Developing a non-revenue water reduction strategy: planning and implementing the strategy

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Abstract A companion paper dealt 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 that 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 Leak detection and location; NRW strategy; O&M; upgrading; zoning

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 to 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.

The first two questions in Figure 1 – “**how much**”? and “**where from**”? have been addressed in a companion paper (Liemberger and Farley, 2004). 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;

Table 1: Tasks and tools for developing a NRW reduction strategy

<table>
<thead>
<tr>
<th>Question</th>
<th>Task</th>
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<tbody>
<tr>
<td>1. How much water is being lost?</td>
<td>Water balance</td>
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<tr>
<td>– Measure components</td>
<td>– Improved estimation/measurement techniques</td>
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<td></td>
<td>– Meter calibration policy</td>
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<td>– Meter checks</td>
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<td>– Identify improvements to recording procedures</td>
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<td>2. Where is it being lost from?</td>
<td>Network audit</td>
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<tr>
<td>– Quantify leakage</td>
<td>– Leakage studies (reservoirs, transmission mains, distribution network)</td>
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<td>– Quantify apparent losses</td>
<td>– Operational/customer investigations</td>
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<td>3. Why is it being lost?</td>
<td>Review of network operating practices</td>
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<tr>
<td>– Conduct network and operational audit</td>
<td>– Investigate: poor practices</td>
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<td></td>
<td>quality management procedures</td>
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<td></td>
<td>poor materials/infrastructure</td>
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<td></td>
<td>local/political influences</td>
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<td>cultural/social/financial factors</td>
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<td>4. How to improve performance?</td>
<td>Upgrading and strategy development</td>
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<tr>
<td>– Design a strategy and action plans</td>
<td>– Update records systems</td>
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<td>– Introduce zoning</td>
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<td>– Introduce leakage monitoring</td>
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<td>– Address causes of apparent losses</td>
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<td></td>
<td>– Initiate leak detection/repair policy</td>
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<td>– design short-medium-long-term action plans</td>
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<td>5. How to maintain the strategy?</td>
<td>Policy change, training and O&amp;M</td>
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<td>Training:</td>
<td>improve awareness</td>
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<td></td>
<td>increase motivation</td>
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<td>transfer skills</td>
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<td></td>
<td>introduce best practice/technology</td>
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<td>O&amp;M:</td>
<td>Community involvement</td>
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<td>Water conservation and demand management programmes</td>
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<td>Action plan recommendations</td>
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<td></td>
<td>O&amp;M procedures</td>
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Figure 1: Tasks and tools for developing a NRW reduction strategy
• 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 a 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 sectorisation, 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.

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 provide 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 (WSA/WCA Engineering and Operations Committee (1994)), in 1994, and was updated by UKWIR with the report “A Manual of DMA Practice” UK Water Industry Research (1999). 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, i.e. it involves checks on the accuracy of meters and secondary instrumentation.

Boundary maintenance includes:

- recording changes to the supply area and customer base;
- making sure that 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.

**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 are 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 conveniently 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, and so can be operated by one person, 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, then 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 be reduced.

To assess the suitability of pressure management in a particular system a series of tasks should be carried out before implementation. These include:
- Desktop 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 specialised models;
- Identification of correct control valves and control devices;
- Modelling 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 factors (drivers) to consider, such as the interests of directors, shareholders, political and financial pressures, as well as customer and public perception. There are also the 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 allowing a 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 leaks in the supply to the customer;
• 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 bypassing (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 a 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 of 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 five years.

Technologies 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 and 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” (Farley and Trow, 2003), 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 – policies 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 underestimating 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.

References

