NON REVENUE WATER - INTERNATIONAL BEST PRACTICE FOR ASSESSMENT, MONITORING AND CONTROL

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ABSTRACT

The key to developing a strategy for management of non revenue water (NRW) is to gain a better understanding of the reasons for NRW and the factors which influence its components. Then techniques and procedures can be developed, and tailored to the specific characteristics of the network and local influencing factors, to tackle each of the components in order of priority. This diagnostic approach, followed by the practical implementation of solutions which are practicable and achievable, can be applied to any water company, anywhere in the world, to develop a strategy for NRW management.

The first step in developing a strategy is to ask some questions about the network characteristics and the operating practices, and then use the available tools and mechanisms to suggest appropriate solutions, which are used to formulate the strategy. Typical questions are;

How much water is being lost?
Where is it being lost from?
Why is it being lost?
What strategies can be introduced to **reduce** losses and **improve** performance?
How can we **maintain** the strategy and **sustain** the achievements gained?

The components of NRW can be determined by conducting a **water balance**. This is based on the measurement or estimation of water produced, imported, exported, consumed or lost – the calculation should balance. The water balance calculation provides a guide to how much is lost as leakage from the network ('real' losses), and how much is due to 'apparent' or non-physical losses.

Because of the wide diversity of formats and definitions used for water balance calculations internationally (often within the same country), there has been an urgent need for a common international terminology. Drawing on the best practice from many countries, IWA Task Forces on Water Losses and Performance Indicators have produced an international best practice approach for water balance calculations, including definitions of its components, and for comparing performance between utility operators.

The paper describes the IWA approach to developing a NRW strategy, a water balance calculation, and an international measure of performance - the international leakage index (ILI).

1. INTRODUCTION

Globally, water demand is rising and resources are diminishing. Water loss from the pipe network, always the *bete noire* of the operations engineer, has long been a feature of operations management, even in countries with a well-developed infrastructure and good operating practices. However, it takes on a new dimension in developing countries, where a combination of poor infrastructure, poor sanitation, and intermittent supplies often poses a serious health risk. In water-scarce countries there is also a temptation to augment treated water with untreated in an attempt to satisfy demand.

Yet not all losses are the result of poor infrastructure and leaking pipes. 'Apparent' losses from the network, and excessive use or misuse of water, are often the result of local customs, combined with low tariff structures or inadequate metering policies. These losses, and the overuse of water, can often be reduced by the introduction of demand management and water conservation programmes alongside initiatives to tackle leakage and improve the pipe network. Together, these programmes form a strategy for restoring a potentially huge lost resource.

The key to developing a water loss strategy is to gain a better **understanding** of the reasons for losses and the **factors** which influence them. Then **techniques** and **procedures** can be developed, and tailored to the specific characteristics of the network and local influencing factors, to tackle each of the causes in order of priority. Whilst there is no quick and easy answer to reducing losses, much can be learned from the recent experiences of the UK water industry. Urged on by the regulators to develop 'more robust' procedures for analysing and controlling losses, industry practitioners now have in place a number of techniques for understanding, measuring, and monitoring losses within the distribution network. The UK National Leakage Initiative (1) (1991-1994) provided a model for the concept of understanding losses and developing solutions. Most companies have also introduced programmes to encourage customers to use less water. Such experience has paved the way for the international water industry to develop strategies which can be applied to any water network, irrespective of local characteristics and infrastructure condition, anywhere in the world.

This paper sets out the approach to developing a strategy for leakage management, based on the recently published IWA book '**Losses in Water Distribution Networks -** *A Practitioner's Guide to Assessment, Monitoring and Control*' (2)

2. A STRATEGY FOR WATER LOSS

A diagnostic approach, followed by the practical implementation of solutions which are **practicable** and **achievable**, is recommended for developing a water loss management strategy. However, practitioners working in developing countries will invariably face a slower pace, greater financial constraints, less developed infrastructure, lower levels of skills and technology, and political, cultural and social influences. These all have an influence on the scope for managing losses and demand, and affect the pace at which changes can be brought about. But the aim should always be to make some improvement to the current operational practice. This can be achieved by the transfer of information or new skills, by increasing staff motivation, and - particularly where consultants are used - to always leave something behind besides a report. The first step in developing a strategy is to ask some questions about the network characteristics and the operating practices, and then use the available tools and mechanisms to suggest appropriate solutions, which are used to formulate the strategy. Typical questions are;

How much water is being lost?
Where is it being lost from?
Why is it being lost?
What strategies can be introduced to **reduce** losses and **improve** performance?
How can we **maintain** the strategy and **sustain** the achievements gained?

Figure 1 summarises the tasks required to address each question.

QUESTION	TASK
1. HOW MUCH WATER IS BEING LOST? - Measure components	WATER BALANCE - Improved estimation/measurement techniques - Meter calibration policy - Meter checks - Identify improvements to recording procedures
2. WHERE IS IT BEING LOST FROM? - Quantify leakage - Quantify apparent losses	NETWORK AUDIT - Leakage studies (reservoirs, transmission mains, distribution network) - Operational/customer investigations
3. WHY IS IT BEING LOST? - Conduct network and operational audit	REVIEW OF NETWORK OPERATING PRACTICES - Investigate: historical reasons poor practices quality management procedures poor materials/infrastructure local/political influences cultural/social/financial factors
4. HOW TO IMPROVE PERFORMANCE? - Design a strategy and action plans	UPGRADING AND STRATEGY DEVELOPMENT - Update records systems - Introduce zoning - Introduce leakage monitoring - Address causes of apparent losses - Initiate leak detection/repair policy - design short/medium/long term action plans
5. HOW TO MAINTAIN THE STRATEGY?	POLICY CHANGE, TRAINING AND O&M Training: improve awareness increase motivation transfer skills introduce best practice/technology O&M: Community involvement Water conservation and demand management programmes Action plan recommendations O&M procedures

Figure 1 Tasks and tools for developing a strategy

3. DEFINING WATER LOSS AND LEAKAGE

Water loss occurs in all distribution systems - only the volume of loss varies. This depends on the characteristics of the pipe network and other local factors, the water company's operational practice, and the level of technology and expertise applied to controlling it. The volume lost varies widely from country to country, and between regions of each country. The components of water loss, and their relative significance, also vary between countries. One of the cornerstones of a water loss strategy is therefore to understand the relative significance of each of the components, ensuring that each is measured or estimated as accurately as possible, so that priorities can be set via a series of action plans. The expressions **'water loss'** and **'non-revenue water' (NRW)** are now internationally accepted, and have replaced expressions such as 'unaccounted-for water' (UFW) which are less consistent and which make inter-country comparisons more difficult.

Water loss = water produced – water billed or consumed

It is important to differentiate between water loss and leakage. The International Water Association has defined water loss as;

Water loss = 'real' losses + 'apparent' losses

The expression 'real losses' has replaced the expression 'physical losses'. 'Apparent' losses has replaced 'non-physical' losses, and 'management' losses.

Real losses comprise **leakage** from pipes, joints and fittings, from leakage through service **reservoir floors and walls,** and from **reservoir overflows.** Real losses can be severe, and may go undetected for months or even years. The volume lost will depend largely on the characteristics of the pipe network and the leak detection and repair policy practised by the company, i.e.;

- the pressure in the network
- the frequency and typical flow rates of new leaks and bursts
- the proportions of new leaks which are 'reported'
- the "awareness" time (how quickly the loss is noticed)
- the "location" time (how quickly each new leak is located)
- the repair time (how quickly it is repaired or shut off)
- the level of "background" leakage (undetectable small leaks)

These influences were acknowledged in the research programme undertaken by the UK National Leakage Initiative (1). There is a vast difference in volume lost from leaks in the different parts of the distribution network., as shown by the results from the research programme, summarised in Figure 2.

Leakage is usually the major component of water loss in **developed** countries, but this is not always the case in **developing** or **partially developed** countries, where illegal connections, meter error, or accounting errors are often more significant.

3. THE WATER BALANCE

This calculation allows the practitioner to answer the first question posed in Section 1 - '**how much water is being lost'?**

Because of the wide diversity of formats and definitions used for water balance calculations internationally (often within the same country), there has been an urgent need for a common international terminology. Drawing on the best practice from many countries, the International Water Association (IWA), through its Task Forces on Water Losses and Performance Indicators has developed an international 'best practice' standard approach for Water Balance calculations (Figure 3), with definitions of all terms involved.

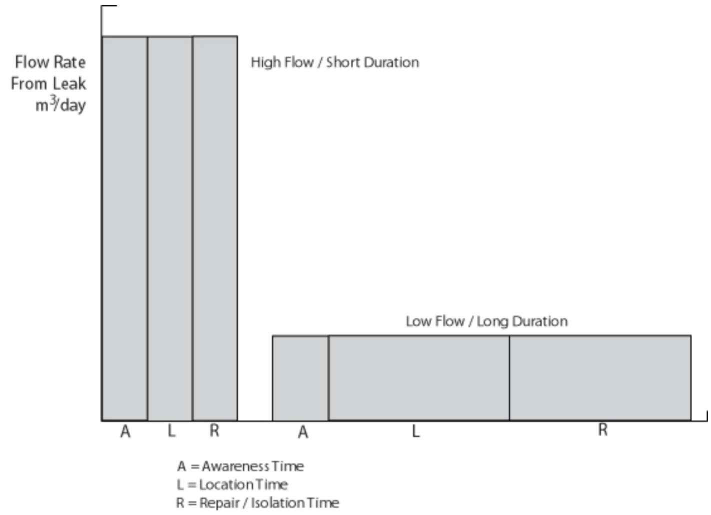

Figure 2. Relative losses from a distribution main and a service pipe

<table>
<tr><td rowspan="9">System Input Volume (corrected for known errors)</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility’s Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer metering</td></tr>
</table>

Figure 3. IWA Standard International Water Balance and Terminology

Abbreviated definitions of principal components of the IWA water balance are as follows:

- System Input Volume is the annual volume input to that part of the water supply system
- Authorised Consumption is the annual volume of metered and/or non-metered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorised to do so. It includes water exported, and leaks and overflows after the point of customer metering.
- Non-Revenue Water (NRW) is the difference between System Input Volume and Billed Authorised Consumption. NRW consists of:
    - Unbilled Authorised Consumption (usually a minor component of the Water Balance)
    - Water Losses
- Water Losses is the difference between System Input Volume and Authorised Consumption, and consists of Apparent Losses and Real Losses
- Apparent Losses consists of Unauthorised Consumption and all types of metering inaccuracies
- Real Losses are the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

4. NETWORK AUDIT

Most water companies are able to provide estimates of production and consumption, but less able to estimate the other components. The network audit allows the practitioner to measure volume flows across the network to support the water balance calculation and helps to provide answers to the second question **- 'where is water being lost from'?**

Measurements can be made in several ways;

- from existing production meters (ca1ibrated or checked)
- from existing bulk meters
- from reservoir drop tests
- by checking pump curves or unmeasured production with insertion meters
- by checking metered consumption (sample of consumer meters checked for accuracy and under-registration at low flows)
- by checking operational use and unmeasured supplies.

The procedure in less developed countries may be prevented by loca1 practices and influences, e.g ummeasured supplies or illegal connections to peri-urban areas and slums these can on1y be quantified in a sample study area

4.1 Measuring leakage

Leakage studies help to quantify leakage from the component parts of the network **-** from service reservoirs, transmission mains, and the distribution network

Leakage from **reservoirs** can be measured by reservoir drop test. In1et and outlet valves are closed and the drop in water level is measured over time. If the reservoir has compartments, each can be monitored in turn. Drop tests are usually carried out at night to minimise disruption to supply.

Overflows from reservoirs are caused by faulty float valves. These should be inspected when reservoir is at top water level, and the volume lost measured over the period when the reservoir is overf1owing.

To measure leakage from **transmission mains** insertion meters or clamp-on ultrasonic meters are positioned at each end of the main to calculate change in volume f1owrate. Alternatively these mains can be included in the zones to measure distribution system leakage.

To measure leakage in the **distribution network -** from the company's mains, service connections and fittings, it is first necessary to create zones, or use an existing reservoir supply zone, and then use bulk meters to measure night flows into the zone. Measured night use is subtracted. Smaller zones, called District Meter Areas (DMAs) can be created within large zones to improve the quality of the data, and can be used as permanent zones for leakage monitoring. DMAs are small zones of 500-3000 households within a supply zone. Each DMA is a discrete zone, with a defined and permanent boundary. Flows into (and out of) each DMA are monitored by a flowmeter. Night flow measurements are used to calculate leakage in the distribution system (distribution mains, service connections and fittings), after subtracting customer night use

When each of the components of leakage have been quantified, the data can be used to improve the water balance calculation, and to prioritise leakage management activities.

5. REVIEW OF NETWORK OPERATING PRACTICES

A review of the network and how it is operated addresses the question '**why is water being lost'**? It reflects the company's management of its network, and can be answered by carrying out an appraisal of the physical characteristics of the network and the current operational practice. The review usually reveals the good practices as well as the problems caused by poor infrastructure and bad management practice.

The review should assess;

- particular country or regional characteristics, influencing factors, components of water loss
- the condition of the network
- current practice and methodologies used for operating and managing the network, including the facilities for monitoring flows, pressures and reservoir stocks

the level of technology for monitoring and detecting leakage

- staff skills and capabilities

Particular tasks should include;

a) Discussions with senior staff - i.e. directors and senior managers on current management practice, perceptions, financial and political constraints and influences, and future planning

b) Discussions with operational staff on system features and practice, including

- physical data (population, demands, topography, supply arrangements, mains length, number of service connections, customer meter location, average pressure)
- drawings and records, billing data
- measurements or estimates of system input volumes
- estimates of authorised and unauthorised consumption estimates of non-revenue water components and performance indicators based on the IWA approach, with confidence limits
- current practice (staffing structure, staff numbers and skills)
- techniques and equipment
- repair programme
- economic data (cost of water etc)

c) Field visits - to appraise current practice and skills

d) Selection of a suitable pilot area - for a future project to demonstrate techniques and equipment, gather results and show benefits, and to train staff.

6. UPGRADING AND STRATEGY DEVELOPMENT

The aim of this stage is to begin reducing losses and improve network performance. Not all countries or regions have the luxury of well-developed network infrastructure - many are struggling to ensure that customers receive a reasonable water supply to sustain health and life, often in a network with an outdated infrastructure, with poor record systems, with inadequate technical skills and technology, an unsuitable tariff structure or revenue collection policy, and a poor operation and maintenance policy. This section addreses the question **'how to improve performance'?** It reviews the tasks required to update or modify the infrastructure to address such issues, and to implement the required changes.

6.1 The zoning concept

The principle of dividing the supply network into sub-networks is well-established. Traditional open systems, while maximising the use of the mains network and allowing free flow from all sources of supply, can cause a number of problems for the operator, with the network being subjected to mixing of water from sources of differing quality and pressure. An open system is also vulnerable to pump failure or loss of power supply, poor system information, and poor control. By dividing the network into smaller 'compartments' the water engineer can understand and more easily analyse pressure and flow profiles and problem areas. Such zones are operationally easier to manage, and allow monitoring and control systems to be implemented more easily.

Zones can be created as discrete pressure areas, e.g a zone which cannot be supplied by gravity can be isolated by boundary valves and supplied by a booster pump. Zones can be created to separate water supplied from different sources, to minimise quality problems. The zoning hierarchy concept, and the creation of smaller zones, is illustrated in Figure 4.

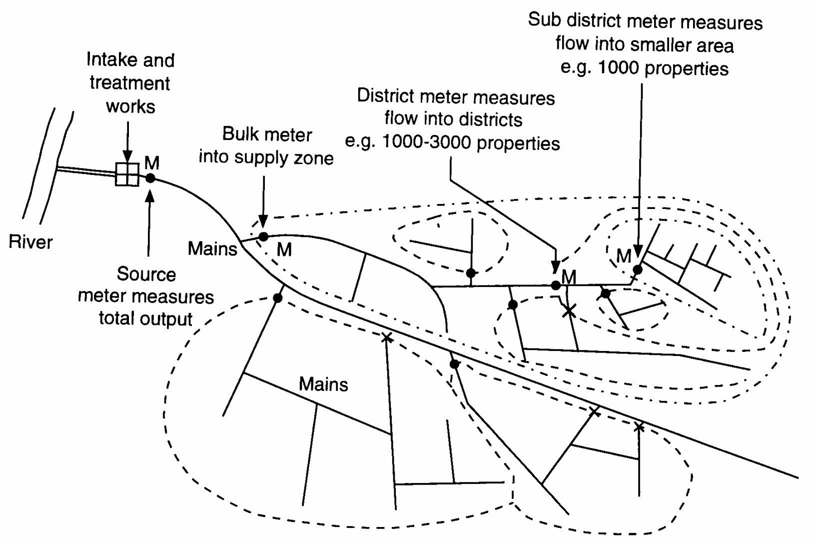

Figure 4. Metering hierarchy and DMA design options (from UKWIR 'Managing Leakage')

In any network, closing too many valves reduces the capacity of the network and may lead to operational or water quality problems. Therefore, wherever possible zone boundaries should be natural hydraulic and geographic boundaries, to minimise the number of mains crossing them. Examples of such boundaries are railways, rivers, canals, and main highways. There is usually some degree of redundancy in the mains network to allow zoning without causing supply problems. The ideal zone will have the following characteristics:

- single source, to minimise quality complaints
- single metered input, to maximise accuracy of flow metering and leakage data

The sequence for creating zones is:

- identify possible zone boundaries using maps, mains records and site inspection
- carry out an audit of the proposed zone, including checking the status and condition of proposed boundary valves
- collate data on the zone characteristics (number of properties, industrial consumption etc.)
- measure zone flows and pressures by network analysis or field test
- isolate the zone and collect diurnal flow and pressure data using survey meters and pressure gauges/transducers
- calculate the required meter size
- evaluate the potential for pressure management
- install equipment
- mark boundary valves with a clear identifier

6.2 Flow metering

It is vitally important to know accurately the load on the network. Continuous flow measurement at the source or reservoir outlets with data transmitted instantaneously to the operational centre is the ideal, but chart recorders or digital data loggers can be effective substitutes. Effective management of the network relies on the ability to monitor flows continuously, at a minimum of hourly intervals throughout the day.

An accurate population count is also of prime importance, as derived data such as per capita demand provides information on growth of demand over time, leakage etc.

Effective metering is an essential feature of network management, particularly for measuring flows into and out of each zone measured to provide data for the water balance calculation.

6.3. Leakage management policies

A water balance should identify the priorities to address in a water loss strategy. Reduction of real losses, or leakage, will, in most networks, be directly influenced by infrastructure improvement, pressure management, and a programme of active leakage control, as illustrated in Figure 5. A programme to address apparent losses will usually be dependent on longer term changes to metering, regulatory and legislative policies.

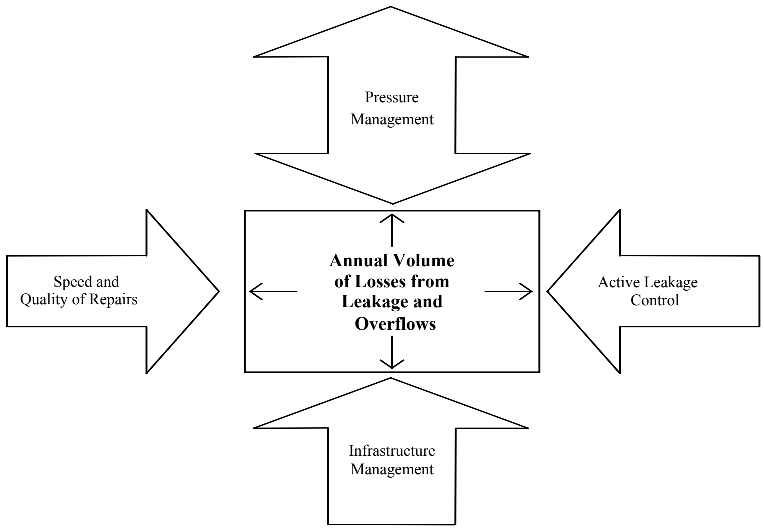

Figure 5. The Four 'Pillars' of Leakage Management

Pressure management

Pressure management is one of the fundamental elements of a well-organised leakage management strategy. The most cost effective schemes are those which cover a large area, and which make a significant impact on average pressures. Pressure management is best undertaken in conjunction with district metering, or when establishing supply zones. As well as the reduction in pressure, good pressure management will also result in more stable pressures, causing less strain on the pipe network, and less chance of fatigue damage at joints.

Active Leakage Control

When first undertaking leakage detection and repair work, leaks will be relatively easy to find. A backlog may have built up due to under investment in previous years resulting in fewer leaks being found and fixed than occur in any given year. However, once the more obvious mains and service bursts have been found, then a higher level of effort has to be put in to reduce leakage by a similar volume.

Infrastructure management and repair policy

Replacing an old water main with a new installation will undoubtedly reduce leakage from the main. However, unless the service connections are also renewed, the benefit may not be a great as first estimated. Reducing the time it takes to repair a leak will also reduce the volume of leakage.

For any water distribution system there is a level of leakage below which is it not cost effective to make further investment, or use additional resources, to drive leakage down further. In other words, the value of the water saved is less than the cost of making the further reduction. This point is known as the economic level of leakage (ELL).

The following sections deal with selecting the most appropriate methodology and technology to support a leakage management strategy.

Leakage management can be classified into 2 groups;

- passive (reactive) leakage control
- active leakage control (ALC)

Passive control

Passive control is reacting to reported bursts or a drop in pressure, usually reported by customers or noted by the company's own staff while carrying out duties other than leak detection. The method can be justified in areas with plentiful or low cost supplies. Often practised in less developed supply systems where the occurrence of underground leakage is less well understood, it is the first step to improvement (i.e. to make sure all visible leaks are repaired). Except in exceptional circumstances leakage will continue to rise under passive control.

Active leakage control (ALC)

Active leakage control is when company staff are deployed to find leaks which have not been reported by customers or other means

The main methods of ALC are

- regular survey
- leakage monitoring

Regular survey is a method of starting at one end of the distribution system and proceeding to the other using one of the following techniques;

- listening for leaks on pipework and fittings

- reading metered flows into temporarily-zoned areas to identify high-volume night flows
- using clusters of noise loggers

Leakage monitoring is flow monitoring into zones or districts to measure leakage and to prioritise leak detection activities. This has now become one of the most cost-effective activities (and the one most widely practised) for leakage management.

6.4 Selecting the most appropriate policy

The most appropriate leakage control policy will mainly be dictated by the characteristics of the network and local conditions, which may include financial constraints on equipment and other resources. Staffing resources are relevant, as a labour intensive methodology may be suitable if manpower is plentiful and cheap. If the geology of the area allows a high proportion of leaks to appear at the surface (e.g. parts of the Middle East and Australia), a policy of regular survey followed by rapid repair may be adequate. Where some leaks fail to appear at the surface, however, a more intensive policy of leakage monitoring is required.

The main factor governing choice, however, is the value of the water, which determines whether a particular methodology is economic for the savings achieved. A low activity method, such as repair of visible leaks only, may be cost-effective in supply areas where water is plentiful and cheap to produce. On the other hand, countries which have a high cost of production and supply, like the Gulf States, can justify a much higher level of activity, like continual flow monitoring, or even telemetry systems, to warn of a burst or leakage occurring.

In many developing countries the method of leakage control is usually passive, or low activity, mending only visible leaks or conducting regular surveys of the network with acoustic or electronic apparatus.

The volume lost from a leak (Figure 2) is a combination of the flow rate together with the awareness time and the time taken for location and repair;

- **Awareness time** – the average time from the start of a leak until the water company becomes aware of its existence
- **Location time** – the average time taken to locate the position of the leak
- **Repair time -** the average time for the company to shut off and repair the leak

The main effect of an ALC policy is reducing the average **duration** of leaks.

The **awareness** time is influenced by the data capture method;

- Telemetered flows – less than 1 day
- Monthly night flow measurements – 14 days
- Regular inspections – half the interval between inspections

The **location** time will be influenced by the nature and extent of monitoring systems, but mainly by the number of staff available and the equipment and technology at their disposal.

The **repair** time will normally be the same for leaks reported by customers or detected by proactive means. However, one of the main initiatives of a leakage management strategy should be to reduce the time taken to repair leaks once they have been located.

6.5 Leak detection in zones

A flow measuring system in a water distribution network should include not only measurement of total flows from source or treatment works (production), but also zone and district flows. This allows the engineer to understand and operate the system in smaller areas, and allows more precise demand prediction, leakage management and control to take place.

The measurement system must therefore be hierarchical, i.e. at a number of levels, beginning at production measurement, via zone and district measurement and ending at the consumer's meter or consumption estimate. This hierarchy is illustrated in Figure 4.

The system comprises:

- measurement of supply at the source or treatment works
- measurement of flow into supply zones, with geographic or hydraulic boundaries, usually 10000-50000 properties
- flow monitoring into district meter areas (DMAs) of up to 3000 properties, with permanently closed boundary valves
- small leak location areas within each DMA, of around 500-1000 connections, where boundary valves remain open except during a leak location ("step test") exercise
- individual consumer meters, both domestic and commercial

6.6 Leakage monitoring

The technique of leakage monitoring is considered to be the major contributor to cost-effective and efficient leakage management. It is a methodology which can be applied to all networks. Even in systems with supply deficiencies leakage monitoring zones can be introduced gradually. One zone at a time is created and leaks detected and repaired, before moving on to create the next zone. This systematic approach gradually improves the hydraulic characteristics of the network and improves supply.

Leakage monitoring requires the installation of flow meters at strategic points throughout the distribution system, each meter recording flows into a discrete district which has a defined and permanent boundary. Such a district is called a District Meter Area (DMA), and the concept of design and operation of DMAs has beeen detailed in two WRc reports: 'District Metering - System Design and Installation' (3), and 'District Metering - System Operation' (4). The DMA concept was reviewed in 'Managing Leakage' - Report J (1), in 1994, and was updated by UKWIR in 1999 with the report 'A Manual of DMA Practice (5)

The design of a leakage monitoring system has two aims:

(a) To divide the distribution network into a number of zones or DMAs, each with a defined and permanent boundary, so that night flows into each district can be regularly monitored, enabling the presence of unreported bursts and leakage to be identified and located
(b) To manage pressure in each district or group of districts so that the network is operated at the optimum level of pressure

Depending on the characteristics of the network, a DMA may be:

(i) supplied via single or multiple feeds;
(ii) a discrete area (i.e. no flow into adjacent DMAs)
(iii) an area which cascades into an adjacent DMA

It therefore follows that a leakage monitoring system will comprise a number of districts where flow is measured by permanently installed flowmeters. In some cases the flowmeter installation will incorporate a pressure reducing valve.

Figure 6 shows an example of the configuration of several DMA types within a 'water into supply' (WIS) zone boundary, and the DMA recording system;

- a transmission main DMA (501D04)
- a discrete DMA off a transmission main branch connection (501D03)

- a cascading DMA (501D02/501D01)

The DMA meters are sometimes linked to a central control station via telemetry so that flow data are continuously recorded. Caution is needed if telemetry is to be considered, as the cost can quickly escalate and exceed the value of the water lost. Analysis of these data, particularly of flow rates during the night, determines whether consumption in any one DMA has progressively and consistently increased, indicating a burst or undetected leakage.

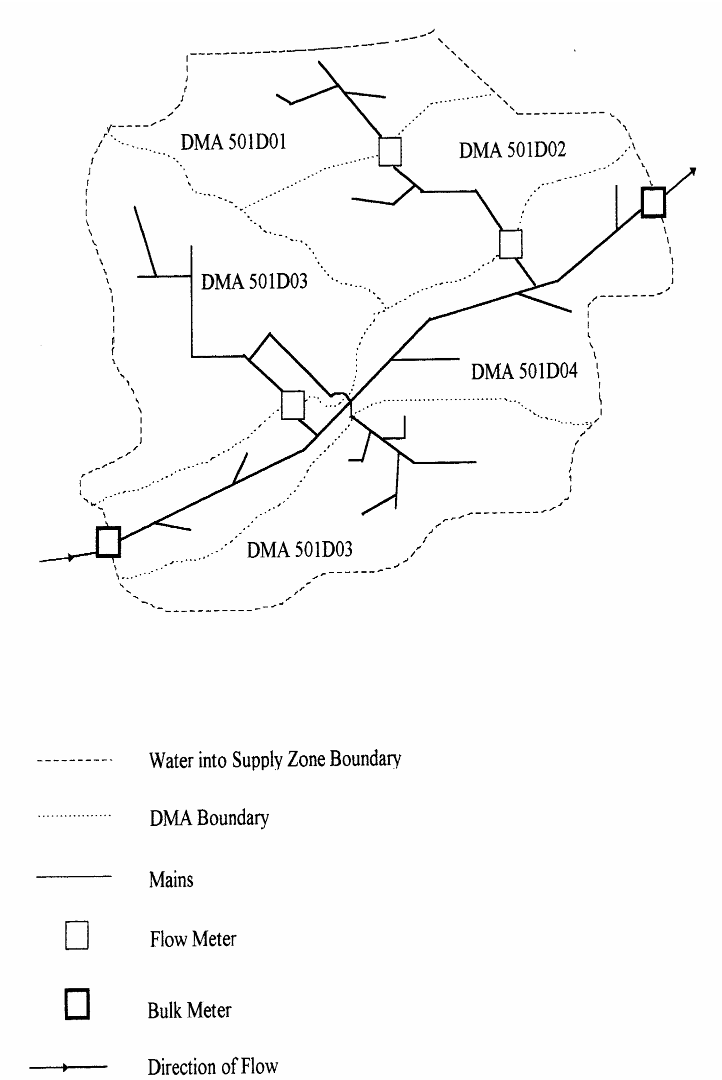

Figure 6. DMA types

It is important to understand the composition of night flow, as this will be made up of customer use as well as losses from the distribution system.

Culprit areas, i.e. ones showing a greater volume of night flow per connection than the others, can then be inspected more thoroughly by carrying out a **leak localising** exercise. Examples of these are:

- step test - a technique which requires the progressive isolation of sections of pipe by closing line valves, beginning at the pipes farthest away from the meter and ending at the pipe nearest the meter. During the test the flow rate through the meter is observed and the times when each section of pipe is isolated is noted. A large decrease in flow, or "step", indicates a leak in the section of pipe which has just been isolated.

- correlator survey
- acoustic logger survey

Inspectors can then be deployed to locate the precise leak position in the culprit section of pipe.

In some developing countries it may be a difficult concept to introduce more closed valves in a system, particularly in low pressure areas or those with intermittent supplies. The benefits can be best demonstrated in pilot areas, when the benefits of leakage reduction on increased pressures and satisfied demand can be clearly seen by the customers. .

6.6 Finding the leaks

Detection and control of leakage varies from company to company, and the choice of methodology is largely dependent on local conditions, which may include financial constraints on equipment and other resources. Staffing resources are relevant, as a labour intensive methodology may be suitable if manpower is plentiful and cheap. The main factor governing choice of technology, however, is whether a particular methodology is economic for the cost savings achieved. A low activity method, such as repair of visible leaks only, may be cost-effective in supply areas where water is plentifu1 and cheap to produce. On the other hand, countries which have a high cost of production and supply, like the Gulf States, can justify a much higher level of activity, like leakage monitoring, or even telemetry systems, to warn of a burst or leakage occurring. In most developing countries the method of leakage control is usually of low to medium activity, mending only visible leaks or conducting regular surveys of the network with acoustic or electronic apparatus.

Leak location is carried out using one or more of the following pieces of equipment;

- basic sounding stick
- electronic sounding stick
- ground microphone
- leak noise correlator

The basic instrument is the sounding stick, which is used either as a simple acoustic instrument, or one which is electronically amplified. This technique is still widely preferred by the majority of practitioners, and is used for;

- blanket surveys, sounding on all fittings
- sounding on valves and hydrants
- confirming the position of a leak found by other instruments (ground microphone, leak noise correlator)

The ground microphone can be assembled for use in either of two modes, contact mode and survey mode. Contact mode is for sounding on fittings, similar to an electronic listening stick. Survey mode is used to search for leaks on lengths of pipeline between fittings. The technique involves placing the microphone on the ground at intervals along the line of the pipe and noting changes in sound amplification as the microphone nears the leak position. When a leak is detected the ground microphone is used in either mode for leak location.

The leak noise correlator is the most sophisticated of the acoustic leak location instruments. Instead of depending on the noise level of the leak for its location, it relies on the velocity of sound made by the leak as it travels along the pipe wa1l towards each of two microphones placed on convenient1y spaced fittings. Hydrophones can also be used to enhance the leak sound in plastic pipes or large pipes. There is no doubt that the latest versions of the correlator can accurately locate a leak (to within 1.0 metres) in most sizes of pipe. The instrument is portable so can be operated by one man, and it has the capability for frequency selection and filtering.

Other technologies

There are a number of other location methods, both acoustic and non-acoustic, which are usually used when acoustic methods fail to find the leak. The most commonly used alternative is **gas detection.** This uses industrial hydrogen (95% nitrogen, 5% hydrogen). The gas is introduced into the pipeline, and is detected by an 'electronic nose' at the leak position as it diffuses through the ground surface. This technique is being increasingly used for locating leaks in non-metallic pipes, and the small leaks associated with house service connections.

Another technology which is becoming an alternative to the correlator in large transmission mains is **in-pipe acoustic** location, where a microphone is inserted into a pressurised main through an air-valve. The microphone cable is calibrated to measure the distance from the entry point to the leak, which is identified and recorded as the microphone passes by.

6.7 Measuring Performance

NRW has, for many years, been quoted only or principally in % terms. Accordingly many non-specialists, including politicians and the media, incorrectly believe that this is the most meaningful measure of performance for NRW and all it's components. So targets are often set, or suggested, at national level in percentage terms. While this is undoubtedly better than setting no targets at all, it discriminates against utilities with low consumption (low system loading), higher than average operating pressures (due to topography), and NRW calculations which include leakage on customers' private pipes. Depending upon the consumption per service connection, the same volume of real losses could, in percentage terms, be anything from 44% to 2.4%. Thus, countries with relatively low consumption, such as Malta, England/Wales, and many developing countries, can appear to have high losses when expressed in % terms; in contrast, % losses for urban areas in developed countries with high consumption can be equally misleading.

When consumption decreases, seasonally or annually, or due to demand management measures, the percentage of real losses increases even if the volume of real losses remains unchanged. When consumption increases, the opposite effect occurs.

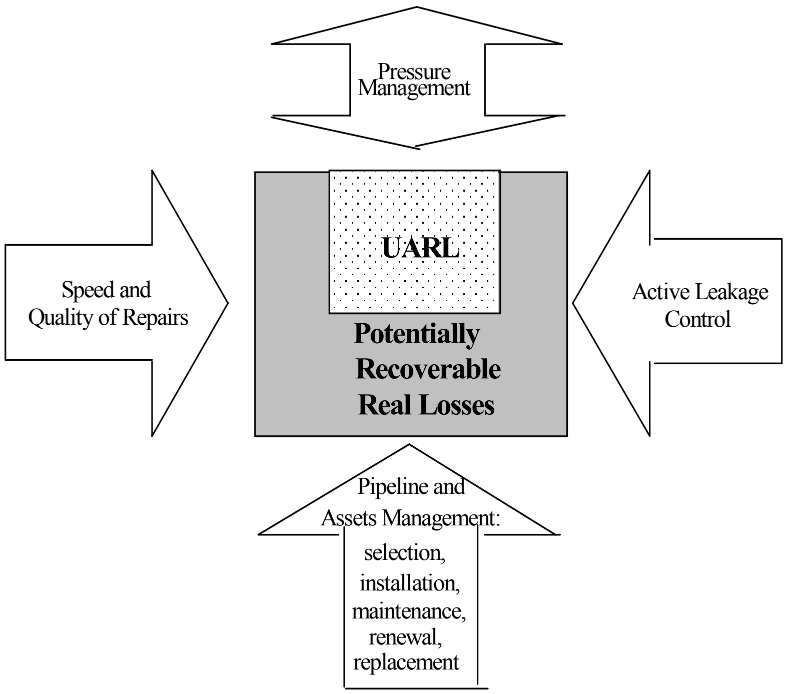

Figure 7. The Four Basic Methods of Managing Real Losses

The International Water Association (IWA) has, through its Water Loss Task Force, developed a method of performance comparison which can be used by a water utility to measure its own success following the introduction of a leakage strategy. It also allows inter-company and inter-country comparisons. The performance measure is the **international leakage index (ILI)**. The index is calculated from the ratio of current annual real losses to unavoidable annual real losses. Figure 7 demonstrates the effect of operating practices on real losses, which will reduce when more efficient operating practices are introduced - the basis for developing a leakage management strategy. The difference between the Unavoidable Real Losses (UARL) in the small rectangle and the Current Annual Real Losses (CARL) in the large rectangle is the potentially recoverable Real Losses. The ratio of the Current Annual Real Losses (CARL) to the Unavoidable Annual Real Losses (UARL) is the Infrastructure Leakage Index (ILI).

The ILI measures how effectively the infrastructure activities - repairs, active leakage control and infrastructure management – are being managed at current operating pressure.

For each of the four activities, there is some economic level of investment and activity, which needs to be calculated or assessed, depending upon the marginal value, in local currency/m^3, placed on the real losses. Depending upon local circumstances and practice this marginal value may be low – perhaps power and chemicals cost only – or high, and this profoundly influences the economic management policies for controlling real losses.

7. MAINTAINING THE STRATEGY

This last section addresses the question **'how to maintain the strategy'** and how to sustain the improvements gained from it? This may require some changes to policies, and will almost certainly require the introduction of operation and maintenance programmes.

At some stage, in all organisations, it becomes necessary to examine the policies for producing and delivering water. Some policies relate to managing elements of the infrastructure - pipework characteristics and condition, and the way in which it is operated and maintained - upgrading and managing the infrastructure has been addressed in previous chapters.

Other policies are largely organisational - they relate to how the company views its relationship with its customers, and having the appropriate staffing and regulatory frameworks in place to deal with its main function - to produce and deliver water to its customers. Such policies are very subjective - they are influenced not only by the physical and local characteristics of the network, and the social and cultural attitudes of the customers, but by the structure of the company itself, whether public or privately owned, or public/private sector partnerships. In this case the organisation will have other drivers to consider, such as the interests of directors, shareholders, political and financial pressures, as well as customer and public perception. There are also increasing environmental risks of balancing new resources against the need to meet ever-increasing customer demand. Such policies include:

- demand management and water conservation
- regulatory and legal frameworks
- customer metering policy, tariff structures, and revenue collection

7.1 Customer metering policy

Most countries have some form of household metering or other charging structure for water used. However, water companies in many developing countries set low or flat rate tariffs, water rates which are subsidised by government, or provide free water. Although this is frequently in the interests of low-income customers, to maintain health and hygiene, it does tend to become the expected norm, and is frequently a politically sensitive issue, especially during local elections. However, there are severe disadvantages to a water company of a allowing zero- or low-rated tariff structure and not charging an economic rate for water:

- it does not encourage sensible use
- it does not encourage the mending of customer leaks
- the company has no incentive to install an active metering and meter replacement policy
- insufficient revenue is generated to provide a sustainable operation, maintenance and repair programme

Often, even on low tariffs, customers (both household and non-household) will vandalise or by-pass meters to save paying. Usually a review of a company's customer metering policy and tariff structure is included in the strategy development procedure.

Correcting the metering policy and tariff structure policy, in conjunction with other water conservation initiatives, is a major step towards reducing customer demand. To overcome adverse reaction from customers and to assuage political sensitivities, a pilot study could be designed within a water loss study programme. The study would include reading a sample of customer meters to check;

- how many meters are working and how many are stopped
- which of those not working are due to meter malfunction, deliberate vandalism, or bypassed (illegal connection)
- how accurate they are (under-registration).

Meter accuracy can be checked by installing a calibrated 'check' meter downstream of the meter on test. Companies should be encouraged to install class C or D meters**.** This is an international standard, referring to highly accurate meter which uses a smaller inferential head whilst retaining the same size meter body, and which improves accuracy at very low flows. Locally made meters should be viewed with caution, as they are usually not off Class C or D standard.

Once the pilot area meter data have been analysed a sample of houses can be fitted with class C or D meters to demonstrate the difference, and to measure customer flows for the water balance calculation. Also demonstrated is the equitability of paying for water used, even if the tariff is low, and particularly in countries where water is scarce.

A tariff system on a rising scale can be introduced for non-household customers, again to encourage water conservation practices. A regular meter replacement programme should be introduced for these customers, particularly high revenue customers, to ensure that the company continues to maximise its revenue. Some companies have a policy where high revenue meters are changed every 5 years.

7.2. Technology transfer and training

Training staff in new skills and techniques features highly in developing a leakage management strategy and for ensuring sustainability. It encompasses the motivation of staff, transfer of skills in the techniques and technology of leakage management, and system operation & maintenance. There is a need to address the tasks, the problems and the constraints associated with introducing a leakage management programme at all levels within the company. It is important that an understanding of the principles of the programme, the steps in its design and implementation, and support for the tasks involved, filters down from senior management level to operations level. A training programme will therefore include;

- awareness seminars for senior staff and decision makers (and also to raise public awareness)
- training workshops for engineering and technical staff
- continuous practical training for operations staff.

7.3 Operation and Maintenance

Operation and Maintenance (O&M) is crucial to the successful management and sustainability of water supply networks, whatever the level of technology, infrastructure, and institutional development. The O&M philosophy applies as much to boreholes and hand-pumps as it does to complex water distribution networks. It requires forward planning and technology transfer at all stages from installation of plant and equipment, through operator training and hand-over, to routine operation and upkeep. O&M therefore encompasses equipment selection, spares purchasing and repair procedures as well as best practice in operating and maintaining the system. It is essential that an O&M programme is built into the project from an early stage and not as an afterthought.

8. CONCLUSIONS

Traditionally water loss management and leak detection have been treated as an afterthought in network operations. However, in recent years a water loss strategy has become one of the major operational tasks of the distribution network. This has resu1ted from a combination of global water shortages, privatisation and regulation, and making companies increasingly accountable to customers, shareholders and regulators.

This paper presents an overview of the stages of developing a water loss strategy described in the book - 'Losses in Water Distribution Networks - a Practitioner's Guide to Assessment, Monitoring and Control' (2), which addresses in detail the steps required to design and implement such a strategy. One of the planks of the strategy is to set up procedures for accurately assessing the volume of Non Revenue Water (NRW), so that policies and action plans to reduce water loss to an economical level which are appropriate, achievable and practicable for the network characteristics, can be put in place

It is possible that countries which do not have such procedures, or a strategy for developing them, are seriously under-estimating total losses. The models developed by the International Water Association for understanding, measuring, monitoring and comparing losses, and the mechanisms for supporting it, can be applied to any water network, anywhere in the world.

9. REFERENCES

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