Developing a Non-Revenue Water Reduction Strategy Part 1: Investigating and Assessing Water Losses

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Abstract: The gap between the sophisticated Non-Revenue Water reduction programmes in well managed water utilities and the situation in many of the world's water utilities (and especially in utilities in developing countries) is widening at a fast pace. In the last decade a comprehensive set of analytical tools, water loss reduction strategies and specialised equipment has been developed. The work of the IWA Operation and Maintenance Specialist Group in general and its Water Loss Task Force in particular has led to a set of performance indicators ideally suited to assess the water loss situation and to quantify the components of NRW. This paper is the first part of the outline of a basic NRW reduction strategy and is intended to motivate utility managers to establish a standard water balance, calculate the level of NRW, quantify its components and identify main problem areas. A separate paper, part 2 of this strategy, will deal with the planning of the strategy and its implementation.

Keywords: Non-Revenue Water, NRW, Water Balance, Performance Indicators

Introduction

Twenty years ago, leakage management was more based on a process of 'guesstimation' than on precise science. This has changed dramatically, kick-started by the regulatory pressure on UK water companies to cut leakage. Significant advances have been made in the understanding and modelling of water loss components and on defining the economic level of leakage for individual systems. Yet, despite some encouraging success stories, most water supply systems worldwide continue to have high levels of water losses.

Part of the problem was the lack of a meaningful standard approach to benchmarking and reporting of leakage management performance. Surprisingly few countries have a national standard terminology and standard water balance calculation …and even then, they all differ from each other!

Being aware of the problem of different water balance formats, methods and leakage performance indicators, the IWA has developed a standard international water balance structure and terminology (Alegre H. et al, 2000). This standard format has meanwhile been adopted (with or without modifications) by national associations in a number of countries and most recently the American Water Works Association (AWWA). The aim of this paper is to convince managers of water utilities with still high (or unknown) levels of water losses that the introduction of these new concepts will be an important first step towards more efficiency.

Investigations and Data Collection

The components of the water balance can be measured, estimated or calculated using a number of techniques. Whilst in ideal cases many of the important components are measured, the reality unfortunately is often very different. Often utility managers do not even start to establish a water balance as key data, such as the total system input, is not really known. The main message of this paper is that it always worth trying to establish a water balance, even if main elements are based on estimates. By doing this, it will be possible to produce a catalogue of required actions in order to improve the accuracy of the water balance. The paper will describe what data have to be collected and how to estimate the unknown elements.

Establishing a Standard Water Balance

The level of water losses can be determined by conducting a Water Audit (North American Term) with the results shown in a Water Balance (International Term). To be consistent with the new international terminology, the term Water Balance has been used in this paper. A Water Balance is based on measurements or estimations of water produced, imported, exported, used and lost.

System Input Volume	**Authorized Consumption**	**Billed Authorized Consumption**	**Billed Metered Consumption**	**Revenue Water**
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	**Unbilled Metered Consumption**	**Non-Revenue Water**
			Unbilled Unmetered Consumption	
	Water Losses	**Apparent Losses**	**Unauthorized Consumption**	
			Metering Inaccuracies and Data Handling Errors	
		Real Losses	**Leakage on Transmission and/or Distribution Mains**	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to Point of Customer Metering	

Figure 1: Standard IWA Water Balance

Water utilities around the world have always established water balances but unfortunately, a wide diversity of formats and definitions is used, often within the same country. So it was (and still is) virtually impossible to compare UfW, NRW, leakage or water losses of different utilities. Being aware of the problem of different water balance formats and methods, the IWA was established a standard water balance (Figure 1 above).

Step 1 – Determining System Input Volume

When the entire system input is metered, the calculation of the annual system input should be a straight forward task. Ideally the accuracy of the input meters is verified, using portable flow measuring devices. If discrepancies between meter readings and the temporary measurements are discovered, the problem has to be investigated and, if necessary, the recorded quantity has to be adjusted to reflect the real situation.

Should there be some unmetered sources the annual flow has to be estimated by using any (or a combination) of the following: (i) temporary flow measurements using portable devices, (ii) reservoir drop tests or (iii) analysis of pump curves, pressures and average pumping hours.

Step 2 – Determining Authorized Consumption

Billed Metered Consumption

The calculation of the annual billed metered consumption goes hand in hand with the detection of possible billing and data handling errors, information later on required for the estimation of apparent losses. Consumption of the different consumer categories (e.g. domestic, commercial, industrial) have to be extracted from utility's billing system and analysed. Special attention shall be paid to the group of very large consumers.

Billed Unmetered Consumption

Billed unmetered consumption can be obtained from the utility's billing system. In order to analyse the accuracy of the estimates, unmetered domestic customers should be identified and monitored for a certain period, for example by measuring a small area with a number of unmetered customers.

Unbilled Metered Consumption

The volume of unbilled metered consumption has to be established similar to that of billed metered consumption.

Unbilled Unmetered Consumption

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

- mains flushing: how many times per month? for how long? how much water?
- fire fighting: has there been a big fire? how much water was used?

Quantifying Real and Apparent Losses

Once the volume of NRW is known it is necessary to break it down into real and apparent losses, which is always a difficult task.

Step 3 – Estimating Apparent Losses

Unauthorized Consumption

It is difficult to provide general guidelines of how to estimate unauthorized consumption. The estimation of unauthorized consumption is always a difficult task and should be done in a transparent, component based way so that the assumptions can later easily be reviewed.

Customer Metering Inaccuracies and Data Handling Errors

The extent of customer meters inaccuracies, namely under- or over registration, has to be established based on tests of a representative sample of meters. The composition of the sample shall reflect the various brands and age groups of domestic meters. Based on the results of the accuracy tests, average meter inaccuracy values (as % of metered consumption) will be established for different user groups. Data handling errors are sometimes a very substantial component of apparent losses.

Step 4 – Calculating Real Losses

The calculation of real losses in its simplest form is now easy: Volume of NRW minus volume of apparent losses – and this figure is useful for the start of the analysis in order to get a feeling which magnitude of real losses can be expected. However, it always has to be kept in mind that the water balance might have errors – and therefore it is important to verify the real loss figure by one of the following two methodologies (i) Component Analysis and (ii) Bottom-up real loss assessment.

Step 5 – Estimating Real Loss Components

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

Leakage on Transmission and/or Distribution Mains

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

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

and then a certain provision for background losses and so far undetected leaks on mains can be added.

Leakage and Overflows at Utility's Storage Tanks

Leakage and overflows at storage tanks are usually know and can be quantified.

Leakage on Service Connections up to Point of Customer Metering

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

Detailed Quantification of Real Loss Components

Step 1 – The Figure from the Top-Down Water Balance

Although real loss assessment can be done without an annual water balance, the total volume of real losses is useful for the start of the analysis in order to get a feeling which magnitude of real losses can be expected.

Step 2 – Component Analysis

The key data required for a real loss component analysis of a water distribution system are:

- Total length of pipe network and number of service connections;
- Average service connection length between curb-stop and customer meter
- Total number of distribution mains repairs per year (reported and unreported)
- Total number of service connection repairs per year (Reported and unreported)
- Average system pressure across the entire network;
- Estimates of the time periods for Awareness, Location and Repair duration
- Estimates of utility storage tank leaks and overflows

Most of this data is readily available in well-organized water utilities; however the determination of the average pressure across the network is often difficult to estimate.

Calculation of Average Pressure

As the average pressure is a key parameter in any real loss analysis, it is certainly worth undertaking some detailed work to obtain a good estimate of the average pressure. Pressures should be calculated as 24-hour averages values.

Calculation of Background Losses

The first of the real loss components calculated are the background losses.

Background losses are individual events (small leaks and weeps) that will continue to flow, with flow rates too low to be detected by an active leakage control campaign unless either detected by chance or until they gradually worsen to the point that they can be detected. 1 provides figures for unavoidable background leakage rates per psi of pressure at an ICF[1] (Infrastructure Correction Factor) of 1.

Table 1: Unavoidable Background Leakage Rates

Infrastructure Component	Background Leakage at ICF=1.0	Units
Mains	9.6	Litres per km of mains per day per metre of pressure
Service Connection – main to property boundary	0.6	Litres per service connection per day per metre of pressure
Service Connection – property boundary to customer meter	16.0	Litres per km of service connection per day per metre of pressure

Source: IWA Water Loss Task Force

Unfortunately the ICF is a mostly unknown factor. Without carrying out detailed measurements, it is impossible to know the ICF. In such cases working with the default values of 1 will mean that there is a good chance that the background losses are underestimated and consequently the recoverable losses are overestimated. Using a higher ICF (of say 5) might easily lead to an overestimation of the background losses which will cause an underestimation of the true excess loss reduction potential. Thus it is recommended to work with the ICF=1 background leakage values unless better data is available.

Calculation of Losses from Reported and Unreported Bursts

At this point two definitions have to be introduced:

Reported Bursts are those events that are brought to the attention of the water utility by the general public or the water utility's own staff. A burst or a leak that, under urban conditions, manifests itself at the surface will normally be reported to the water utility.

Unreported Bursts are those that are located by leak detection teams as part of their normal everyday active leakage control duties.

After collecting the annual numbers of reported bursts on mains and service connections, flow rates and durations have to be established. Unless the utility has investigated average leak flow rates, it is recommended to use the figures from Table 2:

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[1] The Infrastructure Condition Factor is the ratio between the actual level of Background Leakage in a zone and the calculated unavoidable Background Leakage of a well maintained system.

Table 2: Flow Rates for Reported and Unreported Bursts

Location of Burst	Flow Rate for Reported Bursts [l/hour/m pressure]	Flow Rate for Unreported Bursts [l/hour/m pressure]
Mains	240	120
Service Connection	32	32

Source: IWA Water Loss Task Force

The leak duration can be split in three elements – time needed for: (i) awareness , (ii) location and (iii) repair; and estimates will have to be made for each of them:

Awareness duration: the awareness duration for reported bursts is generally very short, probably not more than 24 hours. The situation is quite different in respect to unreported bursts, which by definition are detected by active leakage control methods. The awareness time will depend on the ALC policy. If for example regular sounding is used and the system is surveyed once a year, the average awareness time will be 183 days.

Location duration: the location of a reported leak will in general not take much time – since it is visible and a quick check with a ground microphone will be sufficient to verify the leak location. The location duration also depends on the ALC policy used.

Repair duration: depends on the utility's repair policy and capacity. Often leaks on mains are repaired within 24 hours but small leaks on service connections within 7 days.

Calculation of Losses from Leaking and Overflowing Storage Tanks

This component has to be dealt with on a case by case basis. Plant operators will normally know if there are problems with overflowing storage tanks. Old underground storage tanks may leak, and if this is suspected than level drop tests could be undertaken.

Calculation of Excess Losses

Once all the components mentioned above are quantified, the Excess Losses[2] can be calculated:

(Real Losses from AWB) – (known Real Loss components) = (Excess Losses)

In case this equation results in a negative value for excess losses, the assumptions for the real loss component analysis have to be checked and if necessary corrected.

Step 3 – Bottom-up Real Loss Assessment

24 Hour Zone Measurements

Assuming that no DMA[3]s are established, areas of the distribution network have to be selected which can be temporarily isolated and supplied from one or two inflow points only. Suitable areas shall be selected in various parts of the distribution system, with the objective of obtaining a representative sample of the system. In these areas, 24 hour inflow measurements will be carried out with portable flow measurement devices. These flow measurements shall always be done along with pressure measurements where pressures are

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[2] The volume of Excess Losses represents the quantity of water lost by leaks that are not being detected and repaired with the current leakage control policy.

[3] District Metered Area (DMA): Hydraulically discreet part of the distribution network, ideally with one inflow point equipped with a bulk meter.

recorded at the zone inlet point(s), at the average pressure point and at the critical pressure point. All relevant data on the zone shall be collected, such as: (i) length of mains, (ii) number of service connections, (iii) number of household properties and (iv) number and types of non-household properties.

Night Flow Analysis

The Minimum Night Flow (MNF) in urban situations normally occurs during the early morning period, usually between around 02:00 and 04:00 hours. The estimation of the real loss component at minimum night flow is carried out by subtracting an assessed amount of legitimate night consumption for each of the customers connected to the mains in the zone being studied. The result obtained from subtracting these legitimate night uses from the minimum night flow consists predominantly of real losses from the distribution network. The daily level of real losses obtained from the minimum night flow analysis can be determined by applying the FAVAD[4] principles (Lambert, 2001) and simulating leakage over the full 24h period (see Figure 2 below).

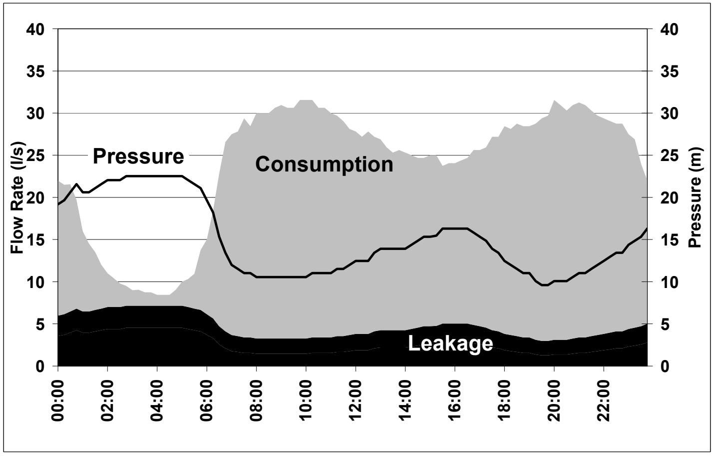

Figure 2: 24h Leakage modelling based on minimum night flow measurement

Step 4 – Compiling the Final Figures

At the end of the real loss assessment process, the advantage of the combined top-down, bottom-up and component analysis becomes obvious. Only by combining the three methods it is possible to get reliable results.

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[4] Fixed and Variable Area Discharge path (FAVAD): Losses from fixed area leakage paths vary according to the square root of the system pressure, whilst discharges from variable area paths vary according to pressure to the power of 1.5. As there will be a mixture of fixed and variable area leaks in any distribution system, loss rates vary with pressure to a power that normally lies between the limits of 0.5 and 1.5. The simplest versions of the FAVAD concept, suitable for most practical predictions, are

Leakage Rate L (Volume/unit time) varies with PressureN1 or $L1/L0 = (P1/P0)^{N1}$

The higher the N1 value, the more sensitive existing leakage flow rates will be to changes in pressures. The FAVAD concepts have for the first time allowed accurate forecasting of the increase or decrease of Real Losses due to a change in pressure. When N1 is not known, a linear relationship (N1=1) can be used.

Calculating Real Loss Performance Indicators

Since the level of water losses, both real and apparent, is a very important efficiency issue, one would assume that accurate performance indicators are used for benchmarking, international performance comparison, or target setting. But unfortunately this is widely not the case. With the exception of the UK water industry, water losses are still quoted as % of System Input.

The serious problems with this indicator were highlighted in many conferences around the world, most recently at the IWA Leakage Conference in Cyprus (Liemberger, 2002). The new and most advanced real loss indicator (recommended by the IWA and the AWWA) is the ILI, the Infrastructure Leakage Index. The ILI is a measure of how well a distribution network is managed for the control of real losses, at the current operating pressure. It is the ratio of **C**urrent **A**nnual volume of **R**eal **L**osses (CARL) to **U**navoidable **A**nnual **R**eal **L**osses (UARL).

$$\mathbf{ILI = CARL / UARL}$$

Being a ratio, the ILI has no units and thus facilitates comparisons between countries that use different measurement units (U.S., metric or imperial). But what are unavoidable losses and how are they calculated? Leakage management practitioners around the world are well aware that Real Losses will always exist - even in new and well managed systems.

It is just a question of how high these unavoidable losses will be. The complex initial components of the UARL formula were converted to a 'user friendly' pressure-dependent format for practical use:

$$\mathbf{UARL\ (liters/day) = (18 \times Lm + 0.8 \times Nc + 25 \times Lp) \times P}$$

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

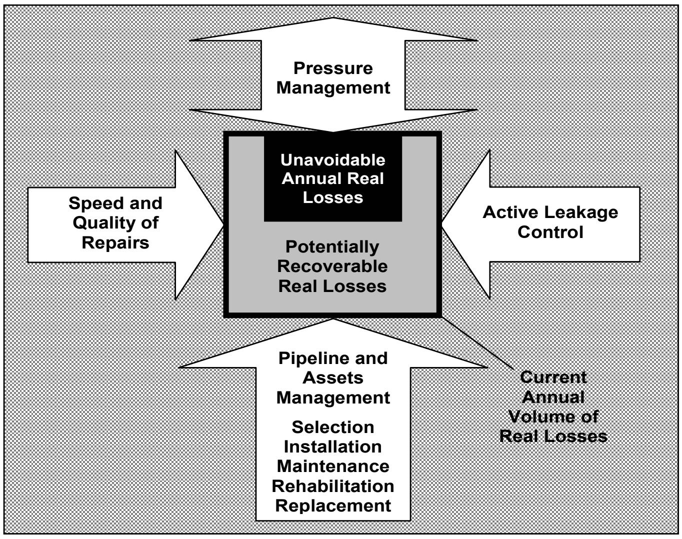

Figure 3: The four components of a successful leakage management policy

The length of mains and number of service connections are normally known to a water utility, but the distance between the property line and meter seems to be a troublesome figure to obtain. But fortunately, in some 50% of situations world-wide customer meters are located close to the property line and Lp is effectively zero. In the remaining cases, where customer meters are located after the property line, it is relatively easy to estimate the average and total length of underground pipe from the property line to customer meters by inspecting a quite small random sample of service connections (Lambert and McKenzie, 2002).

The ILI can perhaps be best envisaged from Figure 3 above, which shows the four components of leakage management. The large square represents the current annual volume of real losses (CARL), which is always tending to increase, as the distribution networks grow older. This increase however can be constrained by an appropriate combination of the four components of a successful leakage management policy. The black box represents the unavoidable annual real losses (UARL) - the lowest technically achievable volume of real loses at current operating pressure.

The ratio of the CARL (the large square) to the UARL (the black box), is a measure of how well the three infrastructure management functions - repairs, pipelines and asset management, active leakage control - are being undertaken. And this ratio is the ILI. Although a well managed system can have an ILI of 1.0 (CARL = UARL), this does not necessarily have to be the target as the ILI is a purely technical performance indicator and does not take economic considerations into account.

Figure 4 shows the ILI and other recommended non-revenue water and real loss PIs indicators based on the IWA's Manual of Best Practice (PIs for Water Supply Services).

Function	Level	Code	Performance Indicator	Comments
Financial: NRW by Volume	**1** (Basic)	**Fi 36**	Volume of NRW **[% of System Input Volume]**	Can be calculated from simple water balance, not too meaningful
Operational: Apparent Losses	**1** (Basic)	**Op 23**	**[m3/service connection/year]** or: **[m3/km of mains/year]** *(only if service connection density is < 20/km)*	Best of the simple 'traditional' performance indicators, useful for target setting, limited use for comparisons between systems
Operational: Real Losses	**1** (Basic)	**Op 24**	**[liters/service connection/day]** or: **[liters/km of mains/day]** *(only if service connection density is < 20/km)*	Best of the simple 'traditional' performance indicators, useful for target setting, limited use for comparisons between systems
Operational: Real Losses	**2** (Intermed.)	-	**[liters/service connection/day/m pressure]** or: **[liters/km of mains/day/m pressure]** *(only if service connection density is < 20/km)*	Easy to calculate Indicator if the ILI is not known yet, useful for comparisons between systems
Financial: NRW by cost	**3** (Detailed)	**Fi 37**	Value of NRW **[% of annual cost of running system]**	Allows different unit costs for NRW components, good financial indicator
Operational: Real Losses	**3** (Detailed)	**Op 25**	**Infrastructure Leakage Index (ILI)**	Ratio of Current Annual Real Losses to Unavoidable Annual Real Losses, most powerful indicator for comparisons between systems

Figure 4: Recommended Indicators for Real Losses and Non-Revenue Water

The PIs are categorized by Function and by Level, defined as follows:

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

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

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

Level 1 Indicators

Fi 36 (Financial): The volume of Non-Revenue Water, expressed as percentage of the system input volume, is a (very) basic Financial PI but not an Operational PI.

Op24 (Operational): As a first step, the Service Connection Density has to be calculated in order to determine what the appropriate indicator will be. As most distribution systems have density of connections >20 per km of mains, 'per service connection' should logically become the predominant basic operational PI for Real Losses.

In the case of systems subject to intermittent supply, the PI is expressed as 'litres/service connection/day when the system is pressurised'.

Level 2 Indicator

No IWA reference (Operational): This PI (litres/service connection/day/m pressure) takes pressure into account and therefore is a more useful indicator for comparing different areas of the same water utility, or different utilities with systems operating at different pressures. However, this indicator should not replace the Level 1 indicator, but should supplement it because high system pressures are largely a management issue and can be controlled to reduce losses.

Level 3 Indicators

Fi35 (Financial): The annual ***value*** of Non-Revenue Water, expressed as percentage of the annual system running cost is true financial performance indicator. For the calculation of the value of NRW the split into real and apparent losses is important, since the average water tariff (to be used to value the apparent losses) might vary greatly from the marginal cost of water (which is used to value the real loss component). If water is scarce, resulting in supply restrictions / conservation measures such that additional water saved can be sold, the value of real losses can increase up to the average water tariff.

Op 25 (Operational): Op 25, the Infrastructure Leakage Index (ILI) the most powerful of all water loss indicators.

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Developing a Non-Revenue Water Reduction Strategy
Part 2: Planning and Implementing the Strategy

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Abstract: Part one of this paper deals with the tasks required to investigate and assess the components of non-revenue water (NRW). This is a necessary first step in a diagnostic approach to understanding the condition of the network, the way it is operated, and the constraints acting upon it. This second part deals with the tasks and tools required to address the constraints, and to develop a strategy to reduce NRW which is practicable and achievable, and which can be adapted for any distribution network anywhere in the world. Not all utilities, particularly those in developing countries, have the luxury of a well-developed and efficiently managed network. The paper deals with the tasks required to upgrade the network, and to review and improve the operational policies and practices, before the tools and techniques to reduce NRW can be put in place. The paper discusses each step of the strategy and its development, from upgrading the network by improved infrastructure management and zoning, to the available techniques and equipment for monitoring and detecting real and apparent losses.

Keywords: NRW Strategy, Upgrading, Zoning, Leak Detection and Location, O&M

Planning and implementing a NRW reduction strategy

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 planning and implementing a NRW reduction 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 for formulating 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 NRW reduction strategy

The first two questions in Figure 1 - **'how much'**? and **'where from'**? have been addressed in part 1 of this paper. The components of NRW, and the priority areas of the network for investigation, can be determined by conducting a **water balance**. The planning and implementation of the NRW strategy addresses the remaining three questions - '**why** is water lost'?, '**how** can we control losses'?, and '**what** policies can be put in place to sustain the improvements'?

The utility needs to address both components of NRW - real and apparent losses. A programme to address apparent losses will usually be dependent on longer term changes to customer metering policy and education, and to regulatory and legislative policies. Each of the influences, and the requirements for upgrading the network, such as zoning and the division of the network into district meter areas (DMAs) - is discussed in the paper.

Why is water being lost?

Review of Network Operating Practices

The question '**why is water being lost**?' can be addressed by a review of the network and how it is operated. This reflects the company's management of its network, and it can be appraised by carrying out a review 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 available for monitoring and detecting leakage
- staff skills and capabilities

Particular tasks should include;

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

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)

Field visits - to appraise current practice and skills

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

Upgrading the Network

Once a review of the infrastructure and the operating practices has been carried out, the need for upgrading the network can be assessed. The aim of upgrading is to bring the infrastructure management to a stage where utility practitioners can begin reducing losses and improve network performance. Not all countries or regions have the luxury of well-developed network infrastructure - many are operating a network with an outdated infrastructure, with poor data management and record systems, with inadequate technical skills and technology, an unsuitable tariff structure or revenue collection policy, and a poor operation and maintenance policy.

One of the fundamentals of network management is zoning. The principle of zoning, or sectorization, is well established - by dividing the network into smaller 'sectors' the utility operator 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. The zoning hierarchy concept, and the creation of smaller zones, is illustrated in Figure 2.

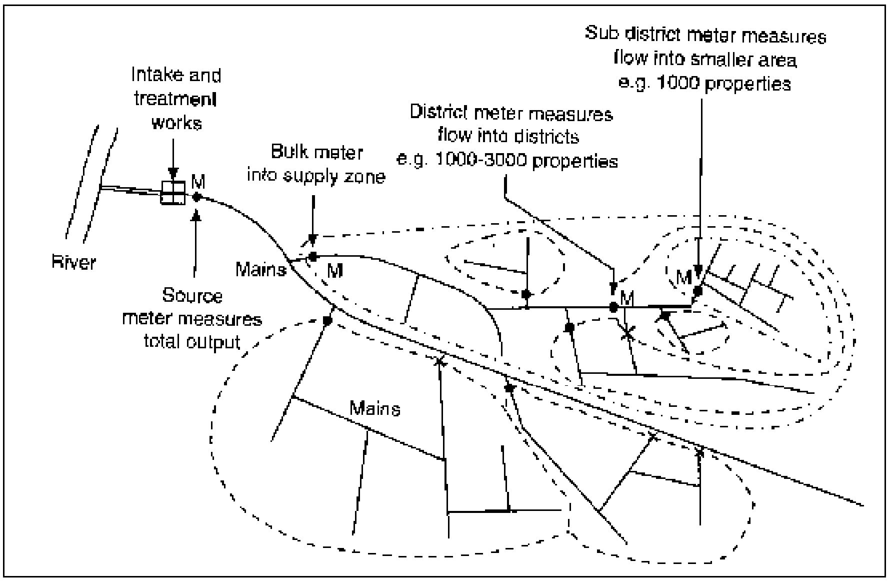

Figure 2 Metering hierarchy and DMA design options (from UKWIR 'Managing Leakage')

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. 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. Zonal flow monitoring is the cornerstone of active leakage management in district metered areas (DMAs) and is described later in the paper.

Network Records and Recording Systems

Record-keeping is an essential part of water network management, and is also the basis for a GIS. Supply zone and DMA records should relate to both physical records and records for leakage analysis. As well as PC based records each DMA should have a dedicated paper based file containing all DMA plans and records. Files should be kept in a DMA filing system, accessible to all leakage staff.

If network records are poor, a network survey is essential before zoning and DMA design can take place, and for accurate leak detection and location to be carried out. There are several items of equipment which will support a survey of the network pipework:

- Metallic pipe and cable locator - an essential pre-requisite for carrying out a pipe location and mapping survey prior to a leak detection survey, and for differentiating between water mains and other utilities' power/communication cables.
- Non-metallic pipe locator - this is used for locating PVCu and other plastic pipes (and asbestos cement/glass-fibre etc.).
- .Iron and steel box locator - this is a metal detector, used for detecting buried valve chambers and covers etc. during a pipe survey.

How can we improve performance?

A successful NRW reduction strategy depends not only identifying priority areas of the network and the network operating policy which need attention, but also on introducing methodologies and policies to assess, monitor and control elements of NRW - real losses, apparent losses, and unbilled consumption.

Active Leakage Control (ALC)

The main methods of ALC are regular survey and 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 district metered areas (DMAs) to quantify leakage and to prioritise leak detection activities. This has now become one of the most cost-effective activities (and the one most widely practised) to reduce real losses. The most appropriate leakage control policy for a particular utility will mainly be dictated by the characteristics of the network and local conditions, which may include financial constraints on equipment and other resources. In most 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.

Leakage Monitoring in DMAs

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 Metered Area (DMA). The concept of DMA design and management 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 (2). A leakage monitoring system will comprise a number of DMAs where flow is measured by permanently installed flowmeters. In some cases the flowmeter installation will incorporate a pressure reducing valve (PRV). Figure 3 shows an example of the configuration of several DMA types within a 'water into supply' (WIS) zone boundary, and the DMA recording system. 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. 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. Calculating night flow is discussed in part 1 of this paper.

DMA maintenance is crucial to maintain the accuracy of the data. It includes maintaining the integrity of the DMA boundary as well as plant and equipment - checks on the accuracy of meters and secondary instrumentation.

Boundary maintenance includes:

- recording changes to the supply area and customer base
- making sure boundary valves are clearly marked and in the correct status
- educating staff as to the purpose of closed valves and ensuring that, if operated, they are returned to the correct status

There are a few constraints to designing DMAs:

- traditional engineering design criteria and reluctance to close valves
- too many closed valves
- low network pressure and critical points
- intermittent supply
- creating dead-ends can reduce water quality

Most of these constraints can be overcome by introducing DMAs in pilot areas, restoring supply temporarily in areas of intermittent supply, using a network model or pressure loggers to assess the effect on customer service levels, and by education and awareness training. Water quality problems can be overcome by a regular flushing programme or by re-designing the DMA boundary.

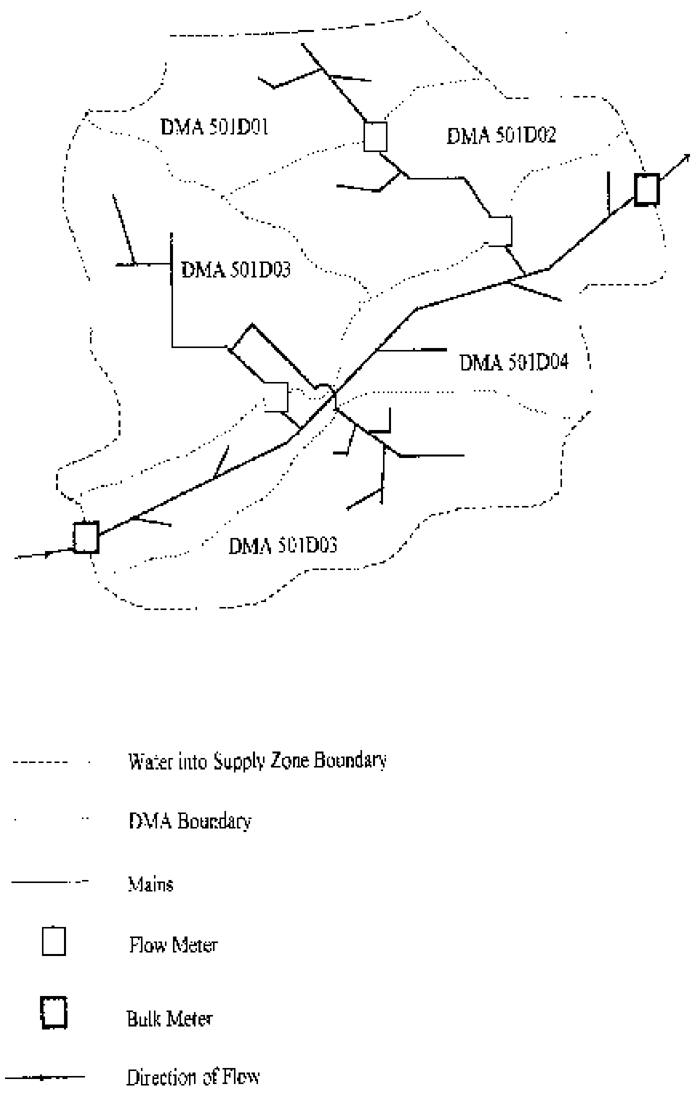

Figure 3 DMA types

Leak Localising

Once the network is divided into DMAs, those 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. Inspectors can then be deployed to locate the precise leak position in the culprit section of pipe. 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 (sometimes combined with correlation).

Leak Location

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

- basic sounding stick
- electronic sounding stick
- ground microphone (or an 'array' of microphones laid along the line of the pipe)
- 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

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 wall 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.

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.

Pressure Management

The rate of leakage in water distribution networks is a function of the pressure applied by pumps or by gravity head. There is a physical relationship between leakage flow rate and pressure, which has been proven by laboratory tests and by tests on underground systems. The frequency of new bursts is also a function of pressure. Pressure management is therefore one of the fundamental elements of a well-developed NRW strategy. If pressure is reduced, the rate of increase in leakage will reduce. This has implications for the level of leak detection resources required, and the flow rate from all leakage paths (bursts and background leaks) will reduce.

To assess the suitability of pressure management in a particular system a series of tasks should be carried out before implementation. These include:

- Desk top study to identify potential zones, installation points and customer issues
- Demand analysis to identify customer types and control limitations
- Field measurements of flow and pressure (the later usually at inlet, average zone point and critical node points)
- Modelling of potential benefit using specialized models
- Identification of correct control valves and control devices
- Modeling of correct control regimes to provide desired results
- Cost benefit analysis

PRVs are usually sited within a DMA, next to the district meter. The PRV should be downstream of the meter so that the turbulence from the valve does not affect the accuracy of the meter. It is good practice to install the PRV on a bypass to enable future major maintenance to be carried out.

Maintaining the Strategy

This section addresses the final 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 a previous section of the paper. 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

Customer metering policy - addressing apparent losses

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 could 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 are they (under-registration)?
- how efficient is the meter reading and revenue collection process?

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.

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.

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.

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 resulted 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' (3), 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.

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