrument allow leak location with a high degree of precision, usually with errors of less than one metre, using the following calculation:

Equation

$$d_1 = \frac{L - (v * \Delta t)}{2}$$

where:

d_1 - leak distance from sensor 1;
L - leak distance between sensors;
v - noise velocity propagation for the relevant diameter and material type;
Δt - delay in noise reception between sensors.

Note that any error relating to the distance between the sensors may result in an error in the leak location equal to half the initial error. The same will happen if there is an inaccuracy in the noise velocity propagation, resulting from an error in defining the material and diameter of the mains. Note that where there is a change in the mains material along the section being analysed and thus behaviour, the material and diameter of each section should be considered, although this is likely to introduce inaccuracies in the noise velocity propagation.

In cases where the distance between sensors, which are of the magnetic accelerometer type, do not allow simultaneous listening of the same noise at both ends of the section under scrutiny, then the method cannot be applied. However, hydrophone sensors may be applied on to the main or installed directly in contact with water, with these having a higher noise reception range. This variant is very common for application on plastic pipes or where there are few accessories for sensor installation.

The signal from each of the two installed sensors are typically use radio communication to a central processing console, where the data application will be parameterized, in particular the distance between sensors, mains material and diameter. When using a correlator as an inspection tool, peak in the correlation

Figure 6.17 **Deploying a Correlator**

graph leads to the suggestion that it is a leak is present (Figure 6.18).

The correlation equipment is portable and simple to install and can be operated by one person. For refinement and analysis results, the equipment usually has the option of selecting multiple frequency filters. However, there are some leaks which are very difficult to locate even with a correlator, particularly for low pressure, large diameter mains of non-metallic materials and infrequent contact points for microphone installation.

Before conducting a correlation inspection, a program of leak detection plan should be created, including a site plan with all valves and hydrants to be used in inspection indicated and which must be numbered and ordered, along with a table indicating the total length of pipes and the estimated distance between the test points.

6.2.4.2 Static Pressure Decay Test

This method, potentially also referred to as a water tightness test, is currently used for the detection of leaks in reservoirs and can also be applied to testing of pipes with an ascending longitudinal profile.

In the latter case, the process begins with the installation of a pressure data logger at the lowest elevation point, to be followed by the suspension of all connections to the main and finally closing of the remaining water inlet valve. After this procedure, there should be a drop in the water column pressure to the elevation of the leak. Knowing the layout of the mains elevation, the location of the leak can thus be identified with accuracy depending on the accuracy of the pressure logger (see Figure 6.19).

6.2.4.3 Tracer Gas Injection

This method of detection involves the supply suspension of the mains section where a leak is suspected, where a tracer gas is then injected and subsequently detected on the surface above the mains alignment.

This method is very effective, although costly because it involves consumables, including the tracer gas itself and should be applied only as a last resort. It is estimated that about 20% of water leaks do not produce enough noise for application of acoustic methods, in particular due to reduced pressure or low noise propagation by plastic materials; hence these cases should be considered for this method.

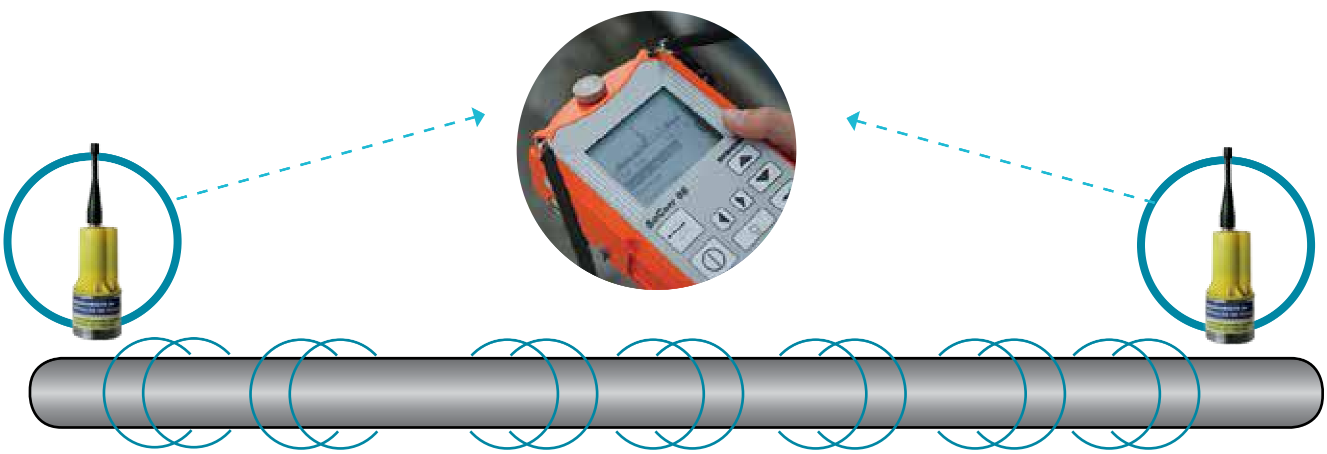


Figure 6.18 Acoustic Correlation and correlation graph

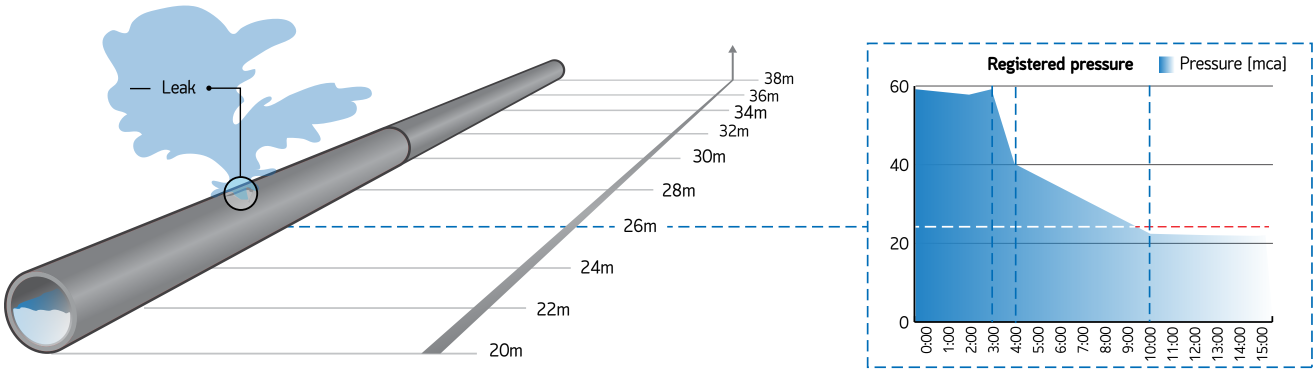


Figure 6.19 **Static Pressure Decay Test**

The process starts with supply suspension of the test section, as well as all service connections, prior to injecting a tracer gas through a hydrant or similar accessory, with sufficient pressure so as to be released through the leak hole in the main (see Figure 6.20). Once stabilized, a gas detector device is used to trace along the surface above the mains being analysed. Once the gas is detected on the surface, concentration values are observed, with higher values corresponding to greatest leak proximity.

Various tracer gases may be used for these tests, with helium or a mixture of hydrogen and nitrogen being the most common for use in mains with water for human consumption. In both cases, the gas has a very small and volatile molecule allowing it to easily escape through a leak hole and allow subsequent detection on the surface.

To implement this method, it first necessary to ensure availability of a sufficient volume of gas to fill the full extent of the main under test, whilst it is important to suspend all service connections or other connecting mains, around the suspected leak location section. The injection process must be as slow as possible to avoid damage to the pipe.

Figura 6.20 **Tracer Gas Injection Method**

7. Organisational changes for Active Leakage Control

Implementation of an integrated monitoring and active leakage control strategy by a utility, usually leads not only to increased operational, financial and environmental efficiency, but also tends to be a catalyst for a profound behavioural change within the organisation.

Indeed, the fact that when utilities change from a relatively passive attitude towards the problem of water losses to a proactive approach, in conjunction with the emergence of positive results arising from the new strategy, this tends to promote an increase in motivation that, initially gives rise to a new dynamism across the utility structure. This permits the various teams to start looking into the problem of water losses as a key objective for the operator, creating the so-called "snowball effect" that, in turn, gives rise to new developments, better analysis and increasing standards requirement, contributing to performance improvement at different levels.

Alternatively, the existence of valuable information made available from monitoring, provides improved knowledge of the supply system and more efficient risk management, particularly in terms of energy optimization and reagent consumption, whilst minimizing impacts to clients resulting from interventions in the network.

In parallel, the implementation of energy efficiency policies can also have an impact on client service and the type of information conveyed to them. It is expected that utility managers may include the theme of conservation and efficient water use in its commercial marketing, raising awareness among domestic, commercial and industrial clients in order to adopt measures that would lead to the elimination or reduction of unnecessary consumption. This can be done by launching awareness campaigns or by including financial incentives in the client tariff in order to reward better economy. Later, when these actions create positive benefits and the majority of clients have adopted improved consumption habits, there is a new type of social judgment, pressing management to maintain or further increase efficiency levels. In this sense, clients will be more sensitive to these issues and demand faster repair of visible leaks, as well as better use of water by utilities.

No less important is the fact that when operational efficiency increases, there is a release of resources, both human and financial, that can be channelled into other activities and which are equally important for any utility, thus contributing to improving overall performance.

In the case of EPAL, productivity of technical teams, as regards leakage, increased significantly since active leakage control activities started to be based on DMA ranking and targeting of the worst performing areas. WONE also gave rise to a cultural change at different levels and areas of the company. Technical areas and commercial department have adopted the concept,

Information available in the WONE application guarantees the sustainable management of EPAL assets, assessing the performance of operational infrastructure, in terms of redundancy and possible replacement, considering efficiency and cost reduction whilst the application is used daily as a management tool and evaluation and also as a tool for distribution network monitoring, safeguarding their performance. Importantly, WONE has enabled the optimization of client service levels and it was thus possible to detect leaks in private networks hitherto unknown by the owners. Currently, information available in the application guarantees the sustainable management of EPAL assets, assessing the performance of operational infrastructure, in terms of redundancy and possible replacement, considering efficiency and cost reduction.

Thus, there is a clear interest in these approaches that a fundamental start should be made as soon as possible on the processes leading to project implementation. This implementation can be undertaken with more or less speed, gradual or phased, but should be guided by an overall objective, taking into account the need to create favourable conditions for essential information and basic tools such as GIS, Client Management System, which can also be iteratively improved, allowing an increase in their contribution throughout the project.

In short, implementation of an integrated monitoring strategy and active leakage control is a worthy option at all levels, contributing to the overall improvement in utility efficiency management, who undertake to safeguard an essential resource for life, namely water.

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