Leakage is one of the crucial issues to be dealt with in order to improve the efficiency and effectiveness of water supply services. Although the techniques and institutional aspects involved in a leakage control programme are well known, appropriate materials for use in training programmes on this problem are lacking. This training manual aims to fill this gap. Its use should be viewed as part of an overall strategy for the promotion of sound Operation and Maintenance (O&M) practices in the context of a comprehensive approach to institutional development.

This training manual is aimed at professionals responsible for Operation and Maintenance of water supply systems, who already have some experience of training. It has been designed to raise their level of training and to make maximum use of the scarce resources available for this type of activity. The manual will greatly help the implementation of training activities and will be an important tool for trainers in the design, preparation and carrying out of training courses on leakage control. At the end of the course, experienced participants should be able not only to repeat the training course with other professionals, but also to help water agencies in the formulation and implementation of a leakage control programme.

LEAKAGE MANAGEMENT AND CONTROL

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Leakage management and control

A BEST PRACTICE TRAINING MANUAL

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Leakage management and control

A BEST PRACTICE TRAINING MANUAL

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2001

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Contents

Foreword

This training manual, prepared by Malcolm Farley, has been developed for training trainers to run workshop programmes on how to control water loss in water supply systems. The document contains individual modules that link together to form a training course that comprehensively covers the key aspects of controlling water loss.

Once trained, trainers can use the package as a base for developing their own training courses tailored to local conditions and to the needs of different course participants.

The manual has been designed for course participants to learn the theory behind leakage control and how to put it into practice in real life. Thus, an integral part of the course involves participants developing plans to put a leakage control programme into action in their own systems.

This manual focuses on the practical application of new principles and techniques. In doing so, it aims to equip O&M personnel with the skills necessary to optimize water supply services by implementing their own comprehensive leakage control and management programme.

The manual is flexible and can be adapted to suit the needs of O&M personnel at every level within a water supply authority. It is an excellent source of information for decision-makers, planners, economists, consultants and other sector professionals interested in this important issue. It can also be used by other sector participants to gain a fuller understanding of the issues that influence the performance of water supply systems.

Leakage Management and Control is part of an overall effort of the Operation and Maintenance Network of the Water Supply and Sanitation Collaborative Council, to improve management and operational practices of water authorities. By improving such practices and by reducing water loss in distribution systems, it might be feasible to extend coverage to many inhabitants of urban settlements who are not served with water supply services and thus are highly exposed to health risks.

José A. Hueb
Coordinator
Operation and Maintenance Network

1. Introduction to the training manual

1.1 Introduction

Importance of leakage management and control in institutional development

Leakage is one of the crucial issues to be dealt with in order to improve the efficiency and effectiveness of water supply and sanitation services. Although the techniques and institutional aspects involved in a leakage control programme are well known, appropriate materials for use in training programmes on this problem are lacking. This training manual aims to fill this gap and is a key contribution to the implementation of Operation and Maintenance Programmes in Member States. Its use in countries is part of an overall strategy for the promotion of sound Operation and Maintenance (O&M) practices in the context of a comprehensive approach to institutional development.

Limitations of the training manual

It is well known that training materials are more effective when they are designed to solve specific problems in situations where performance does not match one's expectations. The preparation of training manuals for the target population of each water agency—after analysis of constraints, profiles of posts and personnel, and the formulation of O&M programmes—is therefore a perfectly good approach. Training materials prepared in this manner would be ideal for each target population. However, as most water agencies in Member States were found to have similar core problems and limitations in their production and distribution facilities, it was proposed that one training manual should be developed for broad application, which would also considerably reduce the cost.

The issues included in this training manual are grouped into specific sections and modules, covering a wide range of techniques and procedures for carrying out leakage management activities. Depending on the problems and constraints faced by the water agencies concerned and the specific characteristics of the target audience for training, appropriate modules can be selected from this manual and assembled for the training course. Preparation of additional modules or adaptation of the available modules may be necessary when problem analysis indicates situations and problems that differ significantly from those foreseen in the manual. Despite these limitations, this manual will help the transfer of information and the development of skills needed for better performance by the water agencies. The training manual is flexible and can be updated from time to time without changing the overall framework.

Courses, workshops and seminars that utilize this manual are intended for managers, engineers and technicians. It is expected that the initial group of trainees will themselves become a core group of trainers, who will exert a multiplying effect by passing on this information and their expertise to workers in national water agencies and users.

1.2 Objectives of the training manual

General objectives. This training manual is aimed at professionals responsible for Operation and Maintenance of water supply systems, who already have some experience of training. It has been designed to raise their level of training and to make maximum use of the scarce resources available for this type of activity. The manual will greatly help the implementation of training activities and will be an important tool for trainers in the design, preparation and carrying out of training courses on leakage control. At the end of the course, the participants should be able not only to repeat the experience with other professionals in their own countries, but also to help water agencies in the formulation and implementation of a leakage control programme.

Specific objectives. This training manual should:

- be a resource for adaptation and preparation of other training manuals for leakage control courses;
- be able to optimize the staffing resources required for such training;
- help the process of training so that more trainees will develop skills to deal with leakage control;
- be used as a manual for trainers and managers involved in leakage control activities;
- be used as a manual for the design and implementation of leakage control services;
- improve the skills in training methods for leakage control activities;
- help reduce the costs of training.

1.3 Description of the training manual

Organization of the modules

Leakage management activities have been grouped into modules, based on the types of professionals involved in their execution (managers, technicians, etc.) and the characteristics and level of development of the water distribution network. The modules incorporate the information required for carrying out combinations of interrelated activities. Each module is self-contained, so that it can be directed to different types of target populations. The modules contain as much information as is required to achieve their particular objectives, and to provide a high degree of flexibility when assembled for use in training courses. These requirements may lead to some overlap between modules.

Thus, a module may include a number of concepts and skills linked to a major issue. Each module can be composed of one or more sections which are interdependent and related to the major theme of the module. There may also be sub-modules dealing with the same issue but differing in complexity.

The training manual adopts a logical and “user-friendly” approach to training water practitioners at levels ranging from senior managers to leak inspectors. It begins by inviting the water practitioner to address some simple questions about the characteristics of the network and how it is operated. It examines the local and institutional factors which affect the network, and the attitudes and perceptions of the population to leakage. It then goes on to show how various tools—methodologies, techniques, operating procedures, etc., sometimes with modifications according to local circumstances—are utilized to develop and establish a leakage management strategy.

The content of each module can be varied depending on the knowledge required for a particular level of trainee. For example, engineers and managers could explore in detail the institutional and financial aspects of leakage control, and would benefit from a cost-benefit exercise to select and develop an appropriate policy. Engineers and technicians responsible for managing a system and detecting leaks would benefit from an understanding of these principles, but the main thrust of their programme would be based on those modules with a more practical and technical approach to system management.

The training material has been made as broad as possible, and includes references to published work from papers, journals, seminars, guidelines, and some textbooks. The trainer can quickly select appropriate material from the modules, and assemble his/her own form of words for each module. The "textbook approach" to training has been deliberately avoided. Much of the material has been collated and reworked from training course notes and visual aids taken from courses and workshops designed and presented by consultants in countries in all parts of the world.

From the time when the training manual was first produced as a resource training package, there have been major advances in the concepts and techniques for assessing, monitoring, and managing leakage. The water industry in the United Kingdom recognized the need for a better understanding of leakage before practitioners could establish the most appropriate mechanism for monitoring and controlling it. With this aim, the U.K. Water Industry commissioned a National Leakage Initiative (1992–94), which developed a set of reports under the title of Managing Leakage. These reports are cited as references in this manual. Much of the conceptual thinking in the reports has been incorporated into the manual, but the original reports, after adaptation to local conditions, provide excellent material for developing training courses. Other supporting source material and suggestions for further reading are listed in the relevant sections. The course also benefits from a review of "state of the art" leakage control technology covering flow measurement, leakage data capture, and leak detection equipment. Commissioned by the U.K. Water Industry, the review presents a range of products and manufacturers, and provides a database of current technology from which to select user-suitable equipment. Two essential components of this manual are:

1. It tailors the course to a particular utility or community's requirements by finding out current system practice, problem areas, successes and failures, etc., and then involving the trainees in producing an Action Plan for their system, based on local knowledge and new skills gained from the course.
2. It gives a practical demonstration of the available equipment over a range of technology, followed by field demonstration (at a pre-selected and prepared site near the course venue). All trainees should have the opportunity to handle the equipment and become familiar with procedures (e.g. programming a data logger, measuring a flow profile, locating a leak).

This approach calls for some planning beforehand and on the first day of the course. Participants are required to provide written information about their water supply system, e.g. physical details like topography, population and demography, and the cause and magnitude of losses, as well as a description of the current leakage control policy, if there is one, and influencing factors such as pressures, typical soil conditions, pipe materials and their age, etc. It would also be useful if participants brought data on production and consumption, revenue meter coverage and policies, etc. On the first day, after the course programme has been introduced, individual trainees or representatives of the groups attending the course are invited to make a brief presentation on the background and current practice of their water supply department. This has three aims:

— in the beginning, to relieve tension between trainers and participants;
— to help stimulate discussion;
— to introduce local material and individual experiences.

Any points raised in these presentations can be dealt with in subsequent modules, with feedback and active participation of the trainees. The local knowledge thus gained is invaluable for constructing an Action Plan at the end of the course, when the trainees will benefit from group work—the different ideas and views acting as an additional stimulus to discussion.

Introducing the manual to trainees

The underlying principles of the manual will be explained to the participants during the course introduction. They include:

1. An explanation of the aims and objectives.
2. A brief explanation of the course programme and practical sessions, and the training style (informality, group exercises and discussions).
3. Presentations of local practice and knowledge by selected representatives from the participants.
4. Discussion to amplify/clarify local issues.
5. Explanation of how the introductory session, together with the ideas and skills gained during the course, will help to highlight appropriate policy-making and decision-making, and contribute to an Action Plan tailored for each utility.

It is important to emphasize during the introduction that a leakage management and control programme can be initiated in any water undertaking, even those providing an intermittent supply (supplies can be partially restored by a low-activity policy such as repairing visible leaks in overground pipes—a policy practised in many developing countries as the first stage of their leakage control programme). It is sustained activity which is important, e.g. by building a leakage monitoring and control element into a company's programme of operation and maintenance.

Contents of the training manual

Sections and modules are arranged in a logical order, which allows the trainees to:

— first understand the **significance and scale** of leakage in relation to other water loss components;
— then **quantify the volume** of leakage by measurement or estimation;
— become aware of the various techniques or methodologies to **monitor and control** leakage;
— select the appropriate **equipment** to support the techniques;
— be trained in the **use** of this equipment;
— **develop a leakage strategy** for a particular network by considering the economic and other factors relevant to the local conditions and infrastructure;
— **design a leakage management and control system** appropriate to local conditions and constraints;
— be aware of the **operation and maintenance** requirements to sustain the methodology once in place.

The manual includes case study material for strategy development, an example of a workshop programme, and a workshop case study.

Presentation material and references

The range of material for illustrating the concepts and practices of leakage management is vast. Trainers should build up a collection of resource material for display, as well as for presentation by overhead projector (OHP) and distribution to the trainees—from the manual itself and from other sources such as:

— local material, reports, studies;
— textbooks, manuals, guidelines, and other documents;
— manufacturers' brochures and operating manuals.

Many of the above can be accessed via websites on the Internet.

Of particular relevance are **references** to reports and manufacturers' material in various sections of the manual:

1. *Managing Leakage*, published by U.K. Water Industry Research Ltd/Water Research Centre (WRc), 1994, and available from the WRc Bookshop, WRc Plc, Frankland Road, Blagrove, Swindon, Wiltshire, SN5 8YF, England. There are nine reports, as follows:

   Report A—*Summary report*
   Report B—*Reporting comparative leakage performance*
   Report C—*Setting economic leakage targets*
   Report D—*Estimating unmeasured water delivered*
   Report E—*Interpreting measured night flows*
   Report F—*Using night flow data*
   Report G—*Managing water pressure*
   Report H—*Dealing with customer leakage*
   Report J—*Leakage management techniques, technology, and training*

   The summary report (Report A) is particularly recommended, as it contains the main text and illustrations to explain the concepts of each of the other reports.

2. Lambert A, Myers S, Trow S. *Managing water leakage—Economic and technical issues*. London, Financial Times (FT Energy) Business Ltd, 1998.
3. Operation and Maintenance Committee. *Losses from water supply systems* ('Blue Pages'). London, International Water Association (IWA) O&M Committee—Task Force 'Documents on Water Losses', 1999.
4. *Water pipelines and network management*—IIR Conference, London, England, 1997.
5. Sewers and Water Mains Standing Technical Committee. *Leakage control policy and practice*. London, UK National Water Council/Water Services Association/WRc, 1985 (Report No. 26)—out of print.
6. Manufacturers' brochures and operation manuals—see address list in Annex 5.

2. Introduction to leakage

2.1 Course introduction

Guidance notes for trainers

The course introduction presents to trainees the basic principles, content, and training style of the course (see section 1.3). This is followed by group discussions, in which the trainees provide feedback on their own systems. As a result, the trainees will become familiar with:

1. The ***objectives*** of the course, as described in section 1.2.
2. The concept of ***participation***—by exchange of information and data on their water supply systems, through discussions during the course, and learning to develop a topic and present a conclusion.
3. The available ***equipment***—their practicality and appropriate selection.

A total of **3 hours** is required for this introduction (1 hour) and the group discussion and feedback (2 hours).

Aims and objectives

- The aims of the course are to:
  (1) promote among trainees a good understanding of the causes of water loss and leakage and the factors that can control them;
  (2) enable engineers and technicians of water utilities to design and manage a leakage control system which suits their requirements.

- The objectives are that, by the end of the course, trainees will understand:

  (a) the factors that contribute to leakage;
  (b) the factors that contribute to total water loss;
  (c) the ways in which leakage and other losses can be quantified and expressed;
  (d) the range of leakage control methods available and any limitations /constraints;
  (e) the way in which the most appropriate method is chosen;
  (f) the range of equipment available for measuring, monitoring and detecting leakage, and their limitations at varying levels of technology;
  (g) the principles of designing, installing, operating and maintaining a chosen leakage control policy.

One of the main features of the course is the “hands-on” experience it offers each trainee, for example:

1. By tailoring the course to a particular water department or community’s requirements—finding out current system practice, problem areas, successes and failures, etc., and then involving groups of trainees in producing an Action Plan for their system, based on local knowledge and new skills gained from the course.
2. By having a practical demonstration of the available equipment over a range of technology, followed by a field demonstration and training session. Each trainee should have the opportunity to handle the equipment and become familiar with procedures (e.g. programming a data logger, measuring a flow profile, locating a leak).

This approach clearly requires some preparation beforehand and during the first day of the course. Trainees will be required to provide written information about their own water supply, e.g. physical details like topography, population and demand, cause and magnitude of losses, type and condition of mains, etc., as well as a description of the current leakage control policy, if there is one. Individual trainees, or a representative of a group of trainees, will be invited to make a brief presentation on the background and current practice of their water supply department.

Any problems raised in the trainees' initial presentations will be dealt with during the course, with feedback from the participants. The local knowledge gained from this exercise will be invaluable for putting together an Action Plan, and for the final discussions at the end of the course.

Summary

This introduction to the course sets out:

- the aims and objectives;
- the course contents and style;
- special features (practical demonstrations, exercises leading to a formulation of an Action Plan).

2.2 Defining leakage

Guidance notes for trainers

This module defines leakage and examines the relative significance of individual leakage in terms of the volume of water lost.

Trainees will be shown a series of slides illustrating leakage. The first is a burst, which shows the high volume of water lost over a very short time; such a leak is usually mended very quickly. Other slides contrast this with illustrations of smaller losses from fittings, which can lead to a high volume of water lost from small undetected leaks over a long period, sometimes years. There is also a slide which shows the volume of water lost from different sizes of hole under a range of mains pressures (Fig. 2.1).

Fig. 2.1 **Volume of water losses through holes of various sizes in a 0.5 inch (1.27 cm) pipe, at 5, 15 and 32 metres pressure**

Discharge in litres/day

5m	15m	32m
7 013	23 376	49 090
2 932	9 970	20 945
2 496	8 308	17 454
421	1 402	2 945
234	779	1 636

Experiments were carried out by Liverpool Corporation to determine the rate of loss through various sized holes in 0.5 inch diameter lead pipe under a pressure of 31.6m head.

The results are shown in this diagram

The concept of leakage is introduced as being a part of 'total water loss' (this expression has replaced 'unaccounted-for water' (UFW)—see below and section 3.2.

The duration of this session is 30 minutes.

What is leakage?

Leakage occurs in all distribution networks—the degree of leakage varying widely from one country to another, and between the regions of a country. It is important to distinguish between total water loss (sometimes referred to as 'unaccounted-for water' (UFW)) and leakage. **Total water** loss describes the difference between the amount of water produced and the amount which is billed or consumed. **Leakage** is one of the components of the total water lost in a network, and comprises the physical losses from pipes, joints and fittings, and also from overflowing service reservoirs. These losses can be severe, and may be undetected for months or even years. The larger losses are usually from burst pipes, or from the sudden rupture of a joint, whereas smaller losses are from leaking or "weeping" joints, fittings, service pipes, and connections. The volume lost will depend largely on the pressure in the system, and on the "awareness" time, i.e. how quickly the loss is noticed and dealt with. This in turn depends on whether the soil type allows water to be visible at the surface. It also depends on the leak detection and repair policy of the water supply company. The other components of total water loss are non-physical losses, e.g. meter under-registration, illegal connections, and illegal or unknown use. The components of total water loss are dealt with in detail in section 3.1.

Waste and leakage

Waste and leakage can be differentiated as follows:

- Deliberate *waste*, e.g. standpipe vandalism, taps left "open" permanently in areas of intermittent supply in order to fill vessels when the supply returns, which then overflows.
- Household losses caused by bad plumbing, tanks overflowing—this is also waste, and can be influenced by an effective policy of household metering (a study in the United Kingdom showed a 10% reduction in demand following metering).

A set of slides shows the range of leak types and their causes, such as:

— leaking lead service pipe;
— leaking joint or connection;
— internal corrosion producing a hole;
— longitudinal split in the PVC pipe.

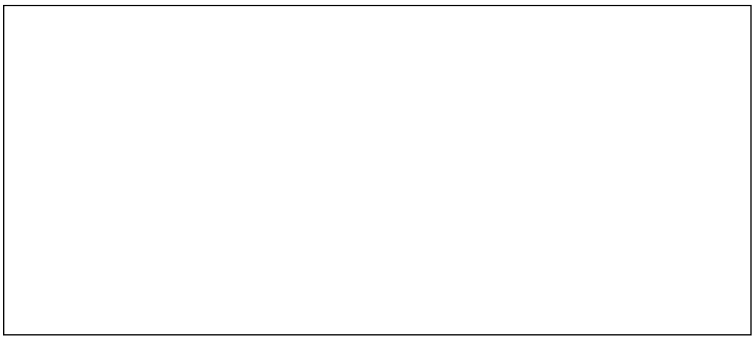
Some examples of leaks and leakage points are shown in Fig. 2.2.

Fig. 2.2 **Some examples of leak types**

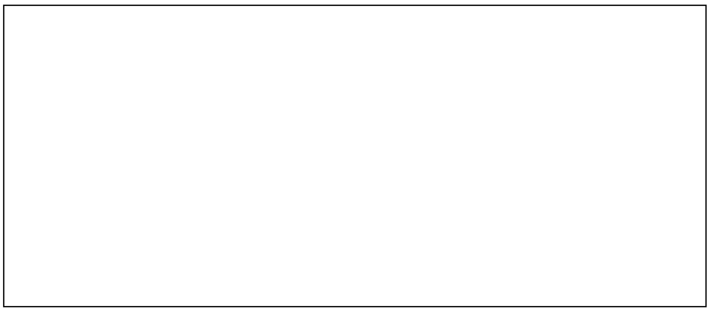
Two mechanisms are generally responsible for leaks which grow slowly: galvanic corrosion ("rust") and erosion (wear). Erosion is caused by the action of a jet of water containing sand particles impinging on the pipe. Examples of corrosion, erosion and combinations of both are illustrated in the figures below.

Galvanic corrosion (rust) occurred as the result of this coupling being left without protection after the galvanised coating had been removed by threading. The wall thickness was also reduced, thus shortening the time required for total failure.

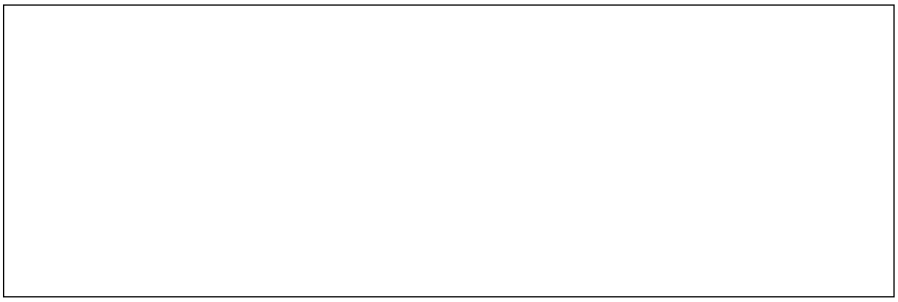
Erosion caused by a jet of water escaping from a leaking packing in the stopcock. Sand particles from the surroundings increased the erosive power of the jet.



Erosion of a cast iron flange, as a result of a leaking gasket.



A primary leak in a coupling on a high-density polyethylene (HDPE) pipe caused the marks on the coupling. A jet of water deflected by a stone in the backfill caused a secondary leak by erosion of the pipe.



A combination of galvanic corrosion aggravated by subsequent erosion.

This vast system of usually short sections of pipe connected together by joints and interconnected by tees and ferrules, with valves, hydrants, meters and other fittings interspersed through the network, presents many opportunities for bursts and leakage to occur. Fig. 2.3 shows the potential leakage points and the activities required for leakage control, as developed by South West Water Services Ltd., UK, for their integrated leakage and network management strategy. The strategy is described fully in Annex 3.

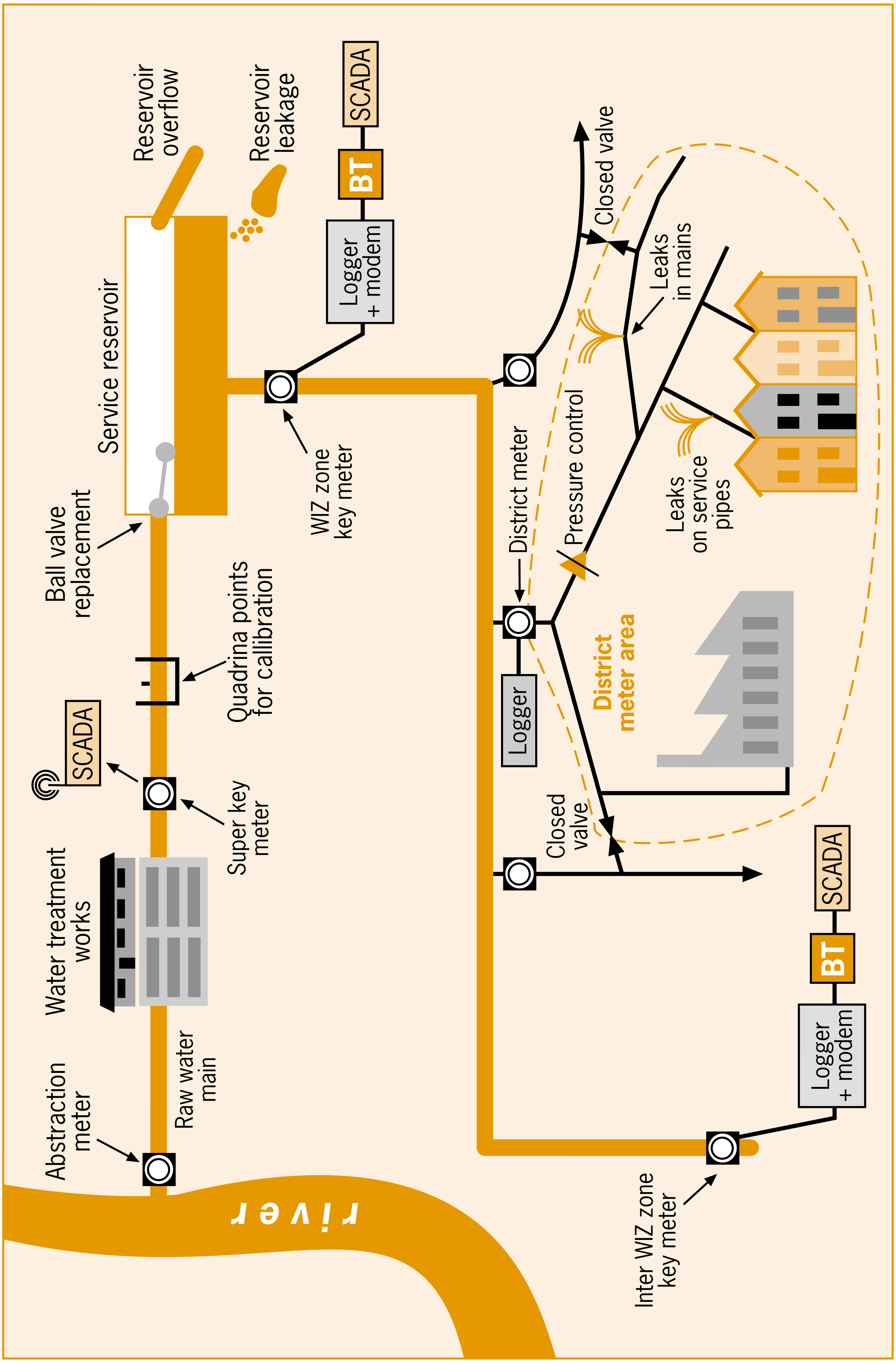


Fig. 2.3 **Key points for leakage monitoring and detection**

Summary

The module explains:

— what leakage is;
— the relationship between leakage, water loss and waste;
— possible types of leak.

Further reading

Stenberg R. *Leakage detection in water supply systems*. Stockholm, Swedish Water and Wastewater Works Association, 1982 (Publication VAV P35E). This publication has illustrations of types of leak, as shown in Fig. 2.2.

2.3 Factors influencing leakage

Guidance notes for trainers

This module is intended to stimulate discussion and promote awareness of the strengths and weaknesses of the trainees' water supply system. Once the concepts on the slide have been presented, trainees should be divided into groups for discussion and presentation of those factors which influence leakage in their own systems.

This session requires a total of **2½ hours**—for explanation of factors (30 minutes) and for group discussions and presentations (2 hours).

How much leakage is allowed to occur in a system is directly attributable to the company's policy, and the influencing factors can be grouped under four policy categories. These factors, which should be illustrated on a slide, are listed below:

1. *Resources*: financial—staffing—water.
2. *Infrastructure condition*: materials—renewal policy—pressure.
3. *Institutional attitude*: structure—regulation—politics.
4. *Leakage control policy*: activity—perception—technical expertise.

The availability of resources is clearly crucial to the volume of leakage. Where water is plentiful, leakage is viewed and tolerated differently to where it is scarce. Financial resources and manpower resources are also significant factors.

The condition of the infrastructure, and the renewal or rehabilitation policy, is perhaps one of the main reasons for the variation in leakage across the world. The choice and quality of materials, and their laying techniques, particularly in aggressive soils, influence the life-span of the network. Although the age of the network itself is not always a factor, it almost certainly becomes one when combined with the other factors. It follows that a company's policy for replacing or rehabilitating the pipe network is a major influence on the condition of the infrastructure and therefore leakage.

The institutional policy largely centres on the perception of, and attitudes to, leakage. These in turn affect the capital and staffing that are applied to controlling it. The attitude of governments, national and local agencies, municipal authorities and the community all influence the organization and the operation of the network. Political influences can also be significant—serving the community by developing a new source or building a new treatment works is more "high profile" than initiating a leak detection policy.

Finally, the leakage control policy itself determines the level of activity and the level of leakage in a network. Policies can range from those of very low activity, like repairing visible leaks only, to those which depend on monitoring flows into discrete zones to pick out areas of high leakage.

Significance and perception. The relative significance of leakage is shown by the contrast between areas of abundant supply (e.g. upland catchments) and areas of scarce supply. Countries of the Middle East, for example, depend on expensive desalination plants for their supply. Many Greek islands have to be supplied by tanker. Hong Kong is dependent on water bought from China. The scarcity of water will influence the way in which leakage is viewed.

Leakage is perceived in different ways by:

- *Governments and other agencies* are subject to political influences, local elections, etc. In a Karachi (Pakistan) pilot study, for example, in order to demonstrate leakage monitoring in a district it was necessary to provide a 24-hour supply; consumers in neighbouring districts were envious and complained to the local mayor; as a local election was approaching, the study was not allowed.
- *Water engineers and managers* sometimes give low priority to leakage in favour of capital programmes; another argument is that the leaked water returns to groundwater and so is not lost, or that it is very cheap.
- *Awareness of the public and consumers* increases in proportion to water shortage and drought, and media coverage. There are clear links here with demand management and water conservation techniques, and with public/consumer education programmes (e.g. water conservation practice in the USA).

Summary

This module lists the main factors which influence leakage:

— level of available resources;
— type and condition of the infrastructure;
— institutional policy and perception;
— leakage control policy.

2.4 Causes and effects of leakage

Guidance notes for trainers

The previous module discussed the factors which influence leakage and leakage control. This module (requiring 1 hour in the course) addresses the factors which cause leakage, and the effects of leakage on the producer and the consumer.

Effects of leakage

It is appropriate first to examine the effects of leakage and waste, which are well-documented. Leakage can lead to:

— *consumer inconvenience*, by reducing pressure at taps, appliances and showers, etc.;
— *damage to infrastructure*, by creating voids which can lead to collapse of highways and buildings;
— *excessive costs*, not only from compensation payments and from repairs to damaged structures, but also production costs (if leakage is 50% of production, energy and treatment costs have been doubled);
— *increased loading on sewers* due to infiltration, leading to the need to over-design sewer capacity;
— *introduction of air into the distribution network* if the water supply is intermittent, causing damage to meters, and leading to over-measurement of the true consumption and errors in water bills;
— *health risks*, in low pressure systems or where the supply is intermittent, by allowing infiltration of sewage and other pollutants into the pipe network.

The effects of leakage, about which a collection of slides could be made, are:

- Damage to infrastructure
- Consumer problems
- Financial losses
- Health risks.

1. Damage to highways, sewers and other utilities by subsidence and voids

Although leakage control programmes cannot greatly influence the catastrophic bursts which occur from time to time and can cause considerable damage to highways and sewers, there is a lower level of leakage which can cause similar damage over a period of time—such as leaking joints and fittings, and defective mains which have not completely failed. This leakage can continue undetected for considerable periods of time, before finally causing the collapse of, for example, a highway or footpath. A systematic leakage detection policy is able to control such leakage and avoid extensive damage by carrying out repairs quickly.

2. Effect on consumers

The most common effect of leakage on a consumer is when the supply fails, or the pressure becomes unacceptably low. This leads to complaints—often the first indication of leakage in a system.

Pressure may be reduced or completely lost in some parts of a demand zone (extremities or high points). Lavatory cisterns and storage cisterns will not fill as rapidly, and showers, washing machines, and other domestic appliance fed from the direct water supply may not work. These factors lead to consumer dissatisfaction. Obviously, the effect is greater if the mains pressure is low and where supply is already in deficit. In addition, just as leakage can cause infrastructure damage it can also cause damage to buildings, resulting in weakened foundations and cracked walls.

3. Financial losses

Apart from the financial implications of repairing the infrastructure and damaged plant, as well as compensation payments, there is an obvious direct cost associated with leakage. Increased pumping costs and electricity charges, and unnecessary capital costs of new sources and mains extensions can all be attributed to leakage. This is obviously one of the major savings to be gained by leakage control.

There are also financial implications in administration costs to deal with a larger number of consumers' complaints, and arising from a deterioration of the water company's public image. In addition, the public and media show an increasing interest in the activities of water companies, especially in times of drought or when new capital schemes are planned. It is at such times that it is difficult to justify high water losses.

4. Health risks

In systems where pressures are very low and supplies are intermittent, there is a high risk of contamination to the water supply from the sewerage system and other sources entering through damaged joints, pipes and fittings (back-siphonage).

Factors affecting leakage

Several factors contributing to leakage are:

1) **Pressure** can affect system losses in a number of ways:
   (a) The rate of leakage from leaking pipes or faulty joints will increase with a rise in pressure. Fig. 2.1 shows this relationship.

(b) In a similar way, especially in older systems, an increase in pressure even by a few metres, can result in a large number of bursts occurring in a relatively short space of time. Conversely, pressure reduction can reduce the rate at which bursts occur.
(c) Leak location—high pressure will increase the rate at which water escapes through a hole and may thus temporarily aid leak location by:
   (i) causing the leak to appear sooner; and
   (ii) increasing the noise level of the leak so that it is picked up more easily by sounding methods.

   Conversely, in systems with poor pressures and intermittent supply, leakage and burst rates are reduced but leak location is more difficult.
(d) Pressure surge—this can happen when a pump is switched on too quickly, or a valve is opened or closed too quickly. The sudden surge in pressure can cause the pipe to fracture, or can move thrust blocks, or damage the socket. There is also some evidence that surge can cause pipes to flex and move against rocks, resulting in local stress concentrations, and sometimes pipe failure (especially PVC pipes).
(e) Pressure cycling—there may be a problem of fatigue in plastic pipelines, which is due to bad design of the system (e.g. booster pumps switching on and off frequently) or badly designed and maintained pressure-reducing valves (PRVs), caused by cycling the pressure between high and low values. Fatigue is also caused by UV degradation weakening the pipe, caused by bad storage practice.

The effect of pressure is explained in more detail in section 6.3.

2) **Soil movement** is caused by:
— Changes in moisture content, particularly in clays, causing shrinkage (transverse failure of cast iron mains has been recorded).
— Changes in temperature.
— Heavy frost.
— Subsidence, e.g. mining, earthquake.

All these soil movement factors can cause a pipeline to break, joints to move, or result in localised stress concentrations within the pipe leading to failure.

3) **Pipe condition**. The most serious problem in this category is the corrosion of metallic pipes.
(a) Internal corrosion is usually more severe in soft (acidic) waters from upland sources. In the case of iron pipes, tubercles develop on the wall of the pipe, and these are associated with pitting and localized areas of metal attack. The pipe wall thickness is reduced so that the pipe loses its ability to withstand pressure, leading to eventual penetration and failure of the pipe wall, and obviously leakage.
(b) External corrosion can arise from a number of causes—aggressive soils may cause damage because of differing levels of dissolved salts, oxygen, moisture, pH, and bacterial activity, leading to corrosion currents in the metal. The corrosion effects are similar to internal corrosion.
(c) Asbestos cement or concrete pipes can be corroded by high levels of sulfates in the soil or water.

4) **Poor quality materials, fittings and workmanship**. In this category are numerous fittings and apparatus, both on the consumers' and the water company's premises. Faulty tap washers, ball valves and poor seals are some of the main causes of waste and leakage on the consumer side, and badly adjusted automatic flushing cisterns in commercial and industrial premises. Repairs are often difficult to enforce on consumers' fittings, so that leakage continues for longer.

More attention is now being paid to the quality effectiveness and suitability of water fittings and materials.

Particular attention is given to internal and external protection (linings on the inside, sleeving on the outside of steel mains) and research is continuing into durability of uPVC and polyethylene pipe materials.

There is also a great variation in the suitability of service and supply pipe materials. Lead, galvanized iron, copper and polyethylene have all been used over the years. These pipes can all suffer from failure, metal fatigue, corrosion, chemical attack and faulty laying, as well as from damage by other utilities and their contractors, and by poor quality backfilling. The choice of material, however, is often influenced by local conditions such as availability of local materials and manufacturing, and company or government budgeting policy.

A series of slides should be collected to illustrate corrosion and damage to a range of pipe materials.

5) **Soil characteristics**. This is an important factor, as it affects the length of time a leak is allowed to continue, i.e. the type of soil and its permeability. In some soils (like clay), water from underground leaks may show on the surface fairly quickly, whereas similar leaks in chalk or sandy soil can continue indefinitely without showing.

6) **Traffic loading**. The effects of vibration and high loading caused by heavy lorries is thought to be a major factor affecting buried pipelines and leading to pipe failure.

7) **Age**. Many of the factors just described are age-dependent—their effect will be greater with time. Consequently, the age of a pipeline can appear to be the most significant factor affecting the likelihood of leakage, but on its own, age is not necessarily a factor.

8) **Leakage control method**. Finally, the chosen method of leakage control, whether a passive or active (metering) method, will determine the level of leakage in a water undertaking, and this is of course completely within the company's control, as is the speed of repair. This factor is discussed in more detail in the modules of Section 6.

Summary

This module first examined the effects of leakage on the consumer and the infrastructure, listing the main effects. It then identified the causes of leakage and the factors which influence leakage.

Trainees should be encouraged to analyse, in groups, the main factors contributing to leakage in their networks. The group feedback should be discussed by the whole workshop.

2.5 Developing a leakage strategy

Guidance notes for trainers

This module introduces the concept of a leakage management strategy. It sets out the steps of the analytical process for examining the issues affecting leakage, how it is currently perceived and managed, and ways to improve its assessment, management, and control.

Throughout the rest of the manual each of the questions, tools, and solutions are examined in more detail.

Questions and solutions

The key to developing a leakage strategy for any network is first to ask some **questions** about the network and how it is operated, and then select the right **tools** to find the solutions. The questions and tools are:

— **how much** water is being lost? (*tool*: water balance calculation);
— **where** is it being lost? (*tool*: pilot studies);
— **why** is it being lost? (*tool*: review of the network and operational practice);
— how can we **reduce** the losses and **improve** the performance (*tool*: development of a strategy and appropriate action plans);
— how can we **maintain** the strategy? (*tool*: training, monitoring, operation and maintenance).

Each element of the strategy, and the tool to address the questions, is listed below. The list can be used to stimulate discussion and can be **re-visited** by trainer and trainees throughout the course. Each stage of strategy development is expanded in subsequent sections of the manual.

Element	Tool
HOW MUCH is being lost?	**WATER AUDIT** Measure components Check production /consumption Recalculate water balance Review records/operating procedures/skills
WHERE is it happening?	**PILOT STUDIES** Quantify total losses How much is leakage? — distribution network — transmission mains — reservoirs How much is non-leakage losses? Refine the water balance calculation
WHY is there water loss?	**REVIEW NETWORK** *Investigate:* Historical reasons Poor practice/poor QA (Quality Assurance) Poor materials/infrastructure Local influences Cultural/financial/social/political factors
HOW TO IMPROVE performance?	**ACTION PLANS/STRATEGY DEVELOPMENT** Update records systems/GIS Introduce zoning/DMAs Monitor water losses and leakage Prioritize areas Address non-physical losses Detect and locate leaks Initiate repair/rehabilitation policy
HOW TO MAINTAIN the strategy?	**TRAINING/AWARENESS** Improve awareness Increase motivation Transfer skills Introduce best practice/appropriate technology Give hands-on experience/continual reinforcement Monitor and follow-up action plans /implementation Involve community Consider demand management policy Initiate water conservation programme

3. Leakage assessment

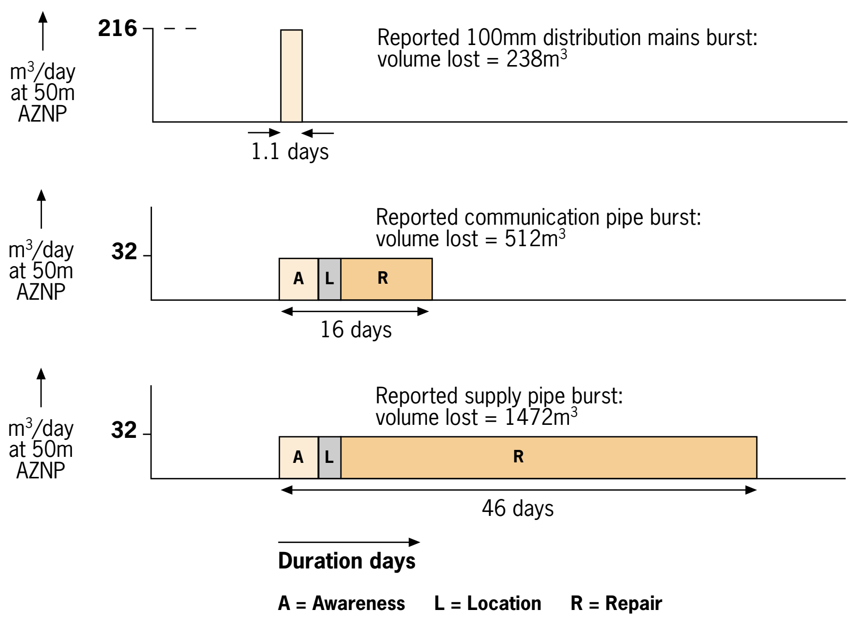
3.1 Understanding water loss and leakage

Water loss occurs in all distribution systems—only the volume of loss varies, depending 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. It is important to differentiate between total water loss and leakage. **Total water loss** is the difference between the amount of water produced and the amount which is billed or consumed. **Leakage** is one of the components of water loss, and comprises the physical losses from pipes, joints and fittings, and also overflows from service reservoirs. These losses can be severe, and may go undetected for months or even years. The larger losses are usually from burst pipes, or from the sudden rupture of a joint, while smaller losses are from leaking joints, fittings, service pipes, and connections. The volume lost will depend largely on the characteristics of the pipe network and the leak detection and repair policy practised by the company, such as:

— the pressure in the network;
— whether the soil type allows water to be visible at the surface;
— the "awareness" time (how quickly the loss is noticed);
— the repair time (how quickly the loss is corrected).

Fig. 3.1 shows the effect of awareness, reporting times, and location on the volume of water lost from three types of leak.

Fig. 3.1 **Estimated durations and flowrates of bursts** (from *Managing Leakage—Report E*)



Leakage is 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 errors, or accounting errors are often major contributors.

The key to developing a successful leakage control strategy is, therefore, first to **understand** the components of water loss, and their relative significance. Then action plans can be developed to address each of the **causes** of the losses. Training and skills transfer are essential components of the strategy, to ensure that good leakage management is sustained.

3.2 Defining total water loss

Total water loss is the expression used for the difference between water produced and water consumed. It is sometimes referred to as 'Unaccounted for Water' or 'Non-Revenue Water'.

Total water loss = water produced—water billed or consumed

Total water loss = physical ('real') losses + non-physical ('management' or 'apparent') losses

Examples of water loss as a % of water supplied were summarized in an international survey by the International Water Services Association (IWSA) in 1991:

Developed countries	8–24 %
Newly-industrialised countries	15–24 %
Developing countries	25–45 %

Typical values for components of water loss in developing countries

Example 1. Arequipa, Peru (from a leakage control study carried out by Binnie and Partners and the Water Research Centre (WRc), and funded by the British Government Overseas Development Administration (ODA), 1987)

Total production	37 108 000 m³
Billed consumption	20 338 000 m³
Water loss	16 770 000 m³

Total water loss was therefore 45% of the total production.

Independent estimates were made for the various components of unaccounted-for water. The total was within 2% of the figure quoted above for total water loss, which suggests that the values of the individual components are reasonably accurate.

Leakage from reservoirs	0 m³	(0.0%)
Leakage from trunk mains	568 000 m³	(3.3%)
Leakage from distribution	11 715 000 m³	(68.7%)
Reservoir overflow	1 068 000 m³	(6.3%)
Meter under-registration	2 617 000 m³	(15.3%)
Filter washwater	473 000 m³	(2.8%)
Other losses in treatment works	252 000 m³	(1.5%)
Supplies to tanker trucks	360 000 m³	(2.1%)
Total water loss	17 053 000 m³	(100%)

Example 2. Hanoi, Vietnam (data from a leakage control training workshop conducted by Malcolm Farley Associates and funded by the World Bank, 1994)

Water consumed (billed):	32%
Water lost:	68% (43% non-billed, 20% leakage, 5% company use)

Example 3. Haiphong, Vietnam (data from a water audit study conducted by Malcolm Farley Associates and funded by the WHO Regional Office for the Western Pacific, Manila, 1997)

Total water loss in Haiphong was 60% of production. There were no estimates of the components, but from studies of other Vietnamese water companies it is known that around two-thirds of losses are due to non-physical losses and one-third to physical losses. The major causes of these losses are summarized below.

Physical losses:

- Poor network design, construction, and quality control
- Aging pipe network
- Leakage at connections, joints, valves, and fittings, and from broken mains.

Non-physical ("management") losses:

- Unregistered use by customers for irrigation, commercial purposes, vehicle washing
- Illegal connections
- Customer household waste due to lack of metering and flat rate tariff
- Customer waste from public pavement tanks
- Excessive customer use, compared with per capita consumption norms
- Poor revenue collection policy (refusal to pay, little enforcement, corruption)
- No water regulations, lack of business ethos.

Particular regions of some developing countries have higher levels, e.g. Hanoi, Vietnam, had 70% losses (1996) due to infrastructure damage from bombing in the war.

3.3 International comparisons

Extracts from a note by the Operation and Maintenance Committee of the International Water Association (IWA)—Task Force 'Documents on Water Losses'—Standard Terminology and Recommended Performance Measures. IWA, London, September 1999.

1. Preliminary remarks

The problems of water and revenue losses are:

- Technical—not all water supplied by a utility reaches the customer.
- Financial—not all the water supplied is paid for.
- Terminology—lack of standardized definitions of water and revenue losses.

The Operation and Maintenance Committee of the IWA's Distribution Division therefore set up a Task Force (1997–99) to review existing methodologies for international definitions and comparisons of water losses from water supply systems. The full text is contained in the IWA 'Blue Pages'—*Losses from water supply systems: Standard terminology and performance measures*, IWA Operation and Maintenance Committee, London, 1999. IWA recommends that these definitions be integrated into international standards and regulations.

2. The importance of reliable metering

- Reliable metering of all water volumes entering and leaving the supply system, and authorized consumption within the system, are the fundamental requirements for water demand management, as well as for the assessment of losses and for water balance calculations.
- Whenever actual metering does not exist, every effort should be made to reach a precise assessment of each component of water volumes and uses, to determine realistic quantities for the water balance. Methods used to estimate any unmetered components of the water balance should be recorded and defined.

3. The components of water balance calculations

Any discussion relating to losses must be preceded by a clear definition of the water balance components. The main definitions are:

- *System Input Volume.* The annual volume input to a transmission and/or a distribution system, including water supplied to the customers **and** water exported to other supply systems
- *Authorized Consumption.* The annual volume of metered and unmetered water by authorized customers. It includes exported water and items such as fire-fighting, mains and sewer flushing, watering of public gardens, public fountains, etc.
- *Water Losses.* The difference between "system input volume" and "authorized consumption" water losses consists in **real** and **apparent** losses.
- *Real losses* are the physical losses of leaks, bursts and overflows up to the point of customer metering.
- *Apparent losses* consist in all types of inaccuracies (input, output, customer meters), and unauthorized consumption (theft, illegal use).
- *Non-revenue water* is the annual volume of total losses and unbilled authorized consumption.

4. Influences on real water losses

For each system there are several decisive local influences on real water losses. They are:

- The percentage of time per year during which the network is pressurized.
- The average operating pressure, when the network is pressurized. With increasing pressure, the leakage rates rise to a much larger extent than would be predicted by the theoretical 'square root relationship between pressure and leakage rates'. Opportunities for pressure management are usually restricted by local topography and standards of service.
- The number of service connections and the location of customer meters can be considered to be the weak point of most distribution networks, as they lead to high failure rates and large volume of losses (low leakage flow rate but long duration).
- The length of mains.
- Infrastructure condition—materials, frequency of leaks and bursts.
- Type of soil and ground conditions.

5. Technical performance indicators (PI) for real losses

- Traditional PIs of water losses are frequently expressed as a percentage of input volume. However, this indicator fails to take account of any of the main local influences. Consequently it cannot be considered to be an appropriate PI for comparisons.
- The recommended basic technical indicator for real losses (TIRL) is:
  litres/service connection/day when the network is pressurized.

- $$\text{TIRL} = \frac{\text{Annual volume of real losses}}{\text{No. of service connections} \times \text{No. of days network is pressurized}}$$
- A better interpretation of the actual real losses in any distribution network is obtained by comparing TIRL with a best assessment of unavoidable annual real losses (UARL) for local conditions.
- Based on a statistical analysis of international data, including 27 diverse water supply systems in 19 countries, a method of predicting UARL has been developed and tested for application to systems with:
  — average operating pressure of between 20 and 100 metres;
  — density of service connections between 10 and 120 per km of mains;
  — customer meters located 0 and 30 metres from the edge of the street.
- As an example, UARL can vary between **20 and 142 litres/service connection/day** for specific combinations of:
  — average operating pressure between 20 and 60 metres;
  — density of service connections between 20 and 100 service connections per km of mains;
  — customer meters located between 0 and 20 metres from the edge of the street and the delivery point (length of connections).
- The ratio of the actual TIRL to UARL related to the local system is a useful non-dimensional index (the infrastructure leakage index—ILI) of the system performance. It is recommended as an additional step for the interpretation of the actual value of TIRL.

6. Financial performance indicators of non-revenue water (NRW)
These should be expressed in terms of volume and cost:

- Non-revenue water, expressed in %:

$$\text{NRW} = \frac{\text{unbilled volumes}}{\text{system input volumes}} \times 100$$

Unbilled volumes include unbilled authorized consumption and total water losses.

- Non-revenue cost (NRC) expressed in %:

$$\text{NRC} = \frac{\text{Annual costs of real and apparent losses + unbilled authorized consumption}}{\text{Annual running costs of the supply system}} \times 100$$

An appropriate cost-value for apparent losses would be the average water sale price.

An appropriate cost-value for real losses would be the unit costs (for chemicals, energy) of producing and pumping water, or costs of importing water (bulk purchase). Running costs are defined as the total annual costs minus the capital costs of the whole supply system.

Calculation of operating and capital costs of water is explained in Section 6.

3.4 Physical (real) and non-physical (apparent) losses

Physical ('real') losses

1. ***Leakage from transmission mains and the distribution network***—caused by:
   — burst pipes (sudden rupture of a pipe section or joint);
   — leaking joints, fittings, service pipes, and connections.

2. ***Leakage from reservoir walls and overflows***—caused by:
   — seepage from old masonry or concrete walls;
   — float-valves not working.

Physical 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, such as:

— the pressure in the network;
— whether the soil type allows water to be visible at the surface;
— "awareness" time (how quickly the loss is noticed);
— location time (how quickly the leak position is identified);
— repair time (how quickly it is dealt with).

Non-physical ('management' or 'apparent') losses

1. ***Over-estimation of production***—caused by:
— inadequate or no measurement facility;
— inadequate calibration programme for bulk meters.

2. ***Under-estimation of consumption***—caused by:
— under-registration of customers' meters;
— poor quality, inaccurate meters;
— stopped meters;
— inadequate meter maintenance/replacement policy;
— inadequate meter reading policy;
— under-estimation of free supplies or operational use.

3. ***Theft of water***—caused by:
— illegal connections;
— vandalized meters, bypassed meters;
— bribery and corruption of meter readers.

4. ***Wasteful use***—caused by:
— inadequate customer metering policy;
— inappropriate charging policy (flat-rate tariff, subsidized supplies);
— cultural and social traditions;
— inadequate community education policy .

4. Quantifying total water loss

4.1 Conducting a water audit

A **water audit** quantifies the total water losses and leakage in a network. This in effect is a water balance calculation where the amount of water put into distribution is compared with the sum of the components of water consumed or used. The shortfall, which is equal to the total distribution losses, is often expressed as a percentage of the distribution input (or production) or, preferably, in Megalitres (Ml) /day.

Although percentage figures are rarely meaningful when comparing different organizations, they can be used to indicate the extent of **reduction** of water loss by a single water supplier.

The practice in the United Kingdom, which has been adapted by the International Water Association (IWA) for international practice, is to divide the distribution input into components which can be individually measured or estimated to provide a water balance, as illustrated in Fig. 4.1.

Procedure for a water audit

A water audit has two components: 1) system appraisal, and 2) water balance calculation.

1. System appraisal

The purpose of the appraisal is to review:

- country/regional characteristics (e.g. influencing factors, components of water loss);
- current practice and methodologies;
- level of technology (reliability of meters/equipment in place, need for temporary meters);
- staff skills and capabilities;
- the company's data and methodology for the water balance calculation.

The appraisal 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.

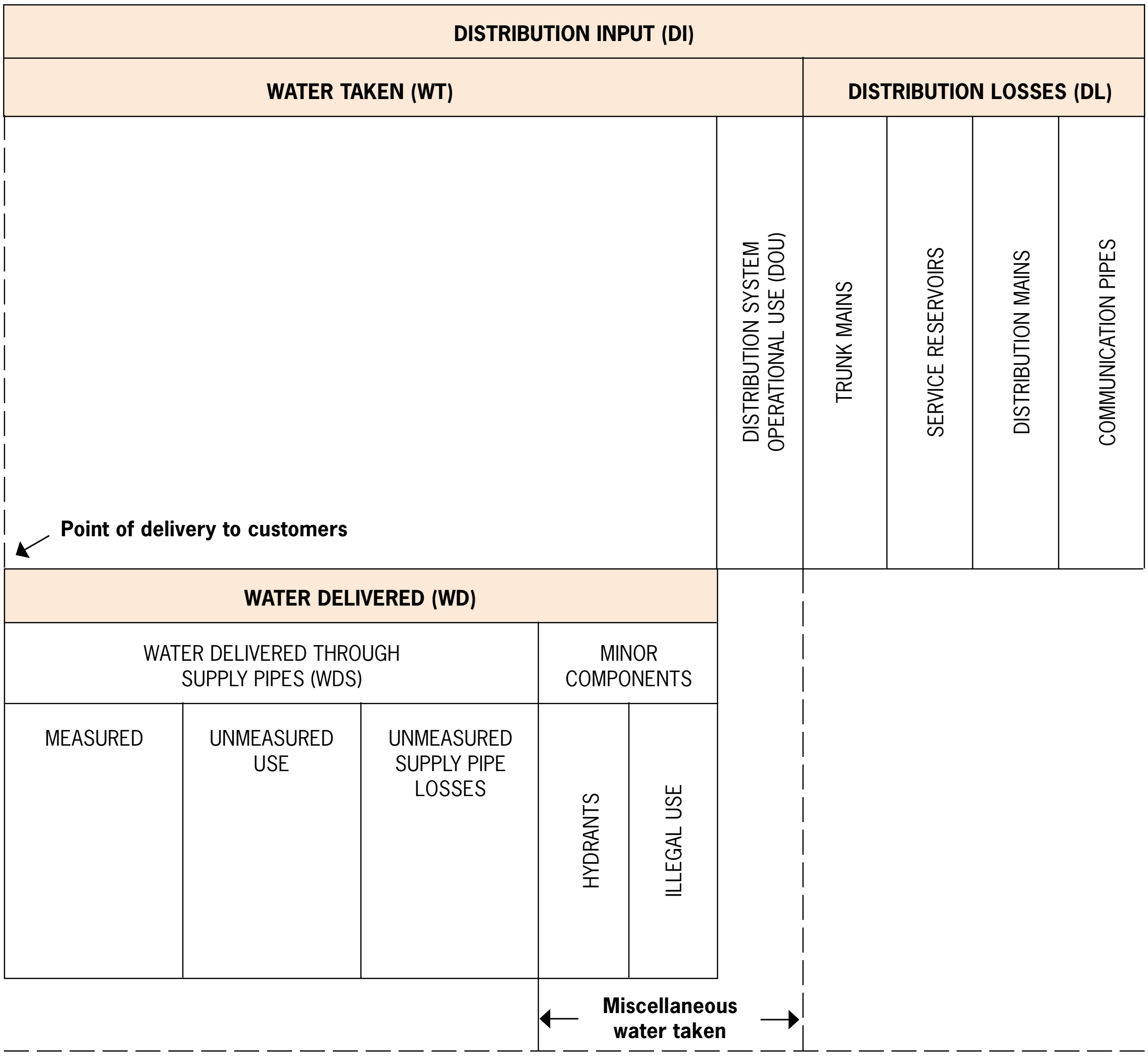
b) *Discussions with operational staff* on system features and practice, including:
- physical data (population, demands, topography, supply arrangements);
- drawings and records, billing data;
- estimates of total water loss;
- estimates of leakage and other water loss components (illegal connections);
- current practice (staffing structure, staff numbers and skills);
- techniques and equipment;
- repair programme;
- economic data (cost of production, 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 train staff.

Fig. 4.1 **Water balance components**
(from *Managing Leakage Summary Report*)

Volume per day not to scale



SIMPLIFIED BREAKDOWN OF DISTRIBUTION INPUT (DI)

DISTRIBUTION INPUT (DI)					
WATER TAKEN (WT)					**DISTRIBUTION LOSSES (DL)**
WATER TAKEN (WT)				DOU	DISTRIBUTION LOSSES (DL)
WATER DELIVERED THROUGH SUPPLY PIPES (WDS)			MISCELLANEOUS WATER TAKEN (WTM)		DISTRIBUTION LOSSES (DL)
MEASURED (WDSM)	UNMEASURED USE (WDSM)	UNMEASURED SUPPLY PIPE LOSSES (WDSL)	MISCELLANEOUS WATER TAKEN (WTM)		DISTRIBUTION LOSSES (DL)

2. Water balance calculation

This is the measurement of distribution input and water consumed. It can be measured using a number of techniques—the most appropriate ones for the system under investigation should be selected. Ideally, all components of the water balance should be quantified over the same designated period, and expressed in Megalitres (Ml)/day.

1. *Distribution input.* This step identifies all water sources and quantifies the water supplied. Measurement is by one or more of the following:
   - existing production (bulk) meters, after checking for accuracy;
   - summation of zone flows where there are existing zone meters;
   - reservoir drop tests;
   - checking of pump curves;
   - insertion meters at points where there are no meters, e.g. upstream or downstream of a treatment works (if upstream, the losses during the treatment process should be assessed and subtracted).

   Section 5.2 describes methods for quantifying flows into the network where there are no existing bulk meters (temporary insertion meter, portable ultrasonic meter).

2. *Measured use.* Billing records are used to quantify measured outputs from the system:
   - identify all non-household customers;
   - identify all household customers.

   Convert billing data over a monthly or quarterly billing period to an average daily flow in Ml/day. Customers who are not metered are treated differently (see 3, below).

3. *Unmeasured use.* This step identifies unmetered households and other authorized unmeasured use:
   - estimate use by unmetered households. Monitor a sample of households by meter, or estimate the per capita consumption;
   - identify and estimate unmeasured use by authorized users, e.g. municipal buildings, parks, fire services, tankers;
   - identify and estimate unmeasured supplies to peri-urban areas (slum areas, squatters, etc.);
   - tidentify and estimate water used by the company for operational purposes, e.g. mains cleaning and flushing.

4. *Unauthorized use.* This step identifies and estimates illegal supplies and theft:
   - estimate the number of illegal connections from past records and anecdotal evidence of inspectors, or by a house-to-house survey of a sample zone (check that each connection has a billing reference);
   - estimate the number of broken or by-passed meters in the same way;
   - use the per capita consumption estimates to calculate the volume used.

5. *Calculate the total losses.* Add together the volumes from steps 2, 3, and 4 (above), and subtract from step 1. The residual is the total water loss from the system.

6. *Calculate leakage.* Total water loss can be further broken down into:
   - leakage from reservoirs;
   - overflows from reservoirs;
   - leakage from trunk mains;
   - leakage in the distribution system—from the company's mains, service connecions, and fittings.

Each of these components can be quantified to improve the water balance calculation and to prioritize leakage management activities. Leakage data from the methods described below are gathered from night flows, expressed in litres/hour. A factor of 20 is used to convert to daily flow, to allow for higher pressures at night. This hour/day factor is currently the subject of research in the United Kingdom.

Leakage from reservoirs. This can be measured by the reservoir drop test. Close the inlet and outlet valves and measure the drop in water level over time. If the reservoir has compartments, each can be monitored in turn. Drop tests are usually carried out at night to minimize disruption to the supply.

Overflows from reservoirs. Inspect the float valves when the reservoir is at top water level (TWL) to identify those which are passing. Estimate or measure the volume passing for the period when the reservoir is at TWL.

Leakage from trunk mains. Use insertion meters or clamp-on ultrasonic meters at each end of the main to calculate the change in volume flowrate. Alternatively, include the trunk mains in the distribution system measurement.

Leakage in the distribution system

1. Supply zone measurement is a method for measuring the night flow into a supply zone and includes trunk main leakage. Use a reservoir bulk meter to monitor flows at night (2 a.m. to 4 a.m.). Subtract the measured night use by large customers and the estimated night use by households. If there are no bulk meters, it may be possible to use another form of reservoir drop test. Close the inlet valve to the reservoir and measure the drop in level over the same period, after subtracting the same values for customer use. This calculation will also include reservoir leakage and trunk main leakage.
2. District Meter Areas (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.

The principle of monitoring leakage in DMAs is described in detail in Section 7. Techniques for quantifying losses in the components of the network are described in detail in Section 4.

The 'tanker technique' described in section 5.3 allows measurement (and detection) of leakage in systems with intermittent supplies.

7. *Other "losses"*. The water balance calculation can be further refined by identifying errors and malpractice. These are often called "management" losses, resulting in a shortfall of revenue for the water supplied. Examples are:
   - *Under-registration by customers' meters.* This can be estimated from a sample survey:
     - use accurate 'C' or 'D' class meters, temporarily installed in line with the customer's meter, as check meters to compare the volume flows;
     - calculate the volume which is lost due to under-registration in the surveyed area and extrapolate.
   - *Stopped or broken meters.* The number of these can be estimated from meter records or a sample survey:
     - calculate the volume lost from meter records or from estimates of per capita consumption.

5. Techniques for quantifying leakage

5.1 Leakage measurement in the distribution network

Guidance notes for trainers

This module develops the concept of flow measurement and leakage calculation explained in the previous two modules. It details the methodologies used for the measurement of leakage in various parts of the distribution network. The time required for this session in the course is 2 hours.

Introduction

Leakage can occur in: (1) reservoirs; (2) transmission mains; (3) the distribution network.

Although leakage in reservoirs and trunk mains can be significant, the majority of leakage occurs in the mains and service pipes within the distribution network. The procedure adopted for leakage measurement depends on the supply arrangements and the design characteristics of the supply and distribution system. The main factors to consider are whether:

— there is 24-hour or intermittent supply;
— the supply arrangements can be temporarily changed;
— the supply is to discrete zones with designated boundaries, or to the total distribution area.

If there is a 24-hour supply, or the system will allow temporary rearrangement to provide a 24-hour supply during the test period, leakage measurement can be made using the total night flow method. If these arrangements cannot be made, the leakage must be estimated using the total quantity method.

The extent to which each of the components of the distribution system can be measured depends on the design of the supply and distribution system. For example, in a system which contains many reservoirs, it will not be practicable to test each one for leakage, and a representative sample must be tested. Similarly, leakage from trunk mains is measured by choosing suitable representative sections.

In a system which has only one or two major supply reservoirs serving the whole of a distribution network it may not be possible to measure reservoir leakage without interrupting the supply, unless the reservoir has two chambers which can be tested independently.

Measurement techniques

(1) Reservoirs

Leakage from reservoirs is measured by conducting a drop test. The aim is to measure the rate of fall of the water level over the duration of the test, with both the reservoir inlet and outlet valves closed. The test should be done at night when demand is at a minimum. It may be possible to rearrange zone boundary valves to supply the zone with its reservoir under test from an adjacent zone.

The duration of the test depends on local supply criteria, but should be at least 4 hours and preferably 12 hours or longer. The reservoir should be full before the start of the test.

The rate of drop can be measured in several ways:

- — graduated scale;
- — depth gauge, which emits an audible signal on contact with the water level at each measurement;
- — pressure transducer and data logger; the pressure transducer is lowered to the bottom of the reservoir, and the data logger records the reduction in pressure (metres) at the transducer as the water level drops.

The larger the surface area of the reservoir the smaller will be the rate of drop, if any. This should be borne in mind when selecting the measurement instrument and its sensitivity.

$$\text{Rate of leakage} = \frac{(d1 - d2) \times A}{T} \quad m^3/\text{hour}$$

where d1 = initial depth (m)
d2 = final depth (m)
A = surface area of reservoir (m3)
T = test duration (hours).

It is recommended that the reservoir levels be monitored for at least 48 hours before planning the test, to determine the time when the reservoir is at its fullest level, and the time when water demand on the reservoir increases rapidly. Knowing these times will determine when the test should be started and finished without disrupting supplies to consumers. If the reservoir does not fill sufficiently, then it may be necessary to implement distribution system management to gradually increase reservoir storage over several days prior to the test.

(2) Transmission mains

These are the major mains for transmission between the sources and the distribution network, with relatively few connections from them to the secondary system.

There are two methods of measuring trunk main leakage; one necessitates removing the main from supply, the other does not.

a) By-pass method

To use this method the following conditions must be met:

(i) the main can be taken out of supply;
(ii) there are valves on the main;
(iii) the valves can be closed and are drop-tight;
(iv) there are usually no branch connections from the main, or they can be turned off during the test.

The procedure is as follows:

1) Select a length of main to be tested. The length will depend on the distance between valves, but should be between 1 km and 5 km.
2) Isolate the section of main under test by closing a valve at each end of the test section. Ensure that each valve is drop-tight.
3) Install a 25 mm positive displacement meter on a bypass around the upstream valve.

4) Record the meter readings before and after the test period. The test period should be as long as possible, within the constraints of system operation, and preferably at least one hour.

   Any leakage from the section under test will be recorded by the meter. Leakage is calculated by the following formula:

$$\text{Leakage in litres/hour} = \frac{\text{flow through meter over test period (litres)}}{\text{test period (hours)}}$$

   Trunk main leakage can be expressed in litres/km/hour. The test can be repeated over several lengths of main.

b) Pairs of insertion meters

To use this method, the following conditions must be met:

(i) Two insertion meters and two data loggers are available.
(ii) Suitable tapping points can be made on the main through which to insert a flowmeter.
(iii) Branch connections can be isolated or metered during the test period.
(iv) The flowrate along the main can be varied, e.g. by throttling a valve.

Two insertion flowmeters are required, one inserted at each end of the section of main under test. The test period is two days. After the first day the meters are interchanged to eliminate inaccuracy from meter error. The leakage rate is calculated when the data loggers are read back at the end of the test.

(3) The distribution network

Because of the size and complexity of the pipework in the distribution network, it is not always possible to measure leakage directly, except in small networks fed by a single metered feed.

Therefore leakage in the distribution network is derived from measurement of night flows into the system or part of the system. Measurement is made by conducting a drop test (in a reservoir supply zone) or by selecting a representative area within the distribution system, and isolating the zone by closing the valves around the boundary. A meter is installed on the main supplying the zone and the night flowrate is recorded. Consumption of large metered consumers is monitored over the same period and deducted from the total night flow to give the net night flow.

The drop test method is similar to the method for measuring reservoir leakage, except that the reservoir outlet valve is open. Zone valves should be checked for drop-tightness, and the reservoir level monitored during the night. The fall in level is an indication of genuine night consumption and leakage. It can be assumed that genuine night consumption is very small, around 2 litres/property/hour, during the time of minimum night flow (usually between 2 a.m. and 4 a.m.).

In those systems where the supply is intermittent, supply arrangements may be changed temporarily to ensure that the zone under test receives a continuous supply. It is advisable to allow the system to equilibrate for 48 hours, for tanks to be filled, etc., before the night flow measurements are taken.

Flows into selected zones can be monitored using:

(a) existing zone meters;
(b) meters installed specially for the test;
(c) temporary insertion probe meters.

Summary

This module details methodologies for leakage measurement in:

— reservoirs;
— trunk mains;
— the distribution network.

5.2 Using temporary meters

Guidance notes for trainers

This module describes a procedure for measuring flows and pressures in the distribution system where there are no existing meters or where the accuracy of existing meters requires checking. The method involves the use of an insertion probe meter, such as a pitot tube, an insertion turbine meter, or an insertion electromagnetic meter, to measure the point velocity and derive the flowrate. An acceptable alternative to such intrusive measurement techniques would be to use a clamp-on ultrasonic meter.

Trainees should be appraised of the techniques by practical demonstration of the instrument and by slides. Manufacturers' brochures and operating instructions are a valuable source of illustrations. Trainees may be shown the application of the technique during the field sessions. The duration of this session in the course is 1 hour.

1. Insertion flowmeter installation

The installation technique is the same for both insertion turbine and electromagnetic meters. Typical instruments are the Quadrina 'Probeflo' insertion turbine meter and the ABB 'Aquaptobe' insertion EM meter. The meter is introduced into the live main through a 2-inch (5 cm) gate valve or ball valve.

The method used for drilling and tapping the main in order to fit a valve depends on the size of the main:

a) A *split collar*, which has been drilled and tapped to a 2-inch (5 cm) thread, is fitted to the main and a 2-inch (5 cm) nipple inserted in the hole. A 2-inch (5 cm) valve is attached to the nipple. An under-pressure drilling machine is attached to the valve, the valve is opened and a hole drilled in the main using a 1.5-inch (3.75 cm) drill bit. The drill is withdrawn into the pressure housing of the drilling machine, the valve is closed and the drilling machine removed.

   One of the advantages of using a split collar is that with smaller diameter mains (100 mm and below), a 2-inch pre-drilled and tapped split collar is fitted but a 1-inch drill can be used, allowing a small-diameter insertion meter to be installed instead of the standard model. In this way, the recommended ratio of 4:1 for pipe diameter to tapping hole diameter is maintained and stress on the pipe wall is minimized.

   The pre-drilled and tapped split collar method, by removing the necessity to use the larger and more expensive under-pressure drilling and tapping machine at the site, reduces both the time and cost of the operation, and enables the trial excavation dimensions to be kept to a minimum.

   As an alternative to the split collar method, a stainless steel pipe repair clamp can be used, which incorporates a female-threaded boss welded to the upper section of the clamp. A male-threaded valve is attached to the boss, and the main is drilled as previously described.

b) *Mains greater than 300 mm diameter.* The method of using a split collar is limited by its size and weight. A split collar to fit a main larger than 300 mm is unwieldy and heavy, and must be fitted using lifting gear. An alternative arrangement is to drill and tap the main direct, provided the wall of the main is of sufficient thickness, and the material of sufficient strength, to allow the safe insertion of a nipple. It may be necessary to weld a plate to the upper surface of some ductile iron mains in order to achieve sufficient total thickness to accommodate the thread of the nipple.

When tapping and drilling large PVC, prestressed concrete, or asbestos cement mains it is necessary to attach a saddle with a pre-tapped flat boss or a stainless steel repair clamp with a threaded boss, so that the procedure described in (a) can be carried out.

When the main is drilled and tapped direct, the larger and more expensive under-pressure drilling and tapping machine has to be used, and to accommodate this it is necessary to allow sufficient room under the main so that the securing chain can be fitted. The drilling and tapping machine incorporates an upper and lower chamber separated by a gate valve. After drilling through the main, using a combined drill/tap, the lower chamber is isolated by the gate valve, and a nipple, sealed by a plug, is inserted into a carrier held by the drill chuck. The nipple is then screwed into the tapped hole, the machine removed, and a gate valve fitted to the nipple. The plug is then removed using a special tool inserted into the gate valve, and the gate valve is closed.

Inserting a plug into the nipple enables the gate valve to be removed after the flow measurement. This prevents tampering with the gate valve and possible contamination of supply. A cap is screwed onto the nipple to protect the plug after the gate valve has been removed. Before insertion through the gate valve, the nipple plug is removed, and a 2:1.5 inch adapter fitted to the gate valve to accommodate the pressure housing of the meter. This is fitted securely in position with a suitable spanner using the flats provided on the pressure housing.

The gate valve is then opened fully and the insertion meter pushed into the main until the centre of the turbine is in the centre of the main, which is the point of maximum velocity in a fully developed flow profile. To ensure a fully developed profile, the insertion point should be at least 10, and preferably 50, pipe diameters downstream of bends or fittings which could cause hydraulic disturbance and change the profile. It is also advisable to have a reasonable length of straight pipe, say 5 pipe diameters, downstream of the insertion point.

The procedure for locating the centre of the main is as follows:

(i) Push the meter into the main until the bottom of the main is located.

(ii) Calculate the distance (D) the stem will need to be withdrawn to locate the centre of the turbine in the centre of the main.
This is expressed as $(D/2 - 1)$ inches.
(When the cage enclosing the turbine head is touching the bottom of the main, the centre of the turbine is 1 inch above.)

(iii) Withdraw the stem until the mark previously made is at the required distance above the pressure housing. At this stage the clamp which secures the pressure housing to the stem may be partially tightened to keep it in position while an alignment check is made on the turbine. This is done by rotating the handle at the top of the stem. When the handle is in line with the main, the turbine will be at 90 degrees to the direction of flow.
An arrow inscribed on the handle enables the flow direction to be determined. If, at the time of the flow survey, the direction of flow is unknown, the ability of the bidirectional turbine head to sense a change of direction enables the flow direction to be confirmed and shows when a direction change takes place. If the

arrow on the flowmeter is facing the same direction as the flow, a positive measurement will be recorded on the chart or data logger. A negative reading will be shown if the flowmeter is initially facing the opposite direction to the flow. If the flow changes direction during the survey, this will be indicated by the sign changing.

Flow and velocity measurements are recorded by means of a suitable data logger. The data logger should be programmed to measure flow at 5 or 10 minute intervals over the period of the flow survey. The data analysis programme requires the internal diameter of the pipe in mm and the calibration factor of the meter in pulses/m, which is supplied by the manufacturer. Suitable data loggers are discussed under leakage monitoring in Section 7.5.

In the methodology described above, it is assumed that the internal diameter of the main is known. If this is not the case, or if it is suspected that the internal condition of the pipe has deteriorated, due to corrosion for example, the interior diameter of the pipe can be measured using a Quadrina gauging rod. The unit consists of a pressure chamber, similar to that of the insertion meter, fitted with an eccentrically mounted measuring rod, with a location arm attached at the end of the rod and perpendicular to the rod axis. After fitting the pressure chamber to the tapping gate valve, the rod is rotated so that the measuring arm passes through the pressure chamber and into the pipe as the rod is pushed into the main. The rod is then rotated through 180 degrees and pushed in until the measuring arm touches the invert of the pipe. The first distance stop is positioned and clamped onto the rod stem. The rod is then withdrawn until the measuring arm touches the crown of the pipe. The second distance stop is then positioned and clamped to the rod stem. The distance between the two distance stops is equal to the internal diameter of the main.

2. Portable ultrasonic meter

Portable (clamp-on) ultrasonic meters (e.g. Micronics 'Portaflow') are being increasingly used as an alternative to insertion meters, both for measuring the water produced where no meters exist, and for meter verification. Their main disadvantage is the cost (around US$ 8000 to 10 000). However, their main advantage that they are non-intrusive, and only part of the main needs to be exposed..

Enquiries from one of the leading manufacturers of clamp-on meters revealed that companies are increasingly using portable ultrasonic meters to measure flows out of reservoirs, but not in pairs to monitor leakage. One company had experimented with a similar technique—exposing the main at intervals along a transmission main and measuring the flows at each point with a clamp-on meter.

The petrochemical industry, however, regularly uses the technique for monitoring losses in their pipelines. The same manufacturer stated that Associated Petroleum Terminals, which controls delivery of the product from the terminal to the refinery, and the Petrochemical Pipeline Association which controls MOD lines, are regular users. Transducers are spaced at 600-m intervals—an accuracy of ± 1% is claimed.

Managing Leakage Report J (Techniques, Technology and Training) refers to a paper by Grimaud & Pascal which describes a pilot exercise in France for permanently monitoring large-diameter strategic pipes, e.g. motorway crossings, to enable fast follow-up action on bursts. Ultrasonic transducers were installed at each end of the main, with acoustic loggers at intervals in between. Monitoring was therefore at two levels: comparison of flow rate and acoustic monitoring. The former is suitable for detecting bursts, the latter for detecting small leaks as they occur.

There is no reason why such a technique should be less accurate than pairs of insertion meters, once the characteristics of the pipe have been accurately assessed and entered. However, one company noted that the results from a meter verification exercise at the same site, carried out by three different operators, showed an error range of 4–20%.

Water mains also suffer from a build-up of encrustation, reducing the accuracy of temporary insertion and ultrasonic measurement techniques. This is not usually the case in oil pipelines.

3. Temporary full-bore meter

There is no reason why full-bore meters (e.g. Kent Helix 4000) cannot be cut into a main for temporary flow measurement, except that, unlike insertion or clamp-on ultrasonic meters, the main must first be taken out of service.

5.3 Leakage measurement and detection in intermittent-supply networks

(From a paper by A Kumar, Tata Consulting Engineers, India, presented at a Leakage Control Workshop, Surabaya, Indonesia, 1991, sponsored by the International Water Services Association (IWSA))

The problem

Leakage in intermittent supply systems aggravates the problem of inadequacies in supplies. Most of the systems in India supply water intermittently, as the demand is usually far in excess of available supplies. In some systems the production of water can barely meet the minimum demand of the consumers. The problem is exacerbated by the following:

— the duration of supply has to be restricted to reduce the high volume of leakage and customer waste;
— the long supply-timing reduces peak demand, but this is feasible only if measures are taken to restrict leakage and the overall system capacity;
— restricted supply-timing subjects the distribution system to high flowrates and low pressure;
— customers tend to over-ride the mains supply and draw as much water as possible by building underground tanks/sumps and pumping water into the house;
— water authorities tend to lay additional mains in order to improve pressures in the system—this results in an overall increase in system capacity;
— supply at low pressure and for a short duration restricts leakage in a system, but this is unsatisfactory for the customer and causes a public health risk from infiltration;
— conventional leakage monitoring and detection methods (e.g. the minimum night-flow method) and pressure management to reduce leakage are not applicable to intermittent supplies. In fact, a high mains pressure is required for leak detection equipment to be effectively used.

Alternative methods

The stop tap method

This has been successfully used in several cities and towns to quantify leakage and to locate the leak points. The steps are as follows:

1. The test area is isolated by closing the boundary valves.
2. Stop taps on customers' service connections are closed.
3. A special supply is arranged for the test area from the nearest water distribution station.

4. Water meters are used to measure the flow through the test area. This is a direct measure of leakage.
5. Leak detection equipment is used to locate the leak points.

The *disadvantages* are:
— arrangements have to be made for supplies to be diverted to the test area;
— a considerable volume of water is lost from leak points during the test;
— supplies to adjacent areas are affected, leading to customers' complaints;
— not all leaks can be identified in a short test and repeat tests are required.

The mobile tanker method

This method was developed to overcome the major disadvantage of diverting supplies to the test area. Water mains are charged over a timed duration, long enough to measure leak flow and to use selected equipment to locate the leaks. The approach was first tested by Tata Consulting Engineers in Ahmedabad city (population: 2.5 million) in India and has been extensively used in Madras Metropolis (population: 4 million).

The *advantages* are:
— the method has been specially designed for intermittent supply systems;
— there is no disturbance in the normal supply;
— only a small area is isolated;
— only a small volume of water is used for testing.

The unit consists of:
(a) a common street water tanker;
(b) a wheel mounted pump;
(c) an easily made pipe assembly with valves to control pressure;
(d) a turbine water meter unit with pulse head and data loggers.

A small test area is isolated. Water is drawn from the tanker and is injected into the area using the mobile pump. A bypass pipeline returns the water partially to the tanker. Valves are provided on the pump delivery return lines. By manipulating these valves, the desired pressure is maintained. The line supplying the injection point contains a meter with a pulse head and a data logger for recording the flow. A pressure transducer is also provided to log the pressure at the injection point. Loggers are downloaded onto the computer, and graphs of flow and pressure with time are obtained.

Customers' support is ensured by distributing leaflets. This makes them aware of the test and builds confidence in the future improvement of their supplies.

A typical test area is 100 connections or 500 m of pipe length. Boundary isolating valves are closed and the stop taps at customers' premises are closed (or the service pipes are cut and plugged). In areas where operating staff are reluctant to operate valves which have been throttled to adjust supplies, the mains can be cut and capped.

The test is carried out during non-supply timings so that there is no inconvenience to the consumers. The test sequence is as follows:

1. Water is injected into the isolated test area through a mobile pump tanker unit.
2. A prescribed pressure at the injection point is maintained by manipulating the unit valves.
3. As the area is isolated and the house services are plugged, the reading on the in-line meter is a direct indication of leakage in the test area.
4. An assessment of leakage can be made for a range of pressures which would prevail in the distribution system later.
5. Pressure transducers and data loggers are also introduced at the other isolation

parts, to check whether the entire area is pressurized to the desired level.

6. Once the leak points are rectified, it is also possible to assess the reduction of leakage in the test area by repeating the test.
7. The improvement of pressure at the isolation points of the mains is an indicator of the overall improvement due to leakage reduction.
8. The exercise is completed when the entire stretch has been scanned by leak detection equipment, leaks have been pinpointed, and the service connections and mains have been restored.
9. In Madras, the total duration for this exercise—beginning with segregation of the area, carrying out the test, and returning to the normal system of supply—took about 8 hours.

A sample survey helps to identify the operating practices and the need to alter them or correct deficiencies, such as:

(a) missing ferrules at house connections;
(b) service connections made with insufficient cover/protection;
(c) poor repair practices (e.g. use of bicycle tyre rubber).

In some systems the leakage was so high that efforts to pressurize a sub-district uniformly were at first unsuccessful. Only after repairs were carried out in part of the test area did the pressure develop throughout the sub-district.

6. Developing a leakage management strategy

6.1 The alternative strategies

Leakage management strategies can be classified into three groups:

— passive control;
— regular survey (sounding, waste metering);
— leakage monitoring in zones or sectors.

Passive control is a reaction to visible leakage due to bursts or drops in pressure, which are usually reported by customers or noted by the company's staff. The method can be justified in areas with plentiful or low-cost supplies, and is often practised in less developed supply systems where the occurrence of underground leakage is not so well understood. It is therefore often a first step to improvement, i.e. making sure all visible leaks are repaired.

Regular survey is a method of inspection, starting at one end of the distribution system and proceeding to the other, listening for leaks on pipework and fittings, or reading metered flows into temporarily-zoned areas to identify high-volume night flows.

Leakage monitoring refers to monitoring the flows into zones or districts in order to measure leakage and prioritize leak detection activities. This has now become the most cost-effective strategy for leakage management and the one most widely practised.

The zoning principle

Ideally, a flow measuring system in a water distribution network would encompass the measurement of total flows—to assist demand prediction and distribution management—and also zonal flows, which will help the engineer to understand and operate the system in smaller areas, and allows leakage management and control to take place. The system is hierarchical, i.e. it covers a number of levels, beginning with measurements at the production end until the consumer's meter for an estimate of consumption. The system comprises:

— measurement of production at the source or treatment works;
— measurement of flow into supply zones, with geographical or hydraulic boundaries;
— flow monitoring into district meter areas (DMAs) of 500–3000 properties, with permanently closed boundary valves;
— monitoring of 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;
— reading of individual consumer meters, both domestic and commercial.

The DMA meters are sometimes linked to a central control station via telemetry so that the flow data are continuously recorded. Analysis of these data, particularly of flowrates during the night, determine whether consumption in any one DMA has progressively and consistently increased, which would indicate a burst or undetected leakage. Each leak location area is then closed off in turn, allowing the flow into each area to be monitored via the DMA meter. It is important to understand that night flow comprises customers' use as well as losses from the distribution system. Where all customers are metered this does not pose much of a problem, except where there is an excess of demand over supply and customers have to be "educated" to waste less water.

Suspected areas, i.e. those showing a greater volume of night flow per connection than the other areas, can then be inspected more thoroughly, using "step testing"—a technique which requires the progressive isolation of sections of pipe by closing the line valves, beginning with the pipes farthest away from the meter and ending at the pipe nearest the meter. During the test, the flowrate 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. Inspectors can then be deployed to locate the precise leak position in the suspected section of pipe. Another technology being increasingly used as an alternative to step testing is leak "localizing". Leak localizers, each incorporating a hydrophone and logger, are attached to a group of hydrants. Noise patterns from each hydrant are analysed, and an anomalous noise pattern from one or more hydrants usually indicates a leak in that locality.

In developing countries there may be difficulties in introducing more closed valves in a system, particularly in areas of low pressure or those with intermittent water supply. The effects can best be demonstrated in pilot areas, when the benefits of leakage reduction on increased pressures and satisfied demand can clearly be seen by the customers.

Detection and control of leakage varies from one company to another, and the choice of methodology is largely dependent on local conditions, which may include financial constraints on equipment and other resources. Staffing resources are also relevant, as a labour-intensive methodology may be suitable if manpower is plentiful and cheap. The main factor governing choice, however, is whether a particular methodology is economical according to the savings in cost. 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 active control, like continual flow monitoring, or even telemetry systems, to warn that a burst or leakage is occurring. In most developing countries the method of leakage control is usually at a low to medium level—mending only visible leaks or conducting regular surveys of the network with acoustic or electronic apparatus.

Leak location is carried out using at least one of the following pieces of equipment:

— basic listening stick;
— electronic listening stick;
— ground microphone;
— leak noise correlator.

The basic instrument is the **sounding stick**, which is used as a simple acoustic instrument, or 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. The *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 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 metre) in most sizes of pipe. The instrument is portable and 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 the one which uses industrial hydrogen (95% nitrogen, 5% hydrogen). The gas is introduced into the pipeline, and is detected 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.

The principles of monitoring leakage in zones is explained in detail in Section 7. Leak detection and location technologies are explained in detail in Section 9.

6.2 Economics and planning

This section is based on a paper by Stuart Trow, RPS Water Services, presented to the IIR Conference on Water Pipelines and Network Management, London, England, 1997. See Section 1.3, Ref. 4.

What is leakage management ?

Ever since water has been distributed through networks of underground pipes, some of it has leaked before it reached its intended point of use. Until recently, water engineers practised “leakage control”, implying that their aim was to prevent the level of leakage from continuing its natural rate of rise, as ever more bursts and leaks occurred in the system. In 1980, ‘Leakage control policy and practice’ (see Section 1.3, Ref. 5) set out the policy issues of leakage control as well as the practical techniques. The policy issues were limited to an appraisal of the economic extent of district metering, and the costs and benefits of pressure control.

The work of the U.K. National Leakage Initiative (NLI) from 1990 to 1994 concentrated on strategic policy issues and methods of interpreting data on leakage to allow the available resources to be directed efficiently. This concentration on effective policies and efficient operations was the reason that the series of reports from the NLI are entitled *Managing Leakage*.

The term “Leakage Management” has gained rapid acceptance since 1994. Already however, a noticeable change of emphasis has taken place. The impact of the 1995 drought in the United Kingdom on the level of service to customers in several parts of the country, and the attention given to leakage management in the political arena have made leakage no longer a problem of interest to the dedicated few, but of concern to the whole water industry. With the spotlight of regulation now clearly focused on the real issues of leakage management, the subject is now a regular agenda item at water company meetings. Many companies have recently instigated “Leakage Reduction” programmes with the aim of achieving a significantly lower level of leakage by the turn of the century.

The questions facing the industry at the present time are:

- What target level of leakage should we aim for?
- How can we justify the cost to reach this target level?

- How long will it take us to achieve this level?
- What are the techniques we should use to achieve the target level?
- What will it cost in capital and operating expenditure?
- How much will we save in production, distribution, and investment costs?
- What will be the effect on customers?

The benefits of formulating a plan for leakage management which takes account of all these issues to produce an economic optimum blend of measures for controlling and/or reducing losses from the water supply and distribution system are outlined below.

Why formulate a plan ?

It is essential that water companies have a plan for leakage management which is consistent with other aspects of the corporate plan. Leakage is an element in water supply and should be viewed as an alternative source of water in conjunction with the type of resource. To an extent, leakage management can produce short-term as well as long-term yields, in the same way as an impounding reservoir.

As well as being of internal benefit to the company, the Leakage Management Plan will be of interest to those who monitor the company's activities, such as:

OFWAT (Office of Water Services, the U.K. 'economic' regulator)

- For customer service issues: will supplies be maintained with high leakage levels?
- For price regulation: does the plan offer the best mix of operating and capital expenditure?
- For comparative efficiency studies: is the company being wasteful in its leakage plan?

Environment Agency/Department of the Environment

- For assessing the validity of new or revised abstraction licences/applications
- For safeguarding and planning the nation's water resources.

Customers

- For continuity of supply without hose-pipe bans or other restrictions.

Politicians

- For comparing profit levels with the signs of under-investment.

What are the key issues ?

Leakage management plans will be specific to each water company, and to supply zones within companies. What is economic for one area may not be appropriate for another. Leakage management strategies will also change with time as unit costs of water and active leakage control change, and new techniques become available.

In formulating a plan for leakage, the company will need to consider the following six key issues.

1. How much do we wish to spend ?

In theory, expenditure plans for leakage will be derived from estimates of current leakage levels, and an economic assessment of alternative measures. The blend of measures with the lowest net present value (NPV) is considered to produce the long-term economic level of leakage.

Price setting by OFWAT does not allow for investment in leakage reduction. It is classified as an efficiency measure, and investment to improve efficiency must be funded by the company and not included in K factors (i.e. the formula for allowing a water company to increase charges to the customer). Any expenditure will therefore have a direct bearing on profit levels. In practice therefore, it is likely that each water company will have to make a judgement on how much it is prepared to spend on leakage management measures, and over what period of time.

At present, leakage targets are set by the companies and policed by the regulators. If mandatory targets are set, then the question becomes, "Who pays for the extra investment needed to achieve these targets?" Price-setting allows for the required investment to meet water quality objectives. There is much discussion whether investment to achieve externally imposed targets for leakage should be given the same recognition and allowed for in setting 'K'.

2. What are the implications of a relatively high level of leakage?

Companies will wish to consider the consequences and benefits of leakage management in both economic and non-financial terms. For example:

- Will high leakage levels affect pressures in the system and cause level of service failures?
- Does leakage affect the ability to maintain continuity of supply?
- Does leakage affect the quality of distributed water?

A term increasingly being used is "Headroom", i.e. the difference between available supply and the forecast demand (including leakage) in the system. Leakage Management is clearly of greater importance in those systems which lack headroom than in places where there is a surplus of supply over demand.

3. What league table position are we satisfied with?

The publication by OFWAT of league tables for comparing leakage in the annual Cost of Water Delivered Report (Ref. 'Leakage of Water in England and Wales', OFWAT, Birmingham, 1997) has led to healthy competition between companies.

Leakage is seen by external observers as synonymous with waste, and high waste is seen as inefficient. Much research has been carried out in recent years to find a fairer method of measuring performance on leakage management. Despite this, the use of percentages is still common. Alternative measures, which use properties or mains length as a scaling factor, introduce their own bias favouring either urban or rural areas.

4. How can we estimate the savings from leakage management measures?

The National Leakage Initiative developed two concepts which have been of significant benefit in the understanding of leakage.

1) The concept of comprehensive water balance, where each and every component of 'water into supply' (i.e. all the components of water supplied to the network, including losses) is identified.

As a result there is now no such thing as "unaccounted-for water", which was the recognized measure of leakage. However, there will always be some elements which do not have a legitimate definition, e.g. use through illegal connections, or leakage from abandoned mains. Some companies have instigated thorough audits of their base data to ensure that their leakage estimates are made from reliable and up-to-date information.

2) A technique known as Burst and Background Estimates (BABE) for modelling the anticipated level of losses from a system with given characteristics and a set leakage management policy.

Since publication of the *Managing Leakage* reports in 1994, the techniques for estimating the components of the water balance and for developing leakage models based on BABE have improved considerably. The initial BABE models relied heavily on industry-approved data. As a result, there was a good deal of scepticism from regulators and from within the industry. The technique has now proved itself in practice. Accurate predictions have been made, using BABE, of the reduction in losses which can be achieved by eliminating a leakage backlog, or applying pressure reduction. It has also been used to develop methods for prioritizing leakage investigations, and for paying leak detection contractors through a system of leakage units, or equivalent service pipe bursts (ESPBs).

Techniques are now available to provide company-specific estimates for:

- Infrastructure Correction Factor (ICF), which is an estimate of the background leakage compared to the industry average.
- Burst Frequency, from a detailed analysis of job records.
- Current Position, from analysis of the trend in distribution input.

Research is ongoing into methods of assessing the level of background and burst losses from empirical measurements in each DMA, which, if found to be reliable, will revolutionize the concept and the approach to leakage modelling. The calibration of BABE-based models will then become similar to the calibration techniques used for hydraulic network analysis models, in which site measurements are used to verify predictions from desk studies.

Leakage forecast

- When setting targets and forecasting future leakage levels, the current position and both short- and long-term targets must be taken into account.
- The economic level will be that which is the most cost-effective. However, the company may adopt another "optimum" level which takes into account other considerations.

5. How do the regulators view targets?

The present regulatory position is quite complex. In simple terms, the companies are expected to set their own targets for leakage, and the regulators accept in principle that there will be differences between companies due to different environmental considerations and different water resources positions. Owing to these differences the regulators expect to see plans which are based on company-specific data and which take account of all of the key variables.

In order to develop a plan which satisfies the needs of the regulators, the following elements and tasks should be reviewed:

- Accuracy of source meters
- Accuracy of per capita consumption estimates
- Extent of District Metering
- Extent of Pressure Control
- Accuracy of data used in metering systems, ensuring correct allocation to districts and zones
- Trunk Main and Service Reservoir condition assessment
- Methodologies for setting leakage targets and for directing investments in favour of leakage reduction.

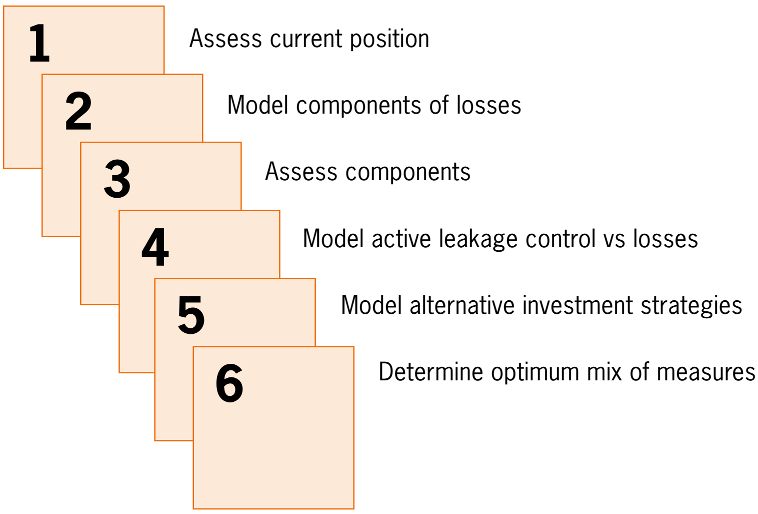
Companies are being judged not only on their current level of leakage, but also on the initiatives they are taking to substantiate that level, to assess the economic optimum plan, to reduce leakage to optimum levels, and to maintain optimum levels into the foreseeable future. It is interesting that while pressure is a prime driver of the optimum level of leakage, it is not taken into account by the regulators in comparisons between companies.

One new issue is the environmental cost of water, for the assessment of which there is no set procedure. It can therefore be seen as a significant issue. Perhaps the best way of including environmental costs is to consider their effect on the economic level of leakage. The effect of higher unit costs can be seen by plotting the economic level against the marginal cost of water. In many cases, adding value to the water beyond, say, £0.15 to £0.30 per m3, does not reduce the short-term economic level of losses significantly. However, higher cost water makes it easier to justify capital investment in leakage reduction measures. The only question then is who pays for the environmental cost?

6. What are the next steps in formulating a leakage management plan?

There are six key stages to formulating an economic optimum plan for leakage management:

- *Assess the current position.* This will include taking alternative views of night flows, integrated flows, and BABE modelling—and reconciliation of leakage estimates based on these.



- *Model the components of current losses.* Assessment of the current position should include an estimate of the components of current losses so that the impact of alternative strategies can be better understood.
- *Assess the components of current leakage expenditure.* Current leakage expenditure will include staff costs, transport, equipment and payments to contractors. It is important to analyse these costs to determine how much is truly marginal and how they relate to the current level of losses.
- *Model ALC vs. Losses relationship.* Once the current components of losses and active leakage control (ALC) costs are understood, techniques are now available to model alternative scenarios in order to carry out "what if" calculations.
- *Model alternative investment profiles and calculate NPVs.* Techniques are also available to determine the shift in the economic level of leakage as capital investment is made in pressure control, mains replacement, etc. The net present value (NPV) of these investment streams can be compared to the savings.

- *Determine the optimum mix of measures.* The optimum forecast will take into account all the above previous stages, as well as environmental, social, political, financial and customer related issues.

6.3 The Bursts and Background Estimates (BABE) concept

This section is based on a paper by Allan Lambert, International Water Data Comparisons Ltd, and presented to IIR Conference on Water Pipelines and Network Management, London, 1997 (see Section 1.3, Ref. 4).

See Annex 6 for a description of software.

Introduction

The U.K. National Leakage Control Initiative (1990-94) provided a focus for the development of a systematic approach to calculating individual components of losses in distribution systems and on customer's pipework, either as part of an annual water balance or for night flow analysis.

The concepts—called Bursts and Background Estimates (BABE)—were developed from a review of international literature, and consideration of the many parameters that influence losses. They have since been applied successfully in the United Kingdom and many other countries, e.g. Canada, USA, Bahamas, Bolivia, Czech Republic, South Africa, Jordan and the West Bank, to assist Leakage Management planning and operations.

The data in the *Managing Leakage* reports form the foundation for the application of the concepts in the United Kingdom. Since 1994, one leading U.K. Environmental Consultant, RPS Water Services, has undertaken case studies in 78 supply areas of ten water companies. During these studies, many of the techniques were refined—in particular, the pressure/leakage relationships—and there have been improvements in the speed and user-friendliness of the software available to perform conceptual modelling. The application of BABEs in countries with many different and more extreme circumstances than in the United Kingdom demonstrates that the concepts are robust. Yet they remain relatively simple, and use data that can be audited and calculations that can be undertaken to any appropriate degree of detail and data availability.

An overview of the state-of-the-art at the end of 1996 is described below. It seeks to correct some areas of misunderstanding which have arisen out of the *Managing Leakage* reports (background losses, customer night use), and includes more recent work such as incorporation of 'rate of rise' studies of leakage into the software and models. A clear need for customized software—rather than 'standard' products—has been identified since 1996, both in the United Kingdom and in other countries.

One of the most important aspects of BABE is that all Leakage Management studies for a particular supply system—whether for planning, economics or operations—draw on the same concepts and the same data and parameter values. This ensures that the results of all calculations are compatible, and there are no 'loose ends' or 'black holes'. Each advance in knowledge is integrated into all the concepts and enhances the reliability of the calculations.

Defining and assessing the components of losses

The original Bursts and Background Estimates (BABE) leakage management concepts and software were developed in 1992–94, during the U.K. National Leakage Initiative. Bursts—events exceeding some defined threshold flow rate (500 l/h at 50 m pressure in the United Kingdom)—are classified as 'Reported' or 'Unreported'; sources of loss with lower flow rates are aggregated as 'Background' losses for purposes of analysis. Each of these three types of losses has different characteristics, and is influenced by different parameters.

The concepts have been designed for international application to any appropriate degree of detail. For application in the United Kingdom, there are six different infrastructure components for any particular water supply system, making 18 possible components of annual losses. The 'bursts' components from plumbing are normally ignored in the United Kingdom.

For night-flow analysis to identify the presence of unreported bursts in District Metered Areas (DMAs), typically seven components are used to calculate the 'Background Night Flow', which is the night-flow rate (m3/hour) which occurs at a particular average zone night pressure (AZNP) when there are no bursts present.

In all applications, the values of components are calculated from first principles using combinations of appropriate parameters. Some of the parameters (e.g. customer night use associated with fixed volume installations such as toilet cisterns) are considered not to be influenced by pressure.

Where the parameters are influenced by pressure, its influence is modelled using Fixed and Expanding Leakage Paths concepts (*3*) rather than Leakage Index concepts originating in Report 26 of the NWC Standing Technical Committee (*4*). Hour-day factors (also calculated using the fixed/expanding paths concepts) are used to convert night-leakage rates to 24-hour leakage rates.

For calculating losses from bursts, the number of reported and unreported bursts are required. The numbers, pressure-corrected typical flow rates, and average durations are used to calculate the annual losses. The average durations consist of three components—Awareness, Location and Repair—which are dependent upon specific active leakage control policies, standards of service, and legislation.

In the United Kingdom, background losses from trunk mains and service reservoirs are taken from re-analysis of Report 26 data, documented in *Managing Leakage* Report E. For service reservoirs, overflows correspond to the 'Bursts' components.

Carrying out water audits and system reviews

In the United Kingdom, water audits are usually based on retrospective 12-month periods ending on 31 March. The volume of distribution input is compared with the components of 'water delivered' and the difference, after allowing for the minor components of Miscellaneous Water Taken, in the 'Distribution Losses'. Note that in this approach, the underground supply pipe losses on unmetered or internally metered properties must be assessed separately in order to assess the 'water delivered'.

Using the BABE components of annual losses approach, the individual components of losses (including those on customers' underground pipes) are calculated from first principles, then added to the metered and unmetered consumption, and the other minor components of Miscellaneous Water Taken. The sum of all these is then compared with the distribution input, and a balancing error is identified.

The software used for these calculations allows rapid sensitivity tests for possible errors in key parameters, to see whether the balancing error is likely to be 'real' or simply within the inherent range of errors in calculation. The individual calculations can be taken to any degree of refinement required, and can incorporate cross-checks with other data. For example, recently developed software (CELLONI, CELLORI) also calculate the 'rate of rise' of losses occurring with passive leakage control, which can be compared with 'rate of rise' studies like those reported by Arscott & Grimshaw (*5*) and Tustin (*6*).

Reconciling estimates of losses from annual water balance and night flows

Because of reporting requirements by OFWAT (the U.K. Economic Regulator) in England and Wales, losses from underground supply pipes (UGSP) must be separated from distribution losses. The BABE components approach allows this to be done on a logical and transparent basis which can be audited, taking into account actual policies relating to the repair of bursts on UGSPs.

Unfortunately, even the most sophisticated statistical analysis of accumulated series of night-flow measurements provides no clue as to what proportion of night-flow losses occur on a customer's pipework after the point of delivery, or how that proportion could alter by changes in repair policies. The night-flow approach, used on its own, also does not provide any estimate of the annual losses from pipework outside the DMAs.

OFWAT's 1995/96 *Water Delivered Report* ('Leakage in England and Wales', OFWAT, Birmingham, 1996) states that the Director "remains concerned that the case studies he has seen (using BABE components) are overly dependent upon national consumptions about background leakage levels". In this respect, the Director (and perhaps most water companies) are clearly unaware of how easily Infrastructure Correction Factors (ICFs) can be established, from zonal measurements, to adjust the 'national' values of background losses to local values that can be audited. Software to accomplish this has been commercially available for at least two years but little used.

The methodology used is a refinement of the methodology in Fig 3.2 of *Managing Leakage* Report F (Using night flow data), and requires continuous night-flow measurements. Immediately following a thorough survey of each DMA, when all located leaks and bursts have been isolated or repaired, the measured night flow will be the 'background' night flow at the current night pressure.

By deducting the customer night use (allowing for components of night use and variability from night to night, see Appendix A of *Managing Leakage*, Report E), the background losses which remain can be compared with the background losses calculated at the current AZNP for the DMA—using the U.K. 'Average' figures, based on 52 DMAs including 13 000 properties, from Table 4.1 of *Managing Leakage*, Report E—and a pressure correction factor.

An Infrastructure Correction Factor (ICF) can then be calculated, relating the actual losses to the U.K. 'Average' losses. The DMA for such studies was 500 to 1500 properties, with few non-households; in larger DMAs the annual numbers of bursts are such that new bursts may occur before all the located bursts have been repaired or isolated, and in smaller DMAs the higher random variability of customer night use may influence the results. A weighted ICF value for each supply system can then be calculated using the individual ICFs calculated for the individual DMAs, and used in more refined calculations of BABE annual components.

In case studies carried out by a consultant in the United Kingdom, weighted ICFs of around the expected U.K. National 'Good' value of 0.50 have been identified for supply systems where there has been extensive rehabilitation. In a recent study for one water company, the ICF for around 100 DMAs averaged 1.0, with values up to 1.35 for individual zones.

Another not inconsiderable advantage of determining ICFs for background losses for each DMA, as part of an ongoing routine, is that, once established, they need only be checked intermittently, preferably when customer night use is likely to be stable. For reconciling DMA night flow measurements with annual distribution losses, this obviates the logistical problems of amassing 365 night flows each year for each of the thousands of DMAs, and then attempting to deduct estimates of customer night use which may vary seasonally.

The use of 'Maximum Likelihood Estimation' to allocate balancing errors in losses (derived from statistical analysis of a limited number of night flows) to all components of distribution input remains unconvincing. Balancing errors exist, and should be specifically identified. If they are small they can be accepted, but if large they can indicate a 'backlog' of bursts from previous years, or the need for further research into key parameters (e.g. hour-day factors).

Customer night use

It is appropriate to emphasise that *Managing Leakage* Report E did **not** state that household night use was a fixed 1.7 litres/household/hour in all situations. Appendix A in Report E gave a methodology from which average values and night-to-night variability can be calculated (depending on the proportion of 'active' properties/population and types of night use).

This methodology has since been used internationally in situations where the toilet cistern sizes and numbers per household differ markedly from those in the United Kingdom. While litres/property/hour (l/prop/h) are widely used in the United Kingdom, it may be preferable to assess household night use by 'active population' and 'active non-households' rather than a fixed value in l/prop/h. This is because the assessment of customer night use, in any country, consists in identifying:

- What proportion of people, or water-using devices are active at night?
- How much water does an activity (e.g. flushing the toilet) use?

At certain times of year, seasonal variations in activity at night can be expected to produce large individual values of household night use, as in a recent study where the data were collected over the Christmas period when many late night parties would be expected to occur.

Identifying and clearing a backlog of bursts

The numbers of reported and unreported bursts used in the annual BABE components calculations should be those which are **occurring** in a particular year. However, company data will relate to the **recorded** numbers of reported, and unreported/located bursts in any particular year. Note that:

- If a consistent leakage control policy has been followed for several years, the numbers should be close to each other.
- If reported or unreported bursts are not being located and repaired, the recorded numbers will be less than the numbers actually occurring and a **backlog** will develop.
- If there is a sudden increase in activity where a backlog existed, the recorded numbers will be greater than the numbers actually occurring in the year.

BABE components-of-losses calculations that show a large positive balancing error, which cannot be explained by uncertainties in the parameter values used, are usually found to be due to the existence of a backlog—e.g. situations where bursts on customer's pipes have been located but not repaired. Where night-flow data exist, this conclusion has been confirmed in case studies using the night-flow component analysis approach to assess the number of Equivalent Service Pipe Bursts.

The identification of significant balancing errors in the BABE annual model can be likened to the identification of significant anomalies between predicted and recorded pressures and flows when a Network Analysis Model is being developed. The causes of significant errors—whether due to data deficiency, incorrect parameter values, or real problems—must be tracked down and resolved until the model represents 'reality' to an acceptable degree of accuracy. **The BABE model, once calibrated, can then be used for a variety of 'what if' calculations**.

Reducing repair times, including bursts on customers' pipes

Identification of a significant backlog of bursts is perhaps the ideal situation for a company that wishes to make rapid progress in reduction of losses, because the recoverable loss consists in a number of specific burst events which can be rapidly repaired, given the will and the resources to do so (e.g. with free or subsidized repairs of bursts on customers' properties). In some cases, replacement of limited sections of deteriorated mains, or of deteriorated services will be preferable to repairs.

In situations where there is no significant backlog of bursts from previous years, one of the simplest options for further reduction of losses—given that the condition of overall infrastructure cannot be radically changed in the short term—is to reduce the repair time for both reported and unreported bursts. The assessed reduction in losses is one of the many 'what if' calculations which can be easily done using BABE annual component models. All that is needed is to change the average duration for repairs, which has been entered in the original model to reflect the current situation.

Calculations which compare the cost of serving Section 75 Waste Notices (and the typical additional time for which bursts run during this process), and the typical cost of a service pipe repair, can be used to show the marginal supply costs at which it becomes economic to undertake free repairs. Alternative options such as subsidized repairs can be easily modelled using the BABE principles.

Economic level of awareness/location effort for current active leakage control policy

The basic principle of an active leakage control policy, based on use of manpower, is **to limit the average duration of unreported bursts**. Any variant of active leakage control policy can be modelled using the concept that company policies—including repair times, effect of legislation, and standards of service—can be turned into average durations for awareness, location and repair of unreported bursts.

For policies of regular survey, the average 'awareness + location' time for unreported bursts is, quite simply, half the interval between surveys. For night-flow measurements, there are a wider range of options for 'awareness + location' duration of unreported bursts.

For setting up a BABE component-of-losses model for a current leakage control policy based on night flow measurements:

— 'awareness' is half the interval between data collection, plus the time taken for analysis of night flows to identify unreported bursts;
— average 'location' time is calculated from the current policy for intervening in DMA, e.g. when the night flow exceeds some threshold level.

By increasing or decreasing activity—in terms of the frequency of data collection from DMAs, and the number of interventions per year—the effect of 'more' or 'less' effort (when a 'steady state' situation is reached) can be predicted using BABE components concepts.

The cost of the increased/reduced activity is also calculated; this gives the relationship between manpower effort and the 'steady state' level of losses. In the early versions of BABE software (e.g. Appendix B2-2 in *Managing Leakage* Report C), this approach was used to produce the 'dish shaped' total cost vs. losses relationship. Recent software developments (e.g. CELLONI, CELLORI) use a subroutine (Costless) to automatically calculate the relationship between marginal costs and Economic Level of Losses from the basic data.

The relationship between level of activity and level of losses can also be modelled for hypothetical areas subject to a particular active leakage control policy, but with different pressures, mains length per property, and burst frequencies (7).

Components of marginal costs and their influence on economic leakage levels

For any particular situation, active leakage control (ALC) policy and operating pressure in a particular supply area, with current infrastructure condition, and economic level of losses (ELL) are asymptotic to a base level of losses which comprise:

- Background losses
- Losses from reported bursts
- Losses due to repair time of unreported bursts.

The general form of the equation is:

ELL = Lb + ÷ (B/(MCS + A))

where MCS is the marginal cost of supply, and A, B and Lb are parameters which vary in different situations, or in the same situation with different policies.

The marginal cost of supply (MCS) normally includes short-term operating costs (power, chemicals, and cumulo rates increasing charges per volume of abstraction); if appropriate, deferred capital costs and environmental costs can also be added. However, each successive increment of marginal cost produces a smaller absolute reduction in the economic level of losses.

The experience of RPS Water Services with case studies shows that, because of the form of the equation, once a company is undertaking active leakage control in DMAs up to around 1500 properties, and achieving economic leakage levels for short-term operational costs by:

— locating unreported mains bursts within 7 days, and by
— locating unreported service pipe bursts when no more than one or two have accumulated in DMAs of less than 1500 properties,

then adding on capital and environmental costs to the MCS makes remarkably little difference to the economic level of leakage calculated on the basis of manpower activity to monitor, find and fix the unreported bursts.

Thus it may be concluded that, in these circumstances, inclusion of capital and environmental costs in marginal costs of supply is likely to have far more influence on investments in infrastructure and pressure management (to reduce the background component of base losses) than on the number of extra leakage inspectors employed to locate unreported bursts more quickly.

Assessing alternative active leakage control policies, pressure management and rehabilitation options

Wider considerations than simple changes in manpower effort within an existing ALC policy could involve one or more of the following:

— possible changes in the **method** of active leakage control;
— telemetry to reduce the 'awareness' time for unreported bursts;
— increasing the number of DMAs (to reduce average size) pressure management;
— changes in standards of service including repair times;
— infrastructure renewals affecting background losses and burst frequencies.

For such calculations, a full software package (UKADB, CELLONI and CELLORI) is required. For night flows, modelling of the manpower cost vs. losses relationship is normally undertaken by assuming that, where unreported mains bursts occur, they are located within X days, but that as unreported service pipe bursts aggregate, intervention to locate them waits until N, N+1, N+2 or N+3 such bursts have accumulated (where N depends on the size of DMA).

Once such a model has been developed and checked for a retrospective water audit in a particular supply area, it can be used for any combination of the above 'what if' options, and can be used to calculate the probable 'steady state' economic level of losses which should be achieved when the policy is fully implemented.

The more recent software packages are designed for very rapid use, with simple sensitivity testing and key parameters on a single screen. There is a clear and increasing demand for such customized software packages.

Choosing the economic optimal sequence and mix of actions

Using the 'what if' facility of the software packages referred to above, alternative combinations of actions can be quickly investigated for individual supply areas. If there is a need to meet a specific technical target for losses, case studies show that a combination of actions—rather than one single activity—will be needed, but the actions will differ in each situation.

Perhaps the largest-scale test of the reliability of prediction of such a combination of activities occurred in 1995/96 in North West Water, England (*8*), where a single BABE models was used for the whole of the region to predict what actions would be needed to reduce total losses by approximately 250 M1/d over a period of 4 years. A specific combination of policies was identified using the assumption of 'average' infrastructure condition consisting in:

— identifying and reducing backlog, and
— reducing repair times (including customers' burst pipes).

Overall pressure reduction by 10 metres was implemented, and over a period of 18 months has already produced a 'steady state' reduction in losses of around 150 M1/d. Implementation of pressure management schemes to deliver the remaining savings is still in progress.

Pressure management options and pressure standards of service

The probable reductions in losses arising from pressure management on a 'macro' scale can be predicted from the annual components-of-losses models. However, for the actual task of prioritizing individual DMAs for pressure management (new or enhanced), different software programmes are appropriate.

The PRESSMAN programme has been designed to enable such calculations to be carried out rapidly, using the measurement methodology (inflows plus pressure readings at three selected points for 24 hours) outlined in Appendix E of *Managing Leakage* Report G. This programme can also be used to assess:

— potential reduction in burst repair costs, and
— possible loss of income from metered customers,

in assessing the payback period for expenditure on pressure management. It also contains a sub-routine which can calculate appropriate parameters for Fixed and Expanding Paths pressure/leakage relationships from a simple test where night pressures are reduced and inflows measured.

Experience in using this programme demonstrates the key relationship between the economics of pressure management schemes and (i) regulatory pressure standards, and (ii) the extent of household metering, particularly for WSA Companies where sewerage charges are on a per m3 basis.

OFWAT does not appear to recognize that such links exist, even though they are fundamental to formulations of company policies.

Based on case studies, *pressure* is the single most important parameter influencing leakage and leakage management in the United Kingdom; any comparisons of leakage management performance which exclude average working pressures must be considered as technically inadequate.

References

1. U.K. Water Industry. *Managing Leakage* Series of Reports, 1994 (see Section 1.3, ref. 1).
2. Lambert A, Morrison J. Recent developments in application of 'Bursts & Background Estimates' concepts for leakage management. *Journal of the Chartered Institute of Water and Environmental Management*, 1996, **10** (2): 100–104.
3. May J. Pressure dependent leakage. *World Water & Environmental Engineering Management*, 1994 (10 October).
4. Leakage Control Policy & Practice, *NWC Standing Technical Committee Report 26*, 1980.
5. Arscott A, Grimshaw J. *Cost-Effective Management of Water Pipelines & Networks,* IIR Conference, 1996 (see Section 1.3, ref. 4).
6. Tustin J. *Cost-Effective Management of Water Pipelines & Networks,* IIR Conference, 1996 (see Section 1.3, ref. 4).
7. Economic Leakage Levels. *Welsh Region NRA Report*, December 1995.
8. Pearson D. Area planning for water supply. *Modelling in the Real World*, CIWEM Seminar, Cavan (Ireland), October 1996.
9. Written Response by OFWAT (Office of Water Services, the UK government economic regulatory body) to the House of Commons Environment Committee, August 1996.

6.4 Setting leakage targets

From a paper by Janet Joy and Andrew Oakes, WRc, presented to IIR Conference on Water Pipelines and Network Management, UK, 1997 (see Section 1.3, ref. 4).

Introduction

The UK Regulator, OFWAT, has stated that where companies do not set defensible leakage targets, or fail to meet their targets, the Director will, if necessary, take enforcement action by recommending mandatory targets to the Secretary of State (*1*). These targets would then become legally enforceable obligations. This raises a number of issues on the viability of determining equitable leakage targets against which a company's performance could be measured.

Reliability of leakage assessment

Leakage estimates are subject to considerable uncertainty. An individual company may be able to monitor trends in leakage if the method used to assess leakage is consistent. However, performance against imposed leakage targets may only be evaluated in a meaningful way if a standard method can be developed to provide reliable leakage estimates for each company. Errors associated with leakage assessments are discussed later (see below).

Criteria for target setting

In 1980, when Report 26 (*2*) was published, it was accepted that leakage targets should be based on the 'economic' level of leakage. This is the level which results in the minimum total cost when the costs of both leaking water and leakage control are taken into account.

In recent years, the demand for water has increased, the environmental lobby has become more powerful, and customer perception is now a driving force. Many companies have set leakage targets which appear to be based on their customers' expectations than on financial constraints.

OFWAT has affirmed its support for an economic approach to target-setting, while stating that 'environmental factors should be taken into account'. It is not yet clear whether companies will be compelled by the Environment Agency to invest in leakage control where this is a more expensive and riskier option than developing a new resource.

Whatever factors are instrumental in setting a company's leakage target, it is important that the minimum-cost position is accurately determined. If the target is below the economic level of leakage, the additional cost of achieving and maintaining the target level should be quantified.

Comparing the results of economic analysis for different companies

High leakage control costs will increase the economic level of leakage. Leakage control may be expensive due to natural factors, such as soil and water type, or due to company factors, such as poor mains condition or inefficient leakage policy or practice. Low efficiency should not be used to justify a high economic level of leakage.

It must be recognized that the relationship between the cost of leakage control and the level of leakage is dependent upon the specific leakage policy that is in place. The form of the relationship and the economic level of leakage will change if the leakage policy is changed. With less efficient leakage control policies, it may not be possible to achieve low leakage and a change in policy, involving major capital investment, may be required. A new approach to modelling the active leakage control cost curve is presented (see below).

Estimating the level of leakage

Leakage cannot be measured directly. Instead it may be estimated by two methods :

1) *The integrated flow approach*

   Leakage = distribution input—consumption

   Leakage is the residual in the annual water balance calculation. A consistent approach is used by companies to provide leakage estimates using this method. Estimates for unmeasured consumption show wide variation, but the influence of the consumption estimates on the leakage estimate may be readily assessed.

2) *Minimum night flow (NFM) approach*

   Leakage = (NFM—legitimate night use) * pressure adjustment factor

   The night flow approach can provide snapshot leakage estimates throughout the year. A pressure adjustment factor is used to calculate the average daily leakage from the leakage assessed at night. There is no consistency between companies with respect to the number and timing of night flow assessments, the recording interval and method whereby the minimum flow is assessed, allowances for legitimate night use, and application of pressure adjustment factors. It is not possible to quantify the impact of the method used on the results as it will depend upon local conditions.

1. Errors in leakage estimates derived from the integrated flow approach

In a recent UKWIR (UK Water Industry Research Ltd) project (*3*), information on methods currently used in the water balance calculations was obtained from a company questionnaire which was returned by seven water only and seven water service companies. The companies were asked to describe the method they use to carry out the annual water balance calculation and to estimate the errors associated with each component in the calculation. They were also asked to explain the reasons for their error assessments.

In general, higher error estimates were reported by companies which had carried out more detailed investigations. The estimated component errors were used to calculate the resulting error on the leakage assessment. The *minimum* error estimates suggest that leakage should be quoted as 14% ± 3%, i.e. somewhere between 11% and 17%. The error range is almost certainly an underestimate.

The *maximum error* estimates suggest that leakage is 14% ± 9%, i.e. somewhere between 5% and 23%.

2. Errors in leakage estimates derived from the night flow approach

Night flows can be monitored by district metering or reservoir drop tests. Drop tests may be able to provide a leakage estimate for the whole supply and distribution system, including service reservoirs and trunk mains. However, most companies find it impractical to carry out drop tests more than once or twice each year. This is useful for monitoring trends in leakage levels, but less valuable for providing a realistic assessment of average leakage throughout the year.

District metering allows night flows to be monitored continuously and is very useful for prioritization of leakage control resources. However, few companies have complete coverage by district metering, and there are questions over the accuracy with which the results can be extrapolated to provide company leakage estimates, and the assessment of leakage from service reservoirs and trunk mains. There may also be problems estimating leakage from night flows during summer periods if night use increases due to watering of gardens. No reliable method is currently available to distinguish leakage from continuous water use.

The error associated with a leakage estimate produced using the night flow approach will depend on the data quality and the method used to analyse the data. It is difficult to make any general comments on the expected errors. For example, analysis of data for four sample areas showed that flows recorded over a fixed one hour period (3 a.m. to 4 a.m.) may be up to 19% higher than the flow during the minimum hour; while there are advantages in moving to shorter recording periods and using monthly percentile values to take account of variations in night use, the allowance for legitimate use should correspond to the period over which the minimum night flow is measured. The allowance for household night use of 1.7 l/prop/h in *Managing Leakage* (*4*) is strictly only appropriate for a fixed one-hour recording period.

By improving data analysis procedures it should be possible to produce more reliable leakage assessments through the use of night flow data than through the integrated flow approach. Efforts should be made to develop a standard approach and to quantify errors in the leakage estimates produced by individual companies.

3. Reconciling the two approaches

Night flow measurements provide snapshot leakage assessments which may not be directly comparable with annual assessments produced from the annual water balance.

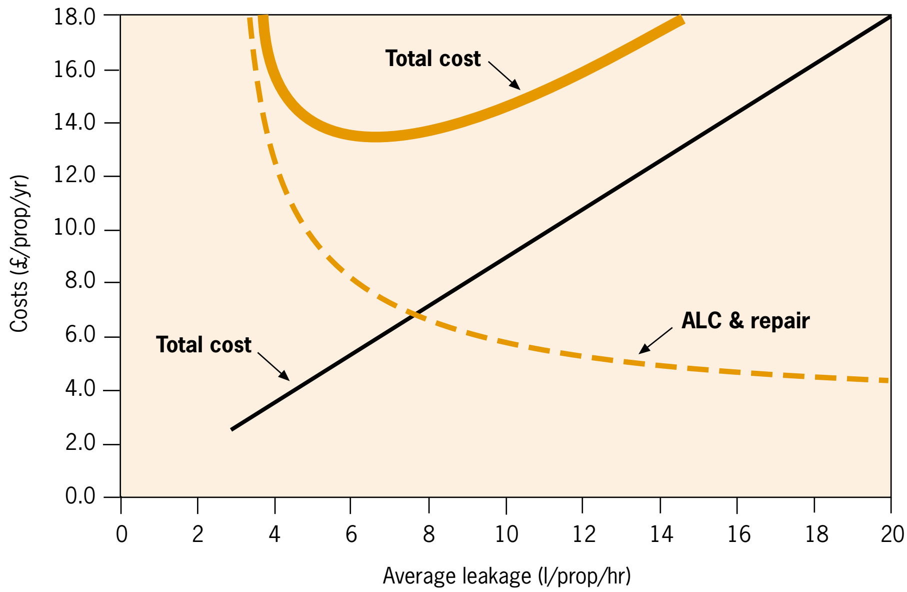
OFWAT expects companies to move to a fully component-based water balance, i.e. to assess each component independently and compare the sum of the components with the measured distribution input. However, the sum of the components may not agree with the measured distribution input due to the associated errors.

It is assumed that annual leakage can be estimated with an error of ± 10% (using the night flow approach) and distribution input is calculated as the sum of the components; error estimates suggest that the error in calculated distribution input could be up to 8%. Measured distribution input is reported to have an error of between 1% and 4%.

Setting leakage targets

The basic approach for determining the economic level of leakage can be explained by Fig. 6.1.

Fig. 6.1 **Determining the economic level of leakage**



The cost of leaking water is assumed to be directly proportional to the volume of water lost. The cost of leakage control increases at lower levels of leakage, and the rate of increase becomes gradually steeper until a level is reached below which leakage cannot be further reduced. By adding the two cost curves together it is possible to identify the minimum cost position. This is described as *the economic level of leakage*.

The active leakage control cost curve in Fig. 6.1 relates to the steady-state condition, i.e. the cost for maintaining a given level of leakage. Transitional costs of moving from one level of leakage to a new level are not included.

This approach was proposed in *Managing Leakage* and further developed by UKWIR (see Section 1.3, ref. 4). Although the principles are straightforward, some of the fundamental influences, such as the natural rate of rise of leakage, are still poorly understood. Modelling the cost of leakage control and the cost of water relationships is a complex task and it should be recognized that the form of the curves may change over time. The relationships must be based on good quality company data and a detailed understanding of the policies that are in place.

From the analysis of company data, the Water Research Centre (WRc) has built on the standard methodology and developed a new approach which allows the costs and effectiveness of different leakage control policies to be compared.

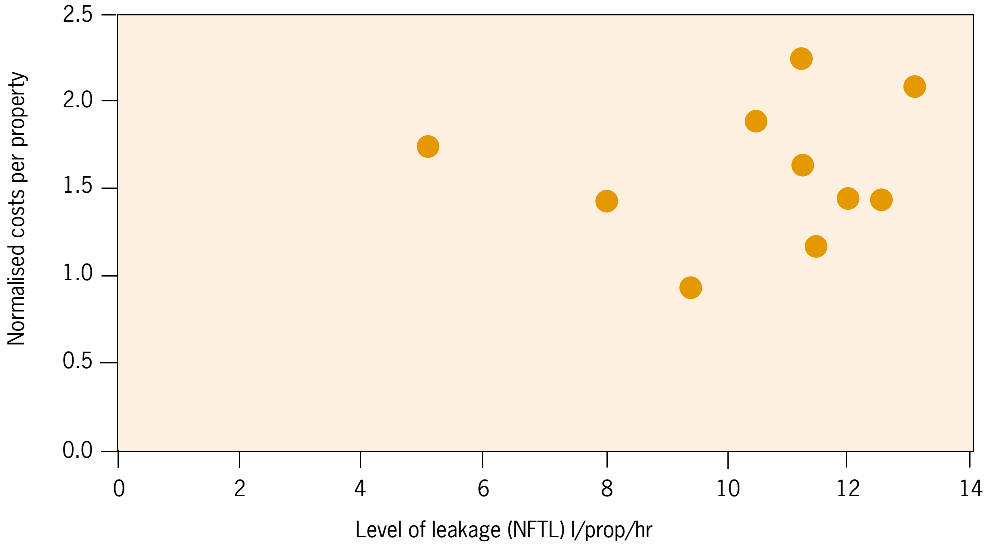
Cost of leakage control

1. Explaining differences in leakage control costs

All the companies represented in Fig. 6.2 used some form of continuous night-flow monitoring and the cost/man-week of active leakage control showed only minor variations from one company to another. The differences in the cost of active leakage control were not explained by pressure or mains length per property. Although factors such as mains condition may have been partly responsible for the variation in costs, it is clear that the data do not follow the pattern of very high leakage control costs at low levels of leakage.

The differences in leakage control costs could be explained by considering the number of leaks currently running in each zone, i.e. the ‘backlog’ of leakage. This will be determined by the historical active leakage control activity.

Fig. 6.2 **Cost of active leakage control: real company data**
(from *Managing Leakage—Report C*, Appendix B1) (5)



2. Backlog of leakage

Consider a zone running at 8 l/prop/h. To maintain this level, 150 leaks have to be repaired each year. Over a period of years, leakage is allowed to drift up (by not putting sufficient effort into active leakage control) and increases to 13 l/prop/h.

Leaks continue to occur at approximately the same rate at this higher level of leakage. Therefore to maintain 13 l/prop/h, 150 leaks still need to be repaired each year. However, there are now, say, 100 more leaks running than before. This means that a similar level of expenditure will be required to hold leakage at the higher level.

To move back to 8 l/prop/h, the company could, in theory, maintain steady state and reduce the average leak run time. In other words, they could attempt to find the 150 leaks more quickly without changing the exit level. (It may not be possible to achieve the required leakage reduction using this approach, as there is a limit to how quickly it is possible to find the leaks.) This would result in a large increase in annual leakage control costs.

In practice, to bring leakage back down to 8 l/prop/h, the company needs to find and repair the 100 extra leaks. This will involve a one-off effort for location and repairs. During the transition phase, substantial additional expenditure will be required. However, once the target level of leakage is achieved, it should be possible to maintain the steady state with only a relatively small increase in the ongoing leakage control costs.

3. Leakage control policy

With limited staff resources, intensive leak location work may succeed in reducing leakage to a low level in target DMAs, but there may then be a long period between leak location exercises. Alternatively, the leakage policy may ensure that DMAs are targeted at frequent intervals but may fail to achieve low leakage, e.g. if sounding is only carried out on hydrants and valves or if the team finds a certain number of leaks and then moves on. These two policies will have the same overall effect.

For the same average intervention period (e.g. sounding, on average, once per year), lower levels of leakage can be achieved through:

- Small metered areas (DMAs or waste areas)—this exploits the variation in natural rates of rise of leakage and results in better prioritization and hence less sounding.

- Frequent data analysis—this allows bursts to be identified more quickly.
- Short repair times—this reduces leak run times, ***but*** it will be more efficient to locate a number of small leaks in a single sounding exercise.

The lowest achievable level of leakage and the shape of the active leakage control cost curve will be dependent upon the leakage control process. The costs of leakage control can be split into component parts. Some of these will be independent of the level of leakage, e.g. the cost of correlating to pinpoint leaks. Other costs must increase if the level of leakage is to be reduced, e.g. staff time on sounding exercises.

The leakage policy will determine the relative size of the different cost components and how the costs would change at different levels of leakage, e.g. if telemetered flow data are available, data collection will be a small component of the total cost of leakage control and more frequent data collection would result in only a small increase in costs. If leakage is high but flows are collected weekly, more frequent data collection will not be required in order to reduce leakage.

The active leakage control cost curve for the current policy uses the current cost components and models the effect of more intensive or less intensive activity. It must be based on good quality company data which relate to the steady-state condition and a good understanding of the active leakage control policy.

A change in the leakage control policy may result in:

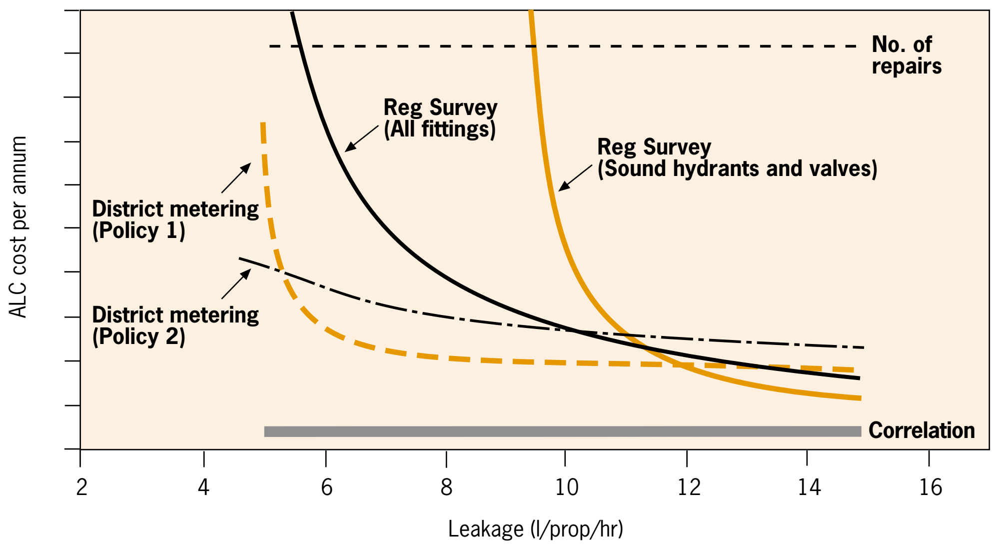
- a change in the leakage control costs, e.g. more intensive sounding methods;
- a change in the level of leakage, e.g. more extensive pressure control;
- a change in the lowest achievable level of leakage, e.g. if step tests are no longer carried out.

This is shown in Fig. 6.3.

More efficient policies will reduce the economic level of leakage and the total cost of leakage. However, moving to a more efficient policy may involve major capital expenditure. The most cost-effective policy will depend upon the leakage target, e.g. district metering is a very efficient way of maintaining low levels of leakage, but less worthwhile at higher levels of leakage.

The impact of the leakage policy on the economic level of leakage raises a number of questions. Should companies which have invested heavily in leakage control, and which

Fig. 6.3 **Active leakage control costs to maintain a steady state**



are therefore likely to have a relatively low economic level of leakage, be compelled by a regulator to meet more stringent leakage targets than companies which have failed to invest? Should companies which are operating control policies that would be expensive at low levels of leakage be expected to undertake major capital investment, such as more extensive district metering or mains replacement, in order to reduce their economic level of leakage? If full life-costing is used to take into account both the capital and operating expenditure involved in implementing a new leakage policy, what would be an acceptable payback period for the necessary investment?

4. Cost of water

The cost of water, or the financial benefit to a company which results from a reduction in the level of leakage, can be divided into:

- *Operating costs*—the savings in power and chemicals due to reducing the volume of water which is lost as leakage.
- *Capital costs*—the savings which can be realized by deferring or downsizing demand-related capital schemes. Capital costs should take account of the timing and size of any capital scheme which would be required to meet an unrestrained demand forecast. This may include the provision of resources, treatment capacity, and supply and distribution capacity. The timing of the schemes must consider the minimum headroom requirement, i.e. the margin of safety between drought-related resource yields and peak annual demands.

The cost of leaking water should be based on the leakage level in each DMA and the corresponding operating and capital costs of water. Allocation of costs at DMA level will help to set trigger levels which take into account the potential cost savings.

In general, where peak and average demands are increasing, the capital cost of water will be high and intensive leakage control activity can be justified on financial grounds. It may also be possible to consider environmental costs in the cost of water, but no clear guidelines have been provided on the approach that water companies should take.

Where demand is steady and no capital schemes are planned, the cost of water may be very low. This is true in parts of Scotland, where there is zero capital cost and the operating cost can be less than £0.01 per m^3. In such circumstances it is difficult to justify a large capital investment and annual expenditure on leakage control.

The capital cost of water is thus the main driving force in determining the economic level of leakage.

Conclusions

1. If leakage targets for individual companies are to be compared on an equitable basis, a standard method must be developed which will provide more reliable leakage estimates.
2. It is important to establish the economic level of leakage, even if the company decides to take account of additional factors in setting its leakage target. If the target level is below the economic level, the extra cost to the company should be quantified.
3. The costs of leakage control will be influenced by past leakage control activities. The economic analysis must distinguish the transitional costs of reducing leakage from the ongoing costs of maintaining a lower level of leakage.
4. The economic level of leakage will depend upon the leakage policy that is currently in place. More efficient policies are likely to result in a lower economic level of leakage and a lower total cost. A detailed economic analysis will help to determine the leakage strategy which will achieve and maintain a target level of leakage at the least cost.

5. The capital cost of water is normally the driving force in determining the economic level of leakage. Where demand is increasing, more intensive leakage control will be justified on financial grounds.
6. The minimum cost position will change over time and should be reassessed on an annual basis.

References

1. *Leakage of water in England and Wales*. Office of Water Services, May 1996.
2. Technical Working Group on Waste of Water. *Leakage control policy and practice*. National Water Council Standing Technical Committee Report No. 26, July 1980, revised 1985 (see Section 1.3, ref. 5).
3. *Annual water balance calculations*. UK Water Industry Research Ltd (UKWIR) Report R&D 008 (unpublished).
4. U.K. Water Industry. *Managing Leakage. Report E: Interpreting measured night flows*. Engineering and Operations Committee, October 1994.
5. U.K. Water Industry. *Managing Leakage. Report C: Setting economic leakage targets*. Engineering and Operations Committee, October 1994.

7. Leakage monitoring and control

7.1 Leakage monitoring in zones or sectors (the DMA concept)

The technique of leakage monitoring requires the installation of flowmeters at strategic points throughout the distribution system, each meter recording the flows into a discrete area with a defined and permanent boundary. Such an area is called a District Meter Area (DMA).

The design of a leakage monitoring system has two aims:

1) 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.
2) To manage the pressure in each district or group of districts so that the network is operated at the optimum level of pressure.

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 incorporates a pressure-reducing valve.

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

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

Fig. 7.1 Typical metering hierarchy and DMA design options
(reproduced from *Managing Leakage—Report J*)

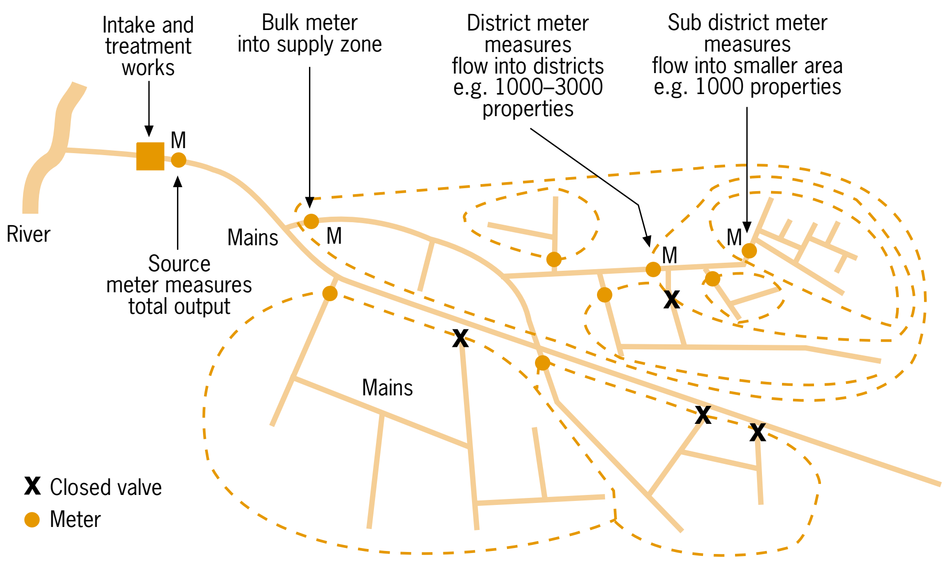


Fig. 7.1 shows a typical DMA design, including the monitoring hierarchy upstream and downstream of the DMA (reproduced from *Managing Leakage*—Report J).

7.2 DMA design

Several factors should be taken into account when designing a DMA, such as:

— the required economic level of leakage;
— size (geographical area and the number of properties);
— variation in ground level;
— water quality considerations.

Economic level of leakage

Each company will have its own criteria for setting economic levels of leakage and for setting leakage targets for each DMA. These will determine the type of active leakage control policy in the future, the size and number of DMAs, and staffing policy. The economics of leakage management are explained in *Managing leakage*: Report C—*Setting economic leakage targets*. Key factors in setting targets are the size of the DMA and the intervention level; the latter is explained in Section 7.6. In a small DMA the operator will be able to:

— identify when bursts occur more quickly, reducing "awareness time";
— identify smaller bursts (e.g. a single supply pipe burst);
— find bursts more quickly, reducing "location time";
— maintain total DMA leakage at a lower level.

DMA size

DMA size is expressed in the number of properties. The size of a typical DMA in urban areas varies between 500 and 3000 properties (ref. *Managing leakage*: Report J—*Techniques, technology and training*). However some DMAs, designed around old "waste meter zones", are smaller than 500 properties and others, designed around reservoir zones or in rural areas, are larger than 3000 properties. The size of an individual DMA will vary, depending on a number of local factors and system characteristics, such as:

— the required economic level of leakage;
— geographic/demographic factors (e.g. urban or rural, industrial areas);
— previous leakage control technique (e.g. ex-waste meter districts);
— individual water company preference (e.g. discrimination of service pipe bursts, ease of location survey);
— hydraulic conditions (e.g. limitations of closing valves in the current network, and the need to maintain standards of service).

DMAs in dense urban areas, e.g. inner cities, may be larger than 3000 properties, because of the housing density. In the rural areas it is also difficult to lay down sizing guidelines, as rural DMAs may consist of a single village, or may encompass a cluster of villages (a small number of properties in a large geographical area).

If a DMA is larger than 5000 properties, it becomes difficult to discriminate small bursts (e.g. service pipe bursts) from night flow data, and it takes longer to locate. However, large DMAs can be divided into two or more smaller DMAs by temporarily closing the valves (see section 9.1) so that each sub-area is fed in turn through the DMA meter for leak detection activities. In this case, any extra valves required should be taken into account at the DMA design stage.

In practice, DMAs fall into three categories:

- small: <1000 properties
- medium: 1000–3000 properties
- large: 3000–5000 properties.

Water quality considerations

Creating a DMA involves closing boundary valves. This creates more dead-ends than would normally be found in a fully open system. Consequently complaints of poor water quality may occur, both during valving-in a DMA and during later operation. The greater number of valves in a DMA, the greater is the likelihood of this happening. The problem can be partly alleviated by a flushing programme, starting at the design stage and at regular intervals afterwards. Some companies have a standardized DMA boundary valve configuration which consists of two valves (one each side of a hydrant) or two hydrants (one each side of a valve) to help the flushing programme. This also serves as a clear marker for boundary valve identification.

DMA design and installation

Fig. 7.2 is a flow diagram to show the stages in design and installation. The procedure is iterative in the early stages of planning, testing and site survey.

DMA planning

The planning stage is the process of dividing the distribution system into suitably sized DMAs. Outline planning is the first step, using small-scale distribution mains maps to draw provisional boundaries. This step utilizes local knowledge of the network and available hydraulic data (pressure and flow) to identify potential trouble spots, which could be made worse by closing in DMAs.

Where the DMA boundary crosses a main, a meter is installed (or a valve is closed) so that any flow at the boundary crossing, either into the DMA or out into an adjacent DMA, is continuously monitored. This allows the net night flow to be calculated. The net night flow, taken at a time when demand is at its lowest, provides the basis for the operation of the DMA, and helps to prioritize each DMA for leak detection and location activity.

Property counts

Exact property counts are not necessary at the design stage, but are essential later when the system is operated, in order to calculate net night flows. Initially, sufficient accuracy is needed to enable a DMA size of between 500 and 3000 properties to be defined.

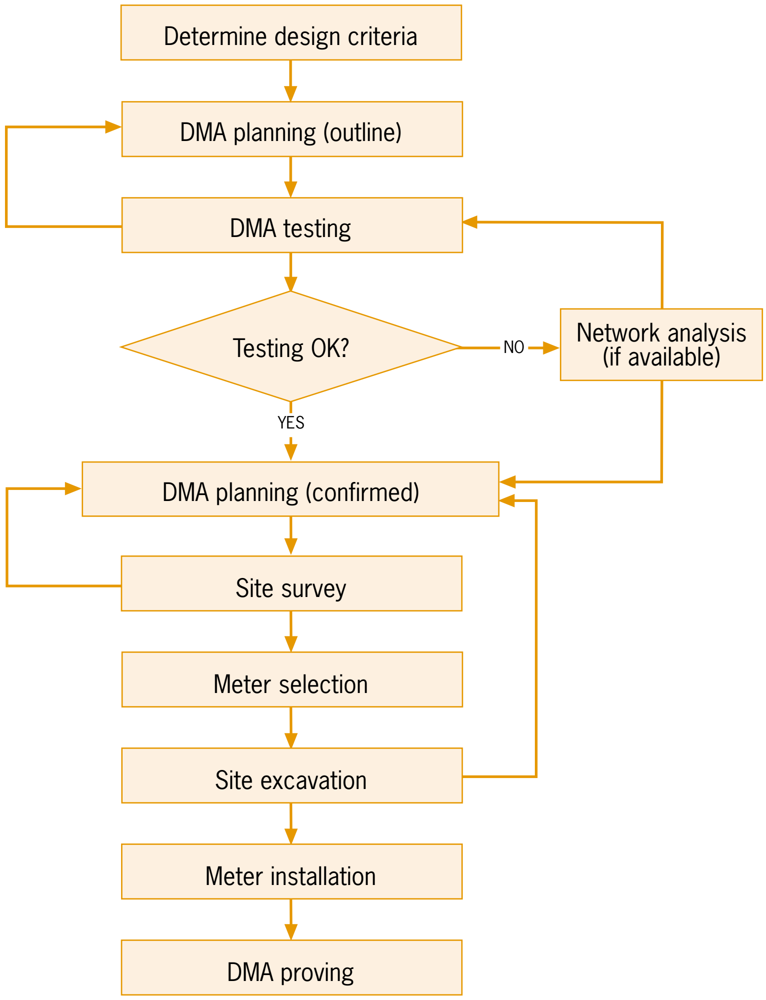
When a network model is used, the number of properties will have already been determined. If not, the best source of property information is from a Geographical Information System (GIS), billing records, post-code information, or a street-by-street survey.

Defining a boundary

The first step in the design of a DMA boundary is to study the area, using experience gained from existing practice and local knowledge, to identify any potential problem areas. Examples of these are:

— areas of low pressure;
— areas where essential supplies must be maintained, both of which may be adversely affected by installing flowmeters, or by closing the valves and diverting the supply.

Fig. 7.2 **Stages in DMA design and installation**



A boundary should be designed not only to fit the broad design criteria for the DMA, but also to cross as few mains as possible. The boundary should follow the "line of least resistance" by using natural geographic and hydraulic boundaries. The aim is clearly to minimize the cost of installation, operation and maintenance.

Reference to the network model will define those mains where a closed valve may replace a meter.

Where possible, trunk mains and large distribution mains (greater than 300 mm) should be excluded from DMAs to avoid costly meter installations, and more importantly, to improve the accuracy of flow information. Where a large proportion of the flow entering a DMA passes out again to other parts of the system, the accuracy of the estimate of demand in that district is relatively poor. This is because changes in inflow and outflow could imply large changes in DMA demand, but in fact could be solely due to compounded errors in metering.

Trunk mains and other large mains can be avoided by drawing adjacent DMA boundaries parallel to the main and metering the smaller distribution mains where they join the trunk main (highlighting in colour all mains larger than 300 mm).

There will clearly be cases where this is uneconomic owing to large numbers of smaller mains leaving the trunk main. The decision must then be made to:

— shut the small supplies, except for one feed;
— create a trunk main DMA;
— if only small distribution areas are being served by the trunk main, exclude them from the DMA system, and use mobile metering or non-metering methods of leak detection.

Fig. 7.3 shows the configuration of several DMA types within a Water into Supply Zone boundary:

— a trunk main DMA (501D04);
— a discrete DMA off a trunk main branch connection (501D03);
— a cascading DMA (501D02/501D01).

Selecting the meter site

A large-scale plan (1:500 or 1:1250) should be used for site selection, so that details of the line of the main, and the position of valves, bends, connections, and obstructions can be clearly seen.

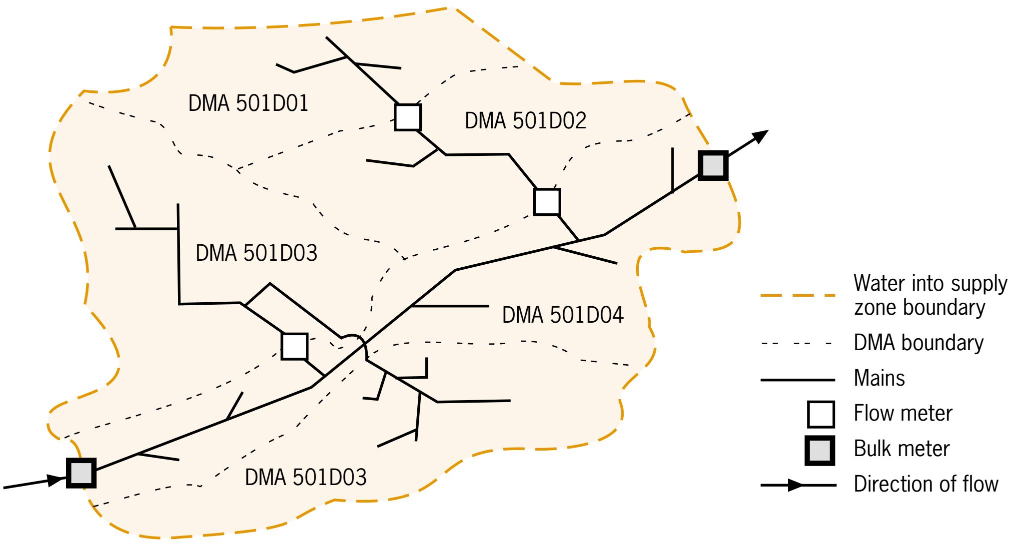
Valves and bends can cause inaccuracies to the flow readings from some meters. It is important to site such meters on a straight length of main, as free from obstructions as possible (particularly bends). Manufacturers' recommendations on the number of pipe diameters between the meter and upstream/downstream obstructions should be followed.

If telemetry is to be considered, this stage can be used to coordinate the meter site with the positions of mains or street light power points, and communication links, for future connection.

DMA testing

Before any further work is carried out, a trial closure of DMA boundary valves should be made. This is to check that DMA pressures are maintained up to the standard of service. Peak flows can be simulated by opening the hydrants. Headlosses across the proposed meter and bypass fittings should be calculated using Table 1.1 to anticipate their effect on DMA pressures once the meter is installed. If pressures are not maintained, the out-

Fig. 7.3 **DMA configurations**
(reproduced by permission of South West Water Services Ltd)



line planning stage will have to be repeated, and extra meters installed to replace the closed valves.

Using a network model (if available)

In all but the simplest of systems, network analysis is usually the next step after outline planning of the DMAs.

The closure of boundary valves and installation of meters during district formation will fundamentally affect the future design and operation of the entire distribution system. Unless these influences are carefully planned, the hydraulic constraints imposed on the distribution system could lead to future supply problems and cause operational limitations to both the distribution system and the DMA. This is particularly significant if the network pressure is to be operated at the optimum level.

The main role of a network model is to provide an understanding of system behaviour, i.e. the range of flows and pressures over changing demand. Initially the system will be modelled and calibrated in its current state prior to boundary valve closure. The network model will be adjusted throughout the planning stage, as boundary valves are closed and meters are installed.

The process thus enables:

(i) faults or limitations of the present system to be identified and, if necessary, eliminated before further planning takes place;
(ii) the effect on system pressure by the formation of district boundaries and new pressure regimens to be tested in advance, and unsatisfactory districts to be modified before any costly site work or installation can take place;
(iii) the flows to DMAs to be analysed, allowing the meters to be selected and purchased.

The ability of network analysis to identify and aid the elimination of faults and unsuspected peculiarities in the system is extremely valuable because, if these remain undetected, the existing operational and supply problems may be significantly worsened by the installation of a DMA.

The model can also highlight peculiarities in the system, which are discovered during the field-testing and model-calibration stages, for example:

— open valves which should be closed (and vice versa);
— faulty or incorrectly set pressure-reducing valves;
— flow constriction and pressure losses due to partially closed valves or high encrustation;
— the need for possible re-zoning to eliminate flow reversals or areas of low pressure;
— high leakage areas.

As well as providing an understanding of system flows and pressures, network analysis will continue to feature throughout the planning stage as each district boundary is defined. The model can be manipulated to determine the likely effect on system pressures of closing the valves on district boundaries and whether more than one meter is needed to ensure that the district design is soundly based.

It should be noted, however, that the amount of work and field measurement required to build a network model is substantial, and will take several months to complete. Often it is impractical to delay the implementation of DMA design and installation until a fully calibrated model is available. However, in practice it has been found that network analysis and the design and installation of DMAs can be done simultaneously. Only in areas where there is significant disagreement between the model and the system, or where the formation of districts is shown as likely to cause pressure problems, is it necessary to wait for a fully calibrated model.

Modifying the model for DMA design

The ability to manipulate the network model becomes a valuable tool at the DMA planning stage. Before the model can be used, however, it is necessary to:

(i) modify those nodes which fall in two districts and apportion the properties accordingly;
(ii) insert those small mains which are crossed by the district boundary;
(iii) set design rules.

By consulting the network model it is possible to identify those mains crossing a boundary which have sufficiently high flowrates to be metered, those where the flow is sufficiently low not to justify a meter, and those mains where the information is insufficiently precise to make a decision at this stage.

Where flows are low it is possible to save on meter installations by closing a convenient valve, or exceptionally by installing a valve and closing it. In each case, inserting a closed valve on the network model will show the likely effect on the flows and pressures in adjacent areas of the network. Account should be taken of peak demands and seasonal fluctuation, the effect of which can also be modelled. It is also important to eliminate any temporary causes of low flows, such as valve closures for mains laying or repairs.

Where network analysis indicates a valve closure is possible, it is important to verify this by closing the valves for at least 24 hours, and preferably for seven days, to monitor pressures. These should be compared with the model, and any customer complaints noted, so that supply problems can be identified objectively. If problems do occur, a meter must be installed.

Network analysis also allows the effect on system pressures, caused by the creation of DMAs, to be assessed objectively. This assessment can be for the current peak-hour demand levels as in the case of closing a valve mentioned above, or it can be made for some future date, e.g. the following summer, taking seasonal demand into account, or in say, ten years time, when population increases could lead to pressure problems that were not apparent when the system was installed.

The effect of headloss caused by installing meters can also be examined using the network model. This effect will be most significant in low pressure zones where headlosses through the meters could increase the problem.

Where the model shows that supply problems could occur it is necessary to re-plan the relevant district boundaries or possibly re-zone part of the distribution system to overcome them. This process of careful planning and checking the effect of the proposed changes prior to implementation avoids expensive mistakes, abortive detailed planning and meter installations, and future operational supply problems.

Several companies have designed successful DMA systems without a network model, by using local knowledge of problem areas and critical points, etc., and by experimenting with valve closures while simultaneously conducting an intensive pressure-monitoring exercise to cover the range of customer demands.

Site survey

A site survey is necessary to verify the potential meter location that was decided in the planning exercise. It is the stage where any errors in the mains records are shown up and where essential information that was not recorded on the mains maps is obtained.

It is recommended that all potential sites on each boundary are surveyed at the same time. A change in the line of the boundary once excavation has started is inconvenient and expensive.

The line of the mains can be verified as follows:

(a) check the mains map against the inspector's local knowledge;
(b) observe the line between actual valve locations (noting that valves may be positioned on cross-connections, which could be misleading);
(c) use a pipe locator to trace the line of the main.

Having accurately located the line of the main, it is advisable to "walk" the main, noting and verifying the positions of valves, bends, and connections, etc.

It is also necessary to determine the position of the plants of other utilities so that they can be avoided when excavating the meter site. In some cases, congestion will cause a site to be unworkable and require either the meter location to be moved, other plants to be re-routed, or in extreme cases the boundary to be redesigned. In the latter case, it will be necessary to return to the DMA planning stage.

Telemetry and power requirements

The practice of connecting DMA meters to a telemetry system, either by telecom or cellular networks, is increasing, particularly when designing new systems.

While conducting the site survey it is useful to note the proximity of the facilities needed for a telemetered DMA outstation. These include:

(a) Mains electricity power supply. Supply to the outstation is provided by jointing to a mains cable or by connecting to a street lamp supply. An alternative to mains power is battery or solar power.
(b) Communication connection. Telecom connection can be made either into a footway box or to an overhead line via a pole. Requirements for cellular or cable networks should be noted.
(c) A suitable site for a housing to contain the outstation instrumentation, which may be underground. Permission should be obtained from the local authority or other landowner.

The meter site should be located as near as possible to the plants of these utilities to minimize the cost of future connections.

Bypass installation

Most companies install a bypass at the DMA meter site. This can either be a bypass around the meter or a meter on a bypass. The site survey should be used to investigate the best site for a bypass excavation, using verges in preference to footpaths, and bearing in mind that the area of excavation necessary is considerable.

The main advantage of a bypass installation is that the meter can be easily isolated for maintenance without disrupting the supplies.

Accessibility problems can be overcome by connecting the meter to a logger, which can be located in a small chamber in the verge or pavement. The meter and outreader are connected by cabling contained in ducting laid in a shallow trench. This enables the meter to be read without accessing the meter (possibly in a busy road) or lifting heavy covers. Meter reading and monitoring instrumentation is discussed in Section 7.5.

Following the site survey and the selection of a potential meter site, the next stage is the excavation of the site to confirm the viability of a meter installation. Further excavation is then carried out, as necessary, as part of the installation stage.

Meter selection

State of the art flowmeter technology makes it possible to select a meter which can cope with peak daily flows and seasonal demand, and which can also accurately measure:

— night flows into a DMA;
— night flows into subdivisions of a DMA;
— the very low flows associated with step testing.

The choice of meter size and type will depend on:

— the size of the main;
— the flow range;
— reverse flow requirements;
— accuracy and repeatability;
— data communication requirements;
— cost of the meter;
— cost of ownership and maintenance requirements;
— company preference.

The flow range and accuracy requirements of the meter will depend on the mode of use. In the past, meters used solely for leakage monitoring in DMAs required good repeatability—for monitoring trends in flow data—rather than absolute accuracy. However, DMA meters are now being used to gather total leakage data from the DMA system, and the accuracy of individual meters is an important requirement.

Accuracy is also important if a DMA contains several meters, measuring flows into and out of the district, as compounded errors in flow calculations could result in misleading leakage levels. In this case, meter repeatability is also important.

The new generation of meters—mechanical, electromagnetic, and ultrasonic—are capable of measuring accurately over the flow range required for DMA monitoring. Most companies use mechanical meters (e.g. Kent Helix 4000). These have a turndown ratio (maximum to minimum flowrate) of 100:1 or better, allowing flexibility in selecting the appropriate meter size. However, electromagnetic meters are being increasingly used, particularly where a full-bore meter is necessary to overcome poor water quality, debris in the main, etc. The DMA market has resulted in cheaper, battery-powered versions of electromagnetic meters with a flow range comparable to mechanical meters.

Annex 5 contains details on the manufacturers of the meters most commonly used by the water industry in the United Kingdom.

Meter sizing

Rules for meter sizing should take account of headloss, seasonal fluctuation, and demand changes. Where reverse flow has been encountered or is considered likely as a result of future operation, a meter capable of measuring reverse flow will be required. A comparison with the records from previous years will give an indication of seasonal differentials.

In areas with existing high leakage, future flow characteristics—particularly minimum flows—can be significantly different. Allowance should also be made for the lower flows that are likely after the leaks have been found and repaired.

If a network model is used, this can be used to predict the flow range of the DMA meter, taking into account peak and seasonal demands and minimum night flows.

If a model is not available, a temporary insertion meter can be used to estimate the flow range, with some adjustment for seasonal and/or exceptional flows.

If neither of these tools is available, the flow range can be estimated from demand calculations, using:

— the number of properties;
— estimates of the per capita household consumption (pcc), estimates of metered use, and estimates of exceptional use of >500 l/hour (for maximum flows);

— estimates of night use (for minimum flows);
— estimates of leakage (for minimum flows after leak repair).

Maximum flow = (No. of households x pcc) + (No. of non-households x average consumption) + exceptional use + estimated distribution losses

Minimum flow = (No. of households x night use) + (No. of non-households x night use) + estimated distribution losses after repair

The formulae in the Burst and Background Estimates (BABE) software can also be used as a source of this information.

The flow ranges for Kent Helix 4000 meters are shown in the Table given below. The maximum flows quoted by the manufacturer are for exceptional flows for short periods; the figures for recommended continuous flow should be used for meter sizing.

Meter size (mm)	80	100	150	200
Maximum flow (m^3/h)	200	250	600	1000
Recommended continuous flow (m^3/h)	**120**	**180**	**450**	**700**
Minimum flow (m^3/h)	**0.5**	**0.6**	**2**	**4**

In practice, the new generation of mechanical helix meters, such as the Kent Helix 4000, have such a high turndown ratio, that "rule of thumb" meter sizing by properties/DMA is usually adequate, as shown in the following example:

No. of properties	Meter size
<1000	80 mm
1000–1500	100 mm
>1500	150 mm

However, if headloss is an issue resulting from the characteristics of the pipe network or bypass installation, a meter which is one size larger than those illustrated above should be considered, as long as it is still adequate at the lower end of its range for the DMA night flows.

Table 7.1 illustrates the estimated flow ranges for DMAs between 500 and 3000 properties, and the expected total headloss across a meter and bypass installation at peak flows.

Table 7.1 **Installation headlosses for 80 mm, 100 mm, and 150 mm meters**

District size properties	Expected peak flow (litres/sec)	Expected peak flow (m^3/h)	Meter headlosses (m)			Meter size	K value	Velocity (m/sec)
			80 mm meter	Headloss across fittings	Total headloss			
500	7.23	26.04	0.10	0.61	0.71	0.08	5.74	1.44
1000	14.47	52.08	0.04	2.43	2.47	0.08	5.74	2.88
1500	21.70	78.13	1.00	5.46	6.46	0.08	5.74	4.32
2000	28.94	104.17	1.50	9.70	11.20	0.08	5.74	5.76
2500	36.17	130.21	2.20	15.16	17.36	0.08	5.74	7.20
3000	43.40	156.25	3.80	21.83	25.63	0.08	5.74	8.64

District size properties	Expected peak flow (litres/sec)	Expected peak flow (m³/h)	Meter headlosses (m)			Meter size	K value	Velocity (m/sec)
			100 mm meter	Headloss across fittings	Total headloss			
500	7.23	26.04	0.00	0.25	0.25	0.10	5.74	0.92
1000	14.47	52.08	0.18	0.99	1.17	0.10	5.74	1.84
1500	21.70	78.13	0.45	2.24	2.69	0.10	5.74	2.76
2000	28.94	104.17	0.70	3.97	4.67	0.10	5.74	3.69
2500	36.17	130.21	1.20	6.21	7.41	0.10	5.74	4.61
3000	43.40	156.25	1.70	8.94	10.64	0.10	5.74	5.53

District size properties	Expected peak flow (litres/sec)	Expected peak flow (m³/h)	Meter headlosses (m)			Meter size	K value	Velocity (m/sec)
			150 mm meter	Headloss across fittings	Total headloss			
500	7.23	26.04	0.00	0.05	0.05	0.15	5.74	0.41
1000	14.47	52.08	0.00	0.20	0.20	0.15	5.74	0.82
1500	21.70	78.13	0.00	0.44	0.44	0.15	5.74	1.23
2000	28.94	104.17	0.10	0.79	0.89	0.15	5.74	1.64
2500	36.17	130.21	0.20	1.23	1.43	0.15	5.74	2.05
3000	43.40	156.25	0.26	1.77	2.03	0.15	5.74	2.46

Meter installation

After selecting the meter, an excavation is necessary to provide sufficient room for installing the meter and constructing the chamber.

The extent of the excavation and the installation design will be influenced by:

(a) the type of meter selected, i.e. whether isolating valves or a strainer are necessary;
(b) the size of the meter in relation to the size of the main—this will influence the degree of tapering necessary.

For the installation of most meters it will be necessary to instal isolating valves upstream and downstream of the meter. By careful choice of meter site, it may be possible to instal the meter near to an existing valve, so that only one valve is necessary at the meter installation.

In areas with a history of dirty water problems, it may be necessary to include a strainer in the installation.

It is worthwhile to instal an insertion meter tapping point upstream of the DMA meter to make flow verification easier.

Consideration should be given to positioning a shelf or bracket for a data logger near the top of the chamber.

Considerations for telemetry and data logging

At the installation stage, it is worthwhile to bear in mind the requirements for remote meter reading.

Provision can be made for a telemetry housing or a small chamber adjacent to the main chamber to house a logger. This is a useful modification when the meter chamber is situated in the highway, when meter reading may be hazardous, or when the chamber is inaccessible.

The requirements are:

— the laying of cabling and ducting between the meter and outstation or outreader chamber;
— a suitable outstation.

The housing for the outstation should be:

— robust and durable, and not easily vandalized (e.g. made of cast iron, steel, or fibreglass);
— weatherproof;
— suitable for electrical supply and communication connections.

Fig. 7.4 shows the layout of a typical meter installation and bypass, and Table 7.2 the schedule of materials.

Fig. 7.4 **Meter and bypass installation**

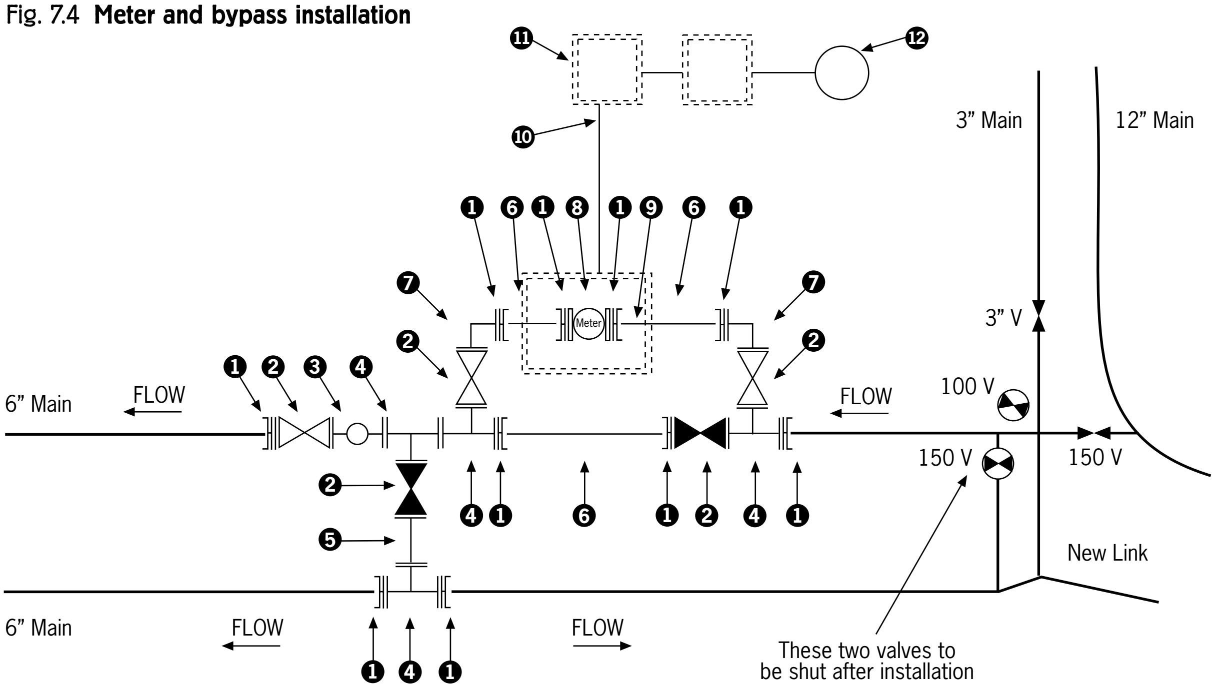


Table 7.2 **Meter and bypass installation: schedule of materials**

Ref. No. (see Fig. 7.4)	**Materials**	**Quantity**
1	150 flange adapter	10
2	150 SV	4
3	150 x 150 x 80 mm tee with W/O	1
4	150 x 150 x 150 mm tee	2
5	150 ductile iron pipe—length to suit	3
6	150 mm 90° elbow	2
7	150 mm ductile iron pipe—length 0.75 m	1
8	150 mm meter	1
9	Pressure tapping	1
10	150 mm ductile iron pipe—length to 1.5 m	1
11	50 mm ducting	As required
12	Boxes	2
	Antenna	1
	Grade A chamber cover	1
	GSM communications (temporary)	

DMA proving

Following the installation of all boundary meters (or the closing of valves where appropriate), it is necessary to "prove" the district to ensure that:

(a) all meters are working correctly;
(b) the district boundary is "tight", i.e. closed boundary valves are not passing and no boundary crossings have been missed (zero pressure test);
(c) all internal valves are at the correct status.

The recommended procedure for proving a district is to attach data loggers simultaneously to the DMA meters(s) during a night test. Supply to the DMA is closed and the drop in pressure and flow are observed.

Inspection of the results should reveal whether one or more valves are letting by. If zero pressure is not recorded, all boundary and divisional valves should be sounded. If faulty valves are found, or valves which should be closed are found open, these should be rectified and the zero pressure test repeated.

Zero pressure test procedure

A typical procedure is as follows:

1. Indicate the boundary valves by marking the valve covers (e.g. with blue paint)
2. Arrange for the test to take place between 01.00 and 05.00 hours. Inform customers with special needs.
3. Ensure that the staff have plans which indicate the DMA boundary, boundary valves, and the DMA inlet valve.
4. Set up a pressure gauge on a standpipe at a convenient hydrant (other than the target point for routine pressure monitoring).
5. Close the valve at the DMA inlet to isolate the DMA.
6. The pressure on the standpipe gauge should drop.
   If it drops immediately, the DMA is zoned correctly with all boundary valves drop tight. If after 5 minutes the pressure has not dropped, a second check is made by opening a fire hydrant (with the inlet valve still shut) to induce some flow, which should zero the pressure. The pressure should remain at zero when the hydrant is closed.
7. If the test fails, i.e. the pressure creeps up, one or more boundary valves may be passing. It may be possible to find culprit valves during the test and to try making them drop tight. If so, a second zero pressure test is carried out.
8. If the test fails and culprit valves cannot be found, this should be reported for the day inspector staff to investigate, and to replace any faulty valves.
9. On completion of the test, the supply valve is opened. The standpipe and gauge are used to ensure that supply has been restored to the DMA.

Before starting the test it is beneficial to have some indication of leakage in the DMA, and the pressures in adjacent DMAs.

DMA management

Once a DMA has been proved, all the work subsequently is related to its management, which is in two stages:

(a) initial work;
(b) routine operation.

Initial work comprises "housekeeping" issues such as:

— setting up records and recording procedures;
— setting up a monitoring and detection team;
— purchasing the necessary equipment;
— carrying out a "first pass" leak detection and location survey in each DMA to ensure that existing leaks are located and repaired.

The resulting night flow provides a reference value for future target setting.

Routine operation is to carry out all the tasks required for continual night flow monitoring (i.e. regularly monitoring minimum night flows as indicators of leakage).

As the efficiency of a leakage monitoring system is dependent on the integrity of each DMA, ensure that:

— the DMA boundary valves are clearly marked for identification by all staff;
— the valves are kept closed, their status is regularly checked, and they are drop tight;
— it is known when data are lost through valve operations or faulty meter installations;
— the property counts are accurate.

The tasks to ensure DMA integrity, and for its routine operation, are described in Section 7.3 of the manual. They include:

— maintenance of the DMA, including keeping property counts up to date, and boundary checks to ensure that the integrity of the DMA is maintained;
— setting up of data capture techniques and technology;
— data interpretation, to determine if more intensive detection and location effort is required;
— implementation of pressure management;
— detection, location, and repair of leaks;
— management of problem DMAs.

7.3 DMA management

This section provides guidance for managing newly commissioned and existing DMAs. It deals with DMA maintenance, including boundary management and the maintenance of plant and equipment. It also includes records management—the setting up of records systems and their upkeep, to ensure that DMA data are accurate and meaningful.

Boundary management

Although the DMA boundary is a "permanent" one as far as leakage monitoring is concerned, the valves can of course be opened temporarily for operational purposes. The main issue is to ensure that if the valves are opened, they are closed again afterwards, and that the duration of the break in the DMA boundary is recorded. This means that when the leakage manager analyses the data, he/she can tell the difference between a genuine burst and an open valve, and can avoid wasting valuable inspection time.

DMA boundary valves are left open for two main reasons:

— as an act of forgetfulness following an operational incident or a flushing exercise when inspectors forget to return them to the correct status;
— as a deliberate act.

Several companies have reported conflicts of interests between staff. Closed boundary valves are blamed for poor pressures and are opened to "restore supply".

The solution to this problem lies in improving communication channels by:

— developing a culture of *awareness of the DMA function* across the company;
— *educating non-leakage staff* on the importance of reporting each valve opening and for how long it was left open, and of ensuring that the valves are closed again after the operation.

In both cases a combination of a warning sign, a physical deterrent, and a programme of awareness training and education on the principles of DMA management is required.

Awareness training and education can take the form of regular briefing sessions for non-leakage staff to inform them about the principles of the DMA system and the successes being achieved.

Valve warning signs include:

— marker posts/plates;
— coloured valve box covers;
— coloured valve caps;
— boundary valve configuration. (At the boundary design stage, boundary valves can be distinguished from other valves by installing two valves, one each side of a hydrant. This also serves the purpose of anticipating water quality problems caused by dead ends, by introducing a DMA flushing programme.)

Physical deterrents include:

— lockable covers;
— foam swabs in the valve chamber;
— non-standard valve head;
— the WIZ-key;
— polystyrene foam sprayed in the chamber.

The last solution is based on the principle that the foam can be removed in an emergency or when it is decided to change the valve status.

The WIZ-key

The WIZ-key is a relatively new piece of technology which is being used as an effective (but expensive) boundary management tool by several water companies in the United Kingdom.

The WIZ-key is a modified valve key which has an in-built data logger and LCD display. The existing valve false head is replaced with a uniquely shaped head to prevent opening with a normal valve key. This head has an inbuilt read/write data capsule which stores valve details and updates on valve status. When in use on a converted valve the display shows:

— the identification number of the valve;
— the type of valve and main;
— the current % open;
— the direction to open;
— the normal operational position.

The key data can be downloaded either on return to the office, or immediately after use by means of a special holster mounted in a vehicle. The holster provides safe storage for the key as well as a facility for battery charging and downloading of information. Software in the holster ensures that data are transmitted via mobile phone or radio link to a central control point.

One company is installing WIZ-keys at zonal boundaries and "foaming" DMA boundary valve chambers.

Record systems

Record-keeping is an essential part of DMA management. 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.

DMA records

These are "static" records relating to:

— the DMA identifier;
— the meter(s);
— the boundary valves;
— pressure-reducing valves (PRVs);
— pressure monitoring points;
— the mains network, valves and hydrants.

A DMA numbering system should follow a logical pattern. There are a number of options, and each company has its own system. One system is for the DMA to be linked by number or name to its "parent" water into supply zone, which may contain several DMAs. The supply zone prefix could be followed by the suffix "D" (for DMA) and the DMA number. Sub-areas within the DMA could be similarly linked to the "parent" DMA.

Plans and records which may assist the leakage team are:

— regional schematic;
— area schematic;
— DMA plans;
— meter records.

The preparation of plans is subject to a company's information system (in-house or bought-in, PC-based or paper-based). Some companies use GIS to generate plans, mounted on portable PCs for field use. The PCs can also contain software for entering DMA data and the algorithms for calculating net night flows and leakage.

Regional schematic

This is a small-scale (e.g. 1:10 000 or 1:25 000) map of the distribution network. It should show the DMA boundaries and metered feeds in relation to the key elements of the water into the supply zones—trunk mains, service reservoirs, pumping stations, supply and pressure zone boundaries. Details of the distribution system within DMAs can generally be omitted unless there are key mains passing through one district to another.

Area schematics

Supply zone drawings can be used to produce a set of DMA plans, showing all DMAs within each water into supply zone. They will show the position of each DMA in the zone, with boundary valve and meter identifiers.

DMA plans

These are detailed plans of each DMA, showing:

— the numbered boundary valves and meters;
— the valves for DMA subdivision or step-testing;
— large metered customers (logged);
— features of the network (mains, line valves, hydrants);
— customers with special needs.

Meter records

These records contain information needed for data interpretation and meter maintenance. It is recommended that the following information be recorded on a suitable form or PC file:

— DMA identifier;
— meters in and out of the DMA;
— meter identification or serial number;
— the meter type and size;
— bidirectional flow;
— the main size;
— maintenance and repair log.

Leakage analysis records

Leakage monitoring and analysis is described fully in Sections 3 and 4. Records required are those which relate to the calculation of net night flow and leakage from total night flow in each DMA, using the basic formula:

$$\text{Leakage (total night flow losses)} = \frac{\text{min. night flow—customer use}}{\text{number of properties}}$$

$$\text{or} \quad \frac{\text{min. night flow—customer use}}{\text{length of main}}$$

Records required are:

— night flows at each meter;
— non-metered household count;
— occupancy rate;
— numbers of metered users in each category (see Section 4);
— large industrial users;
— allowances for night use;
— net night flow;
— average zone night pressure;
— pressure profile at mid-zone;
— hour to day factor.

Night flows

These should be recorded at selected intervals over a selected period, adding and/or subtracting flows from multiple DMA meters.

Non metered household count

This should be entered in the file for each DMA, and updated regularly.

Metered users

Record the number of metered customers in each category, preferably using Standard Industrial Classification (SIC) codes Record the total estimated night use of each category, based on customer demand studies.

Include non-metered commercial properties in the domestic property count, unless they are significant night users.

Customer night use

These records relate to each of the customer categories and their night use. Night use is an important record as it is subtracted from night flow delivered to derive leakage on non-metered household service pipes, and their plumbing losses, in the DMA.

Large metered customers

Customers who use significant amounts of water at night should have their night flows recorded simultaneously with DMA monitoring.

Other metered customers

Consider a study of each category to provide a better estimate of night consumption.

Operational use

This includes water abstracted for night mains flushing and fire fighting, which, although comparatively small, may influence minimum night flow readings on a particular night.

Leak location and repair records

Most companies use two databases, one for DMA leakage analysis (to monitor total leakage), the other a customer database (to monitor progress with service pipe repairs).

Records are needed to:

- — monitor when boundary valves are open or closed;
- — assist the inspectors in planning a location exercise following DMA monitoring and/or a detection exercise;
- — direct the repair gang in finding the location of a leak;
- — monitor progress during repairs;
- — provide leak and burst records for the DMA file.

The time taken for leak location and repair in each DMA should also be recorded for future analysis and decision- making to assess improvements to leakage levels.

It is good practice to record the approximate leak positions on a DMA map. This builds up a picture of the leakage characteristics, and helps to identify clusters of leaks which may relate to the age of the pipe or the pipe material. This will provide useful information for a future rehabilitation strategy, and will enhance the DMA database by identifying characteristics which may affect future decisions on leak location.

Leak repair records

Following leak repair, records should be kept of:

- — the date of repair;
- — the exact position of the leak (if different from the estimate);
- — the cause and type of leak, and repair carried out;
- — pipe material and size, and whether pipe replacement was necessary.

First pass leak detection and location survey

The next stage in managing a newly commissioned DMA is to reduce leakage to the minimum level achievable by one or more leak detection and location surveys. This provides a reference level of leakage for a DMA. When leakage rises, the difference between the current level and the reference level indicates the volume of water which could be saved if the DMA were surveyed again and all leaks were repaired. The reference level will vary from one DMA to another, and must be determined by practical means. However, the level should be tested against levels suggested by predictive software, which is becoming an increasingly reliable indicator.

Target levels can be defined at a later stage by assessing the characteristics of each DMA and using predictive software to set a target level of leakage for each DMA. This is discussed in Section 4.

7.4 DMA maintenance

This is a response to changes in supply and distribution within the system which may influence the operation of a DMA, particularly data interpretation.

Potential changes to the system are:

(i) changes in zone boundaries;
(ii) new supply connections;
(iii) changes in operation.

1. Changes in zone boundaries

These occur mainly as a result of the reallocation of pressure zone boundaries resulting from a pressure reduction exercise or an extension of the supply area. It will be necessary to re-route the boundaries of affected DMAs following the design criteria discussed in Section 1. Other components of the system operation, such as record keeping and data interpretation, will also be affected, and appropriate actions are listed below. They are similar to those actions recommended as part of the initial work in Section 1:

— update mains maps to show new DMA boundary and boundary crossings;
— record new closed DMA valves, or valves which have changed status and are now open;
— record new meter positions—update meter records for meter type and number, main size, etc.;
— check whether existing meters are affected by new design criteria (e.g. changes in flow range, flow direction)—if necessary, install a new meter or closed valve;
— update the property counts;
— update the records of industrial and commercial users—review the numbers of large users who should be data logged, and review the significance of other metered users and non-metered commercial users on DMA demand;
— revise DMA flow data in the calculations—add or remove meters, note effect of change of direction of flow in or out of a DMA;
— re-appraise DMA cost data and demand levels.

2. New supply connections

There are two implications of new supplies within a DMA:

(i) An increase in the number of properties.
(ii) An increase in boundary crossings by new mains.

If the numbers (e.g. new housing estates) are significant, new domestic properties must be added to the district property count. New industrial/commercial metered or unmetered properties must be recorded, graded to the appropriate category, and monitored.

Where new supplies are laid across a boundary between adjacent districts, the new main should be metered or valved if there is a supply from an alternative source. If a new main is laid across a boundary which does not join two districts, the boundary is extended to encompass the new area of distribution.

3. Changes in operation

Flow changes within a DMA, or between DMAs, can significantly affect the interpretation of flow data.

Changes to the flow pattern fall into two categories:

(i) Permanent changes to supply practice.
(ii) Temporary changes during normal system operation.

Permanent changes

(i) Increase or decrease in pressure: the effect of pressure on demand and leakage is well known. Any permanent change to system pressures should be followed by night demand measurement and a repeat achievement of base levels of leakage.
(ii) Changes in pumping: additional or reduced pumping may affect the range of flow through the DMA meter. A pump switching on and off during supply operation may cause a change of direction, e.g. by gravitation. Corresponding changes in flowrate, velocity and flow direction may require a new meter.
(iii) Re-zoning: sudden changes in demand by re-zoning, or by changes in population or industry may affect the flow range of the meter and flow direction.

Temporary changes

As with permanent system changes, the pressure, flowrate and flow direction can be affected in the short term during normal operation of the distribution system. Examples of these changes are:

(i) sub-division of the DMA by valving during leak detection and location;
(ii) valving during routine operations such as repairs, cleaning or renovation;
(iii) temporary changes in demand caused by population fluctuation or cyclic industrial demand patterns.

These should be recorded, as awareness of such activities will affect data interpretation.

4. Maintenance of plant and equipment

The efficient operation of a DMA system depends on regular and accurate collection of flow data by:

— efficient maintenance and fast repair of meters to minimize loss of data;
— regular meter checks to ensure they are maintained within accuracy limits;
— regular maintenance of secondary instrumentation.

5. Meter maintenance

Companies adopt different approaches to DMA meter maintenance, ranging from “catastrophic” (replacing meters when they fail) to regular maintenance (routine meter checks). However, with OFWAT’s requirement for more accurate leakage data from DMAs, companies may wish to review their meter verification and maintenance policy.

When DMA meters are installed it would be worthwhile to install insertion meter tapping points upstream of the installation to make such checks easier.

In practice little maintenance is necessary, other than the manufacturers’ recommended checks. The main distinction between meter types is that intrusive types (e.g. mechanical helix) have moving parts and may need regular maintenance and repair, whereas the non-intrusive types (e.g. electromagnetic) need very little maintenance.

When a DMA is first commissioned, supply meters will have been checked, calibrated or renewed. DMA meters will either be newly installed, refurbished or checked for accuracy. Large revenue meters, and other meters which have a significant influence on DMA nightflow will have been identified.

At this stage the system is performing to peak accuracy. Any subsequent work on meter checking or calibration within the distribution system depends on the value attached to the data, i.e. whether data are used for revenue, leakage analysis or OFWAT reporting.

High volume meters are invariably linked to higher values of information and higher values of water, and justify more frequent inspection. Some undertakings have regular calibration checks carried out on production (water into supply) meters and replace certain large revenue meters on a rolling programme.

The scope for meter calibration depends on both size and site. Source and station meters within a DMA are invariably calibrated *in situ*, whereas the calibration of DMA meters depends on site facilities, which often preclude *in situ* calibration.

Experience has shown that mechanical meters usually either fail catastrophically, or slow down to such an extent that the flow data become suspect. The flow data are thus the trigger to start further investigation, which may result in maintenance, calibration, repair or replacement. Simple operating checks should be made as a first investigation to check that valves are in the correct status, and that strainers, where fitted, are clear. Electrical and wiring checks, where appropriate, should be made next, and the meter head is removed only as the final investigation. To remove the meter head the meter must be isolated for a short time.

In cases where a DMA is supplied through one meter only, a boundary valve can be temporarily opened, noting this action in the DMA records. Another option is to change the meter head at night, when demand is minimal.

It is recommended that following removal of the meter head a spare head is installed in the meter body, minimizing the time the meter is isolated. The faulty head can be refurbished and checked in the meter shop.

It has not been found to be cost-effective to carry out a regular maintenance programme on mechanical flowmeters other than a visual check of the register or outreader at the time of flow recording. Repair or maintenance invariably follows a slowing of the register or catastrophic failure.

However, some companies are now conducting DMA meter audits to ensure that meters are:

— suitable for the DMA flow range;
— installed correctly;
— performing accurately.

Suspect or faulty meters can be withdrawn from service and checked on a meter test rig.

6. Equipment maintenance

Most data capture technology has been developed specifically for the water industry, is designed to withstand conditions associated with underground meter or logger chambers, and designed to IP 68 (immersion proof).

Loggers are solid state, and usually have batteries with a 5 or 10 year guaranteed life.

Maintenance should follow the equipment manufacturer's guidelines, and records should be kept of equipment faults and repairs.

Likely telemetry faults are linked to failed or inadequate power supply or communication line.

Suggestions for troubleshooting sensor/logger/meter combinations are made in Section 7.5.

7.5 DMA monitoring

Monitoring principles and terminology

The concept of DMA monitoring is to measure flows into a discrete area with a defined boundary at a time when water demand is lowest. This is to eliminate customer demand from leakage.

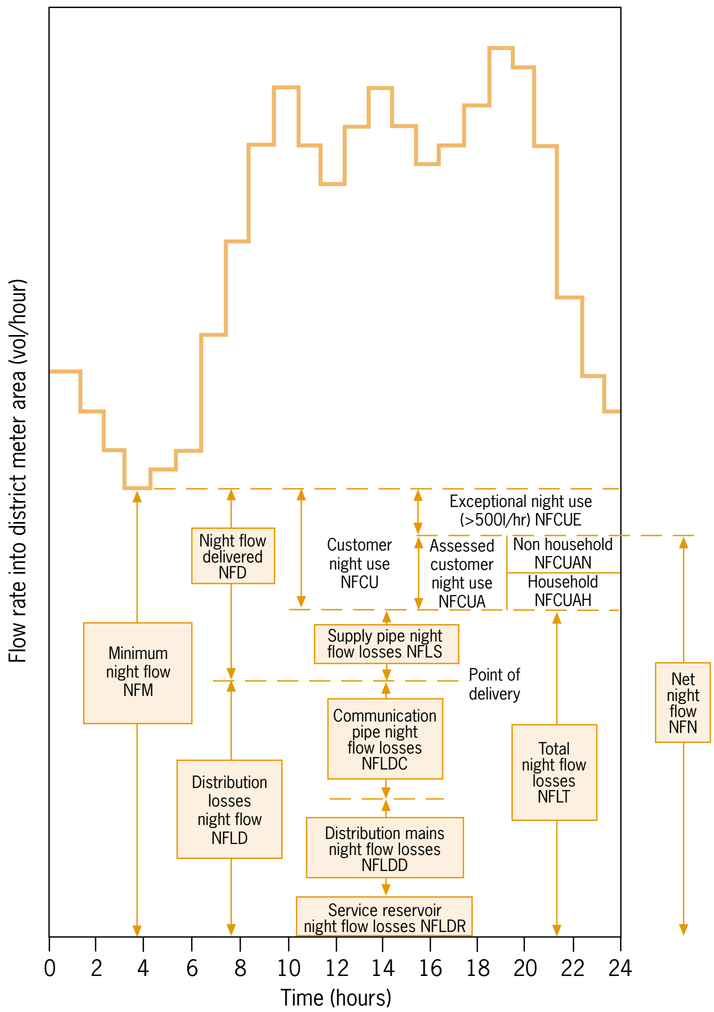
Managing Leakage: Report E—*Interpreting Measured Night Flows* provides a glossary of terms for night flows, ater consumed by customers, water actually used by customers, and leakage, both in the distribution system and on the customers' premises.

Fig. 7.5, reproduced from Report E, illustrates the components of night flows.

Managing Leakage—Report E highlights the relative contribution to total losses made by bursts, background losses, and supply pipe leaks, and on the relative time taken for a burst to be discovered, located, and repaired (awareness time, location time, and repair time). Bursts which are reported are likely to have a lower total volume loss than those which are unreported, i.e. found during a leak survey. While the volume rate of flow from a mains burst is large, the time the burst is allowed to run is short. A service pipe burst, on the other hand, has a low flow rate but could run for a long time, leading to a greater volume loss.

Research conducted for Report E showed that a burst at 50 m pressure on a 100 mm

Fig. 7.5 **Components of minimum night flows**
(reproduced from *Managing Leakage—Report E*)



distribution main would run on average for 1.1 days before being repaired—a total volume loss of 238 cubic metres. However, a leak on a communication pipe, because of its apparent lower priority, would be repaired after about 16 days, representing a volume loss of 512 cubic metres.

Monitoring practice

In most situations, minimum night flow will occur between 02.00 and 04.00 hours.

Logging frequency, i.e. the average period for each measurement, is usually 15 minutes (recommended as standard in *Managing Leakage*—Report E). Standardizing to 15 minutes from other periods is discussed more fully in Section 7.6.

When companies use more frequent logging periods (e.g. 1 minute), taken throughout the night, to derive the absolute minimum night flow, care must be taken when subtracting allowances for unmetered household night use. This is likely to be less than the standard 1.7 l/p/h under these conditions.

Consumption by large metered customers is measured simultaneously if they are significant night-users, or estimated if they are not. As it is impossible to monitor all metered customers, allowances for night use are made, usually taken from a sample in each category of customer. *Managing Leakage*—Report E gives a table of average values of night flow delivered to non-household customers, based on one company's survey of 3000 customers. The customers are classified both in standard industrial classification (SIC) codes, and in five groups of customers with similar average use. The range of use is from 0.7 l/p/h to 60.6 l/p/h. See Table 7.2 in Section 7.6.

Demand studies

Following the commissioning of the DMA meters, it is important to:

(a) investigate patterns of night flow delivered and night use by domestic customers;
(b) identify and record the large metered customers;
(c) identify and record the other metered customers and unmetered customers.

Step (a) is to derive customer use. The *Managing Leakage* reports suggest an allowance of 1.7 litres/property/hour or 0.6 litres/head/hour for household use.

Step (b) is for measuring night flow delivered to large customers (simultaneously to DMA night flows if they are also night users).

Step (c) is for calculating allowances for those customers in certain categories. The *Managing Leakage* reports suggest a general allowance of 8.0 l/h for non-household properties.

Large metered customers

Night use by large metered customers, particularly industrial users with variable demand patterns, is perhaps the biggest single influence on DMA leakage calculations.

It is therefore important that as much accurate information as possible is received from large metered customers. Very large users, particularly those with fluctuating demand, should be monitored regularly, and simultaneously to a night flow monitoring exercise. Some companies adopt the practice of metering such customers individually with a DMA meter which is read in the same way as meters on the DMA boundary ("industrial DMA").

Significant large users are identified as follows:

1) From previous records, identify those who are known to use water regularly at night. If such records do not exist, the customers should be contacted and their night demand pattern identified. It should be noted that night demand may not

only be due to direct use such as shift work of 24 hour production, but also indirect demand such as tanks filling overnight for the following day's production.

2) List separately those customers who intermittently use large volumes of water at night or whose demand behaviour does not follow any particular category. Their meters should also be read or logged simultaneously with the district meter night flows. Alternatively, if there are many customers in this category, or if resources are limited, their use can be estimated.
3) Irrespective of their pattern of usage, all large customers should be checked initially. It is recommended that each customer is informed of the recorded night use because high demand may be attributable to leakage.

Other metered customers

Customers in this category are generally those who do not use significant quantities of water at night, except for autoflush cisterns and tank filling, e.g. hotels, public buildings, offices and schools.

They should again be divided into categories and a sample of each category monitored for one week to establish a demand pattern and the volume of water used during the minimum night flow period. This information is used to produce a standard night demand for each category. Alternatively, the national data contained in Table 4.2 can be used.

Additional work was undertaken, both as a 1997/98 UKWIR (UK Water Industry Research Ltd) research project and by individual companies, to conduct surveys of non-household night use to achieve a more detailed set of allowances. One company classifies its non-household customers into three grades of night user:

- major user: >10.0 m3/hour (all permanently logged);
- medium user: 0.5–10.0 m3/hour;
- minor user: < 0.5 m3/hour.

Section 7.7 (Table 7.8) illustrates the effect of non-household customer use on DMA data.

In DMAs with a high proportion of industrial users, a volumetric check from meter readings should be made (from weekly volumes or night flows) to identify anomalous data.

Unmetered customers

In this category, leakage must be calculated on a per property basis. Unmetered consumers are classified as:

— unmetered households: defined as premises occupied by a customer and separately identified for billing purposes;
— unmetered non-households: customers having little or no night demand except that similar to a domestic property, e.g. tank filling, autoflushing toilets, and leakage from worn ball valves and faulty fittings.

Several companies are conducting night demand studies, using cul-de-sac meters or individual property meters, to confirm the standard recommended allowance of 1.7 l/p/h.

Monitoring equipment

A DMA monitoring system involves:

— the acquisition of data;

— the transmission of data from local sites to operations;
— the archiving and presentation of data and reports.

The system requires:

— a sensor, for gathering data at source;
— data logging equipment, for local site storage;
— a communication system, for transferring data to the operator;
— software, for archiving and presenting data.

Sensors

A typical monitoring system will include sensor capacity and interface leads for a range of DMA meters and pressure monitors:

— digital and analogue (e.g. 4–20mA, 0–1V) output;
— specific pulse heads for helix meters (e.g. Kent PD100 pulse disk bidirectional sensor);
— other proprietary sensors (HRP, LRP, reed switch, BPG20);
— optical sensors;
— magnetic sensors;
— pressure and depth transducers.

Data capture

Data capture requires the use of pulse generators, pulse counters and data loggers (portable or with telemetry) to capture data from the DMA meter.

Pulse generators

These are units attached to the register of a mechanical meter to provide a pulse output, in effect creating an electromechanical meter. Kent Meters supply the LRP (10 pulses/rev) and HRP (100 pulses/rev) units which are attached to the range of their helix meters. They are solid state units which have replaced the Kent PU10 and PU100. Wessex Electronics also supply a solid state unit, the “Metermate”, which will interface with any of the Kent helix meter range and any data logger.

Pulse counters/low-cost data loggers

These units are usually low-cost single or dual channel data loggers used to record pulse output signals. Their main use is as a temporary installation data logger to record night flows over several nights as an indicator of leakage prior to a full data logging exercise. They are also suitable for household and non-household demand logging. Some loggers can be mounted directly onto helix meters, eliminating the need for a pulse generator.

An outline specification for this type of logger is as follows:

- logging interval from 6 seconds to 60 minutes;
- 120 days memory at 15 minute intervals;
- submersible to IP68;
- temperature from –10 °C to +60 °C;
- digital input to support:
  — range of mechanical helix meters
  — electromechanical insertion probes
  — EM insertion probes
  — contact closure pulse units

— electronic pulse units used with a range of mechanical
— meters;
- pressure input facility to support:
  — 0–25 bar for distribution monitoring sensors
  — 0–350 millibar for reservoir depth sensors
  — range of electrical inputs;
- RS232 interface.

Data loggers

Data loggers are used to regularly monitor DMA flows on a 24-hour basis. They are dual or multi-channel, designed for permanent installation if required.

A suggested outline specification for this type of logger is as follows:

- logging interval from 1 second to 24 hours;
- 380 days memory at 15 minute intervals;
- submersible to IP68;
- shock proof from 1.0m drop;
- temperature from –10 °C to +60 °C;
- digital input to support:
  — range of mechanical helix meters
  — electromechanical insertion probes
  — EM insertion probes
  — contact closure pulse units
  — electronic pulse units used with a range of mechanical meters;
- pressure input facility to support:
  — 0–25 bar for distribution monitoring sensors
  — 0–350 millibar for reservoir depth sensors
  — range of electrical inputs;
- communications:
  — software selectable
  — local via RS232 interface, telemetry options;
- battery life 10 years (lithium chloride);
- alarm capacity.

It should be noted that some manufacturers supply data loggers with a sufficiently high specification to serve as both pulse counters and permanent data loggers. It is recommended that practitioners use the above specifications as a guide for selecting from a manufacturer the data logger suitable for the purpose.

All logger types should be compatible with the range of European and North American flowmeters which are now being used by the UK water industry for DMA monitoring. They should be able to receive digital and analogue signals so that they can also be used for pressure monitoring and level sensing, and with temporary insertion/clamp-on meter installations.

Data communication

Data is communicated from site by:

— site interrogation via a laptop or palmtop (e.g. Psion) computer;
— return of the data logger to the office for PC interrogation;
— telemetry, either via PSTN, GSM or Paknet.

Telemetry data logger

Telemetry loggers should be capable of linking to a range of communication systems. In addition to the data capture specifications listed above, they should have the option of:

— internal PSTN modem;
— GSM (Cellnet or Vodaphone) module;
— Paknet radio-pad.

An initiative by one water company (reported in "Water Bulletin", January 1998) involves connection via Vodaphone's wireless data network, using 1200 "Paknet Radio-Pad" connections (modem equivalent). It is claimed that purchase and installation of the radio network would cost 10% of a fixed line system, which can cost up to £3000 for a single connection. Line rental is also less (50% of a standard telecom line). The monitoring system uses ABB Kent-Taylor meters and a mix of Radcom and ABB data loggers. The antennae are housed in polyethylene pillars.

Individual manufacturers can provide more detailed specifications for their monitoring equipment. Leading manufacturers are listed in Annex 5.

Monitoring software and information systems

Software is required to arrange logged data into a form where it can be used for analysing and interpreting total night flow losses in each DMA.

Software for calculating and displaying total night flow losses is usually provided by logger manufacturers. Companies use manufacturers' software, or commission consultants, or use their own in-house facilities for writing software for leakage reports and for DMA management. Typical information required for these reports are:

— DMA details;
— DMA night flow data and aggregated flows;
— total night flow losses in each DMA;
— estimated leakage and priority DMAs;
— company leakage figure;
— historic burst records;
— repair times and cost.

DMA data identify unreported bursts (from sudden changes in volume) and cumulative leakage (from a combination of small bursts and weeping joints and fittings).

In a telemetered DMA system, night flow data can be received and analysed regularly. This enables changes in the night flow of each DMA to be quickly identified, reducing the awareness time. When compared with previous readings and with other DMAs, it enables the leakage control team to prioritize inspection. The logger software typically contains an "error table" which identifies those DMAs where night flows have increased above a pre-set alarm level. The leakage control team is able to scan the error table daily to identify unreported bursts or, in response to poor pressure complaints, to confirm a reported burst.

Software should be Windows-based, and should provide facilities for graphing and report generation to prioritize the work.

Data validation

Basic data should be validated each time a logger is downloaded, i.e. daily in the case of telemetered data, and weekly or monthly for manual downloading.

The following points should be checked:

— whether the logger has successfully downloaded and the data are correctly stored

in the filing system;
— whether there are data (if night flow is zero, check that there is flow at other times during the day);
— whether the data look reasonable.

The controlling software should be capable of flagging the first two points; it may be possible to automate the third point by setting limits and alarms, or some manual interpretation may be necessary.

If data for a particular site are not available, it should be possible to determine which parts of the reporting structure are affected, e.g. where a meter acts as an export from one DMA to another, the lack of data at this point would affect reporting from both DMAs.

Each company should adopt a strategy for such a problem. This could be:

— to disregard all reporting affected by data failure;
— to substitute “normal” or the most recent data for the site.

In any event, any loss of data should be highlighted, and the reason for the problem remedied as soon as possible.

Troubleshooting sensor/logger/meter combinations

A suggested troubleshooting kit will have the following:
— spare sensor(s);
— spare logger(s);
— plug-in telephone;
— mobile phone;
— pulse head tester;
— spare battery pack;
— logger displaying raw data (pulses in or analogue signal);
— small tool kit;
— laptop or Psion to download the logger.

Problem 1. Telemetry logger not communicating with software

- Call the logger directly on the handset. If there is sound at the logger modem, the problem is probably in the software or the office modem.
- If it is not possible to call the logger modem, get BT (British Telecom) or other telecom service to check the line.
- If the line checks out OK, a site visit is necessary.
- At the site, use the plug-in telephone to test the line. This can be done in both directions by calling to, and then from, a mobile phone.
- If the line checks out OK, install a spare logger and call it up with the mobile phone. If the sound of the modem is heard the problem will be in the original logger.
- Check the battery level on the original logger, reboot on-board software if possible, check for physical signs of a problem (water ingress, lightning strike). Return to manufacturer for repair or battery replacement as appropriate

Problem 2. Portable logger not communicating with software

- Check that the baud rates in software and logger match.
- Check that the download lead is not damaged.
- Check that the logger is not in a mode which stops communications.
- Check the battery level, reboot on-board software if possible, check for physical signs of a problem (water ingress, lightning strike). Return to manufacturer for repair or battery replacement as appropriate.

Problem 3. Logger records zeros

- Check whether the calibration in the software is set correctly.
- On site, check whether there is flow through the meter. If the meter is stationary when it should be recording the flow, check with operations staff for local valving or operations which shut out the meter.
- If the meter is recording the flow, plug the original sensor into the spare logger showing raw pulses or analogue signal and check if it is working. Alternatively, check the sensor by using a pulse head tester.
- If the sensor is faulty, replace with a spare and check whether the new sensor is working before leaving the site.
- Other causes may be lack of power, or failure of an in-line battery, in powered sensors for mechanical meters, and failure of the power supply (mains or battery) to EM meters.

Problem 4. Readings out by a factor of 10 or 100

- Check calibration of the logger and software. Units per pulse should be correct for the meter/sensor combination, for example:
  — 1 litre per pulse for PU100 with 80 mm Kent Helix 3000;
  — 10 litres per pulse for PU100 with 150 mm Kent Helix 3000;
  — 10 litres per pulse for LRP with 80 mm Kent Helix 3000.

This is a common problem when a sensor has been upgraded or replaced.

7.6 Responding to DMA data

Setting intervention policy

Intervention is the decision-making process for entering a DMA in order to inspect and locate any leaks, and for withdrawing from a DMA. The policy should be set so that:

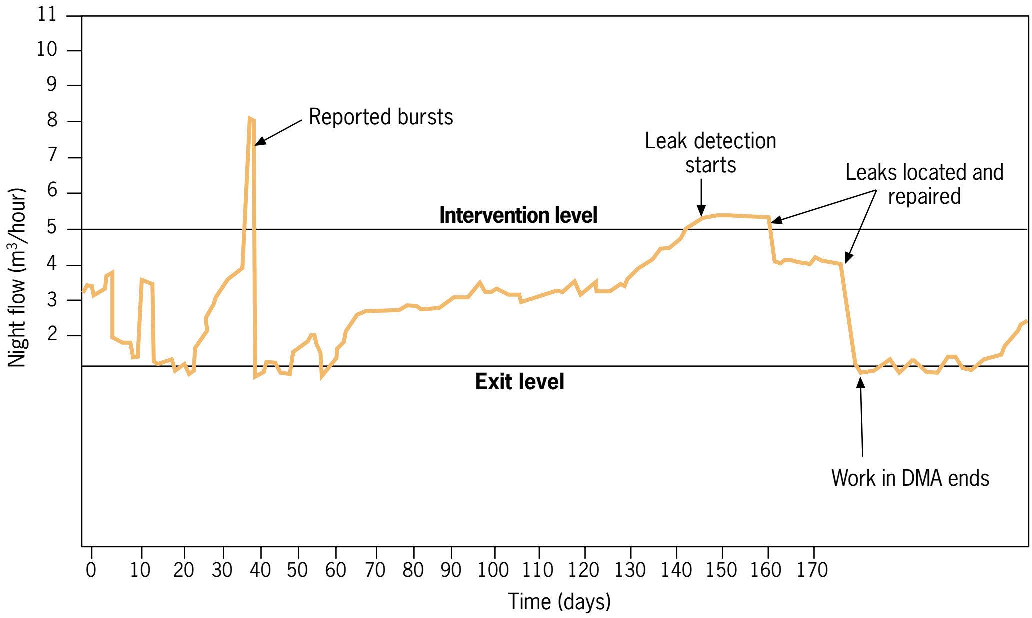
— intervention and exit policies are consistent with water supply zone and company leakage targets;
— it is achievable within each DMA;
— leakage is targeted in a cost-effective manner;
— it is understood by practitioners.

It should be possible in a DMA to convert leakage targets at the company level to local intervention and exit levels. However, in reality it is rarely possible to adhere to these targets strictly, as the amount of leakage control carried out in a given area is governed, in the short term, by the amount of leakage manpower available. Therefore the approach should be to balance the available resources with the area leakage targets and implement an intervention policy which will direct the leakage control staff, in the most cost-efficient way, to those DMAs where their intervention will be most cost-effective.

While water supply zone targets are annual average targets, DMA monitoring is over much shorter time scales and unreported leaks do not occur at a constant rate. Therefore, even given the correct staffing levels to achieve the annual leakage targets, the intervention and exit levels will not always be achieved.

Intervention and exit levels in a DMA are illustrated in the figure below. The intervention level is that level of night-flow losses at which leak detection should be started in a DMA to maintain a leakage target at company level. The exit level is that level of night-flow losses at which further leak detection and repair should be stopped in a given DMA. This is illustrated in Fig. 7.6.

Fig. 7.6 **Illustration of intervention and exit levels**



Data requirements

To understand, monitor and prioritize leak detection in a DMA using night flows, the following data are required, with the following priority:

- Number of households
- Properties with exceptional night use
- Number and type of non-households
- Average zone night pressure (AZNP)
- A measure of the background losses
- Population
- Length of mains
- Hour-to-day factor.

Note that this priority of data requirements will vary depending on local conditions. For example, in very rural areas the length of main may be important; or if the background losses have been directly measured, rather than inferred, then the AZNP is less important. If hour-to-day factors vary markedly and prioritization of districts is to be based on total losses, then the hour-to-day factor will become important.

Customer use estimates

There is an accepted method for calculating customer use, based on the methodology set out in the Managing Leakage series of reports. This is set out below. There are also variations on this method, which are also noted in this section. In addition, there are methods which use the short-term variations in night flow to estimate the total night use. These methods are not yet accepted, but may be more fully developed in the near future. These methods are not covered in detail in this section.

Customer use, by the *Managing Leakage* methodology, is divided into three categories as follows:

1. Exceptional night use

From the *Managing Leakage* series of reports, this is the sum of the night use by customers using >500 l/hr at min night flow. These customers can be identified from meter reading records. It is then usually necessary to log the customer meters at night, or read customer meters at one-hour intervals typically between 01:00 and 05:00 am.

Some customers will have consistent night use, while others will have night use which will change markedly from night to night, or week to week. This can usually be verified by asking the customer. If night use is variable for a large customer, several night flow meter readings or several meter loggings could be used.

A good proportion of exceptional use is due to isolated incidents, where a normally insignificant user uses >500 l/hr for only a few nights in a year. These should not be included as exceptional users. For example, a factory may use very significant amounts of water occasionally at night for maintenance operations.

Very large metered customers should have their meters measured as export meters from the DMA. This is especially important if night use is variable.

2. Household night use

The household night use can be estimated as follows:

Household night use = No. of households x Occupancy x Per capita night use

In *Managing Leakage* Report E the per capita night use allowance is 0.6 litres per hour per person. This is still seen as a reasonable value, but is derived from toilet flushing as the main night use element. Some companies are deriving their own values as a function of a wealth index. The occupancy rate is normally around 2.5 in England & Wales.

3. Non-household night use

To identify non-household night use in a DMA, it is useful to identify the non-households that lie within the DMA. *Managing Leakage* Report E gives a basic method for calculating non-household night use, as follows:

Non-household night use = No. of non-households x 8 litres/hour

It has been found that this calculation often underestimates the actual non-household night use.

Managing Leakage Report E also gives a more complex method, based on five categories of night user, as follows:

Non-household night use = Sum of (non-households in category x allowance for category)

The five categories and their allowances are shown in Table 7.3.

Table 7.3 **Non-household night use categories**

Category	Customer type	Night use allowance (l/hr)
A	Unmanned fire/police stations, telephone exchanges, banks, churches, chapels, gardens/allotments, market gardens, water and sewage treatment works	0.7
B	Shops, offices, craft centres, launderettes, depots, large domestic properties, guest houses, garages/filling stations, touring caravan sites, farms, smallholdings, cattle troughs	6.3
C	Hotels, schools/colleges, restaurants, cafes, public houses, social halls, residential caravan sites, livery stables	10.4
D	Hospitals, factories, public toilets, works sites	20.7
E	Old peoples homes, mines, quarries	60.6

Many companies have now derived their own allowances. These are of three types:

1. Based on SIC (standard industrial classification) codes, or on some other classification. Each classification has an associated per property night use allowance.
2. Where the night use allowance is a percentage of the metered annual use. The allowance used is typically between 20% and 40% of the metered annual use. The percentage will generally be based on the results of logging of a selection of metered non-households.
3. A combination of the above, where the night use allowance is a percentage of the metered annual use, but each category of customer has a different percentage. For example, the percentage may be larger for smaller non-households. Alternatively, the percentage may be larger in certain parts of a company where non-households are known to be more active at night.

The assignment of the non-household night use to DMAs can be carried out in one of two ways. The first method is to assign every non-household to its DMA explicitly. This is often done using billing records. The second method is to calculate a per property night use allowance using the sum of the night use allowance for households and non-households, divided by the total number of properties in the region. In this way, it is not necessary to assign non-households to DMAs.

It is important to note that most of the above methods for deriving non-household night use have been developed for use in leakage reporting at zone or regional level. There are inherent errors when applying these general relationships to DMAs or any other small region. Therefore it may be necessary to obtain more detailed data for the night use of certain companies. For example, a change in the shift pattern of a metered customer may lead to an apparent increase in night-flow losses. One way to obtain more detailed information is to include customer meters with variable night use as logged exports from the DMA.

Measuring minimum night flow

The minimum night flow is the lowest night flow into a DMA on each night. In simple DMAs this night flow will be from a single meter. However, in many cases the flow will be the aggregation of several import and export meters.

The night flow should be the average over a set time. The normal standard is one hour. If flows are measured for a longer period, such as two hours, then a correction should be made to the value. Managing Leakage Report E sets out the correction that should be made to the net night flow. These are set out in Table 7.4, but are not a reliable correction for all circumstances. If flows are measured over a shorter period, then a correction can be made in a similar way. However, the night flows will be more variable over this shorter period. The one hour period should be used if feasible.

Table 7.4 **Correction factors to change non one hour minimum night flows to one hour flow equivalents**

Measurement period	Multiplier for net night flow
15 minutes	1.02
30 minutes	1.01
1 hour	1.0
2 hours	0.98

The minimum night flow should be the one hour minimum of the aggregation of all the import and export meters, not the aggregation of the one hour minimum of all the meters.

Data verification

When minimum night flow data are received, and a minimum night flow is calculated which is above the target night flow (or would lead to the DMA being targeted for leak detection), several checks should be carried out by the leakage engineer before assigning leak detection crews to search for unreported bursts.

- *Night use allowance.* Night use allowances should be checked for obvious anomalies. This is especially important where the DMA is only recently set-up, or where changes have recently occurred in the DMA boundaries. (See "Boundary integrity" below)
- *Comparison with normal variations in night flow* in DMA, and length of time over which the increased flow has been measured. If an increase in night-flow occurs over a single night, it is normally good practice to await at least a second night's data before acting on the change.
- *Exceptional night use.* It may be possible to track down exceptional night use, especially if the night use patterns of the larger customers are known. For example, it may be worthwhile to find out whether night working has started in a particular premises. However, in many cases the exceptional night use is not readily detectable. In this case, the best option is usually to ensure that an increase in night flow is consistent before directing leak detection crews to the DMA.
- *Boundary integrity.* Sudden changes in minimum night flow are often caused by DMA boundary valves being opened or closed. If a sudden change in minimum night flow is seen, then a system should be in place so that those changes are communicated to the leakage engineer deciding on where to send leak detection staff. This system has two parts: the valve operation recording and communication to the leakage control staff. The valve operation recording system can be :

  — An electronic WIZ-key type system whereby changes in valve state are recorded automatically
  — A paper-based system
  — A GIS-based system where changes in valve state are recorded by the field staff on remote GIS outstations.

  The communication to the leakage engineer can be in the form of:
  — A note on DMA records that the DMA is breached and therefore the data is invalid
  — A paper or e-mail message that certain valves have been operated.

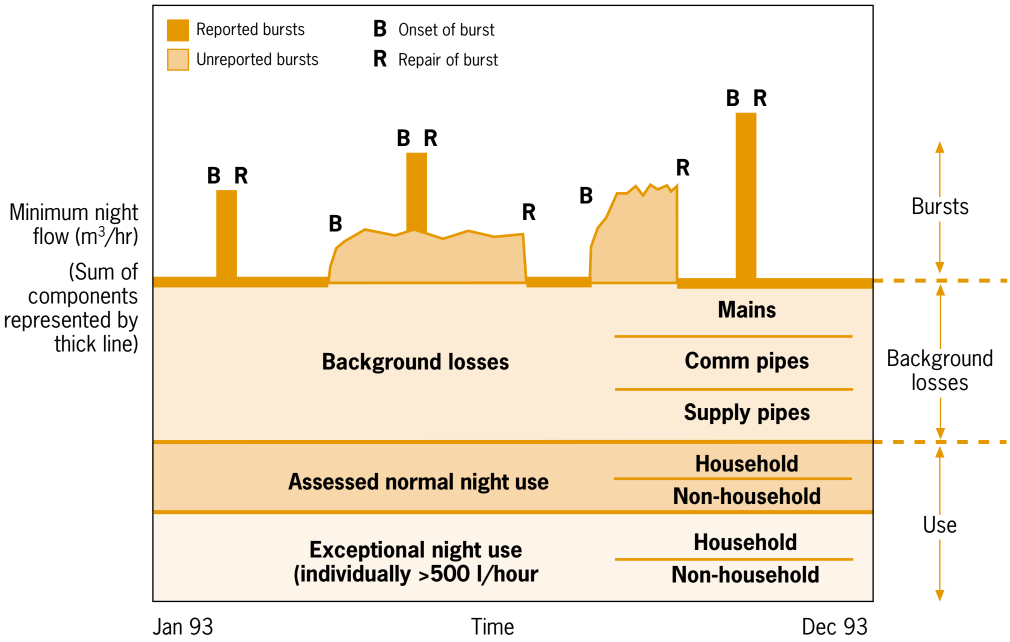
  Whichever system is used, it is important to have a system in place. This system will help to make leak detection staff more effective.
- *Reported burst repairs outstanding.* Any burst repairs outstanding in a DMA should be identifiable by the leakage engineer.
- *Metering.* It should be possible for the leakage engineer to know when data are missing from some meters making up the night flow in the DMA.
- *Changes in total daily flows.* If total daily flows into DMAs can be measured and reported, this can be checked to ensure that the increase in night-flow shows a corresponding increase in daily flows.

For most of these data verification checks the ability to graph DMA night flows and night flows through the meters making up those night flows is extremely useful.

Calculating excess losses

Using burst and background principles, the night flow into a DMA can be viewed as consisting of the following components:

Fig. 7.7 **Components of minimum night flow**



- Customer night use, made up of exceptional, non-household and household night use.
- Reported burst losses, made up of bursts on supply pipes, communication pipes and mains.
- Unreported burst losses, made up of bursts on supply pipes, communication pipes and mains.
- Background losses (L_B), made up of background on plumbing, underground supply pipes, communication pipes and mains.

These components are set out in Fig. 7.7.

It is the unreported burst losses that can be minimized by using DMA night flows to direct leak detection. To do this a measure of the unreported burst losses is needed. This measure is called the excess losses. To calculate the excess losses the other components must be measured or estimated.

Customer night use is described in Section 7.3. Reported burst losses are, by their nature, readily identifiable. Therefore an estimate of background losses is required. The background loss estimate at 50 metres used in the Managing Leakage series was:

LB (50m) (l/hr) = (4 x No. of properties) + (0.04 x metres of main)

A more flexible approach has been the following equation:

LB (50m) = ICF (4 x No. of properties) + (0.04 x metres of main)

ICF is the Infrastructure Condition Factor. Its value normally lies between 0.5 and 2.0, depending on the condition of the mains—0.5 if the mains are considered to be in good condition, or 2.0 if they are considered to be in poor condition from a water tightness point of view.

The background estimates also require a pressure correction using the average zone night pressure. There are several pressure correction factors (PCFs) in use. Two of the commonly used ones are given in Table 7.5. The Report 26 value was derived as a relationship between the pressure and night-flow losses. The 1.5 power law value was derived specifically for background losses.

Table 7.5 **Pressure correction factors for background losses**

AZNP (m)	PCF (report 26)	PCF (1.5 power law)
20	0.33	0.25
25	0.43	0.35
30	0.53	0.46
35	0.64	0.59
40	0.75	0.72
45	0.87	0.85
50	1.00	1.00
55	1.13	1.15
60	1.27	1.31
65	1.41	1.48
70	1.56	1.66
75	1.72	1.84
80	1.88	2.02
85	2.05	2.22
90	2.22	2.41

So, overall the background losses in a DMA could be given by:

LB = ICF x PCF x (4 x No. of properties) + (0.04 x metres of main)

An alternative estimate of the background losses can be made for each DMA by using the minimum achieved level of losses after leak detection is carried out. This works well where the leak detection has been intensive, but overestimates the background where leak detection has not been intensive enough to detect all unreported bursts.

A combination method could be used:

- where the ICF is calculated for each DMA;
- when the ICF is greater than a cut-off value, a default value is used and the background losses are calculated from that;
- when the ICF is less than the cut-off value, the minimum achieved losses are used as an estimate of the background.

An example calculation is given below.

Assessing background losses: an example

DMA data: Brandiswood high level

Population	2700
No. of households	1100
Length of mains	12570
No. of non-households	254
Average zone night pressure	58 m
Hour-to-day factor	21.6

For this district the background night flow losses (LB) could be estimated using:

LB = ICF x PCF x (4 x No. of properties) + (0.04 x metres of main)

The ICF could be set at between 0.5 (good condition) and 1.5 (poor condition), depending on the condition of the mains. In the present case there is no reliable information, so a value of 1.0 is chosen.

The PCF (see Table 7.5), using the power law method, is between 1.15 (at 55 metres) and 1.31 (at 60 metres). The AZNP (58 metres) is three fifths of the way between 55 and 60 metres, so the PCF should be three fifths of the way between them, i.e. PCF = 1.24.

The expected background night flow losses are therefore:

$$LB = 1.0 \times 1.24 \times (4 \times (1100 + 254)) + (0.04 \times 12570) = 7339 \text{ litres per hour}$$

This corresponds to 7.4 m^3 per hour in background night flow.

The night flow background losses for a DMA with 10 metres of main per property would be expected to vary as in Table 7.6 with AZNP and with condition. Table 7.6 demonstrates that the background losses can be very dependent upon both the condition of the infrastructure and the average zone night pressure.

Table 7.6 **Variation of night flow background losses with AZNP and condition**

	Background losses (l/prop/h) for infrastructure in:		
AZNP	Good condition	Average condition	Poor condition
	ICF = 0.5	**ICF = 1.0**	**ICF = 1.5**
20	0.6	1.1	1.7
30	1.0	2.0	3.1
40	1.6	3.1	4.7
50	2.2	4.4	6.6
60	2.9	5.8	8.7
70	3.6	7.3	10.9
80	4.5	8.9	13.4
90	5.3	10.6	15.9

[Note: on 10 m of mains/property]

Prioritizing DMAs for leak detection

The equivalent service pipe burst (ESPB) concept

There are several methods for prioritizing leakage detection from the results of DMA losses. Several of these methods use the concept of the equivalent service pipe burst (ESPB). Studies for the *Managing Leakage* reports showed that the median service pipe burst flow rate was 1.6 m^3/h at 50 metres pressure. This can be converted to a median flow rate in a DMA using a square root relationship, i.e.:

$$\text{Median service pipe burst flow rate } (m^3/hr) = 1.6.\ \sqrt{(AZNP/50)}$$

The excess night flow for each DMA can be expressed as a number of equivalent service pipe bursts. This gives an immediate indication of the maximum number of bursts which are to be looked for in each DMA, recognizing that a mains burst is equivalent to several service pipe bursts.

The danger of using ESPBs for prioritizing districts is that it is not directly equivalent to volume losses. It could prioritize leak detection in low pressure DMAs, whereas leak detection in higher pressure DMAs would be more productive.

Prioritizing methods

Some of the methods for prioritizing leakage detection from DMA losses are set out in Table 7.7.

Table 7.7 **Methods for prioritizing DMAs for leakage control**

Criteria	Comments
Increase in night-flow	A basic method, used when little DMA-specific information exists. Useful for controlling recurrence, but of little use in meeting leakage reduction targets
Total night-flow losses	Assumes that achievable leakage reductions are proportional to total losses. This is not consistent with burst and background principles. However, if the background estimates have low confidence, this method may be justifiable.
Excess night-flow losses	This is a useful measure, but ignores the variations in DMA sizes, so larger DMAs will be chosen by this method, when smaller DMAs may have higher per property excess losses. This measure should be used if there are high set-up costs and low per-property costs.
Excess losses per property	Gives a guide to how effective leak detection will be in the DMA. This targets the DMAs where leak detection should be most productive, but assumes that set-up costs are a small proportion of the cost of leak detection.
ESPBs from excess night-flow losses	Gives a guide to the number of bursts which need to be found. This assumes high set-up costs and low per-property costs. Because the ESPB flow rate is pressure corrected, this method will not necessarily prioritize districts with the highest excess losses.
ESPBs per 1000 properties from excess night-flow losses	Gives a guide to how effective leak detection will be in the DMA. This targets the DMAs where leak detection should be most productive, in terms of ESPBs found, but assumes that set-up costs are a small proportion of the cost of leak detection.
Marginal cost of excess night-flow losses	This gives a direct link to leakage economics, and directs leakage control to save costs most effectively. At a local level this is only useful if marginal costs are different across the area covered by a set of leakage control staff.
A function of excess total losses, using the hour-to-day factor for the DMA	This is the proper approach in principle. The methods above could be applied to this. However, note an hour-to-day factor for the excess losses is required for each DMA. This hour-to-day factor will be different to the hour-to-day factor used to calculate total losses.
Properties per ESPB	This is similar to the ESPBs per 1000 properties, in that it gives a guide to how effective leak detection might be.

There are several variations played on this theme. In particular, the criteria can be normalized by the number of properties. This gives a guide to the savings per stop-tap sounded. This is useful where set-up costs for detection in a particular DMA are small.

7.7 Dealing with problem DMAs

There are several types of problem DMAs, including:

— high apparent leakage;
— low apparent leakage;
— high burst frequency;
— water quality problems.

We shall concentrate here on the leakage-related problem DMAs. In this context, a problem DMA is defined as a DMA where the apparent leakage has remained high in spite of intensive leakage control activity and the application of normal DMA maintenance procedures.

The investigation and correction of the problem is in three, fairly distinct phases:

1. Ensure that leakage is actually the problem
2. Find the leakage
3. Remediation.

These are covered in three sections below. Before entering the investigation stage, each problem DMA should be assessed for the potential benefit of a detailed examination. If the DMA is small, and the value of the excess losses is small, then the investigation may not be worthwhile.

1. Ensure that leakage is actually the problem

There are many possible causes of apparently high leakage levels. The first task is to find out whether the problem is actually due to high leakage, or to some other cause. Some of the recommended actions are listed in Table 7.8. In essence, this task is a repeat of the checks carried out when a district is set up. If a discrepancy is found, further checks may still be worthwhile.

Table 7.8 **Actions to ensure that apparent leakage is real**

Action	Comments
1. Check the internal consistency of metering results	First, a simple water balance, using the total flows, and the losses calculated from night flows should balance approximately. Second, a check that the flows registered by the meter, and the flows used for leak calculation are the same. A simple way to do this would be to read the meter physically, twice, say 24 hours apart. The total flow through the meter from those readings could be recorded. This could be compared to the total flow over the same period using the system by which DMA leakage is calculated. If these values disagree, the system by which data get from the meter to the leakage calculation should be audited. This audit would include common problems such as an incorrect pulse unit multiplier. Third, the method by which meter readings are added to give a total flow into the DMA should be checked.
2. Check basic DMA data	The basic values used to calculate the leakage level should be checked. This includes all the allowances for household and non-household losses, the numbers of households and non-households, the exceptional users, and the data required for the background losses calculation.
3. Check the leakage calculation	Using the re-checked DMA data, and the re-checked night flow information, the excess night flow calculation should be re-performed independently of the normal leakage calculation software or system.
4. Check on metering errors	If the DMA has several metered imports and exports, then a calculation of the total metering error would be useful. If the total metering error, using a ± 5% error, would account for the excess leakage, then consideration should be given to either a redesign of the DMA to reduce the number of meters, or a replacement of those meters where fairly small percent errors would give large errors in reported leakage.
5. Check the boundary valves	Boundary valves should be checked in the same way as they would be checked when setting up a new DMA.
6. Perform the pressure zero test	A pressure zero test should be performed to ensure that no unknown connections exist that breach the DMA boundary.
7. Perform the DMA drop-test	If possible, a drop test should be performed to re-check the reported leakage from the DMA. The pressure at a pseudo AZNP point should be monitored during the test. The measured pressure during the drop-test can be used to correct the actual leakage level to give a leakage level that would have been found at the normal DMA AZNP.
8. Short- interval flow logging	Use a short-interval flow logging technique to calculate the time-variable night use. This may show that night use is higher (or lower) than assumed.

Action	Comments
9. Verify meter accuracy	Some of the import or export meters to a DMA may have flows that are verifiable indirectly using other meters or combinations of meters. However, there may be others where no verification is possible. In this case some verification of flows should be carried out. Verification could consist of replacement of the meter. After the meter is replaced, the new meter results should be used for a new leakage calculation. Another method may be the use of an insertion meter downstream of the existing meter, and comparing the flows recorded. Night-flows could be checked to ensure that no mechanical meters stall at minimum flow. If a stalling meter is an export, this could lead to apparent high leakage. The installation could be checked against manufacturers' recommendations. This includes the required length of straight pipe up and downstream, and situations where jetting could occur. The installation could also be checked for foreign bodies.
10. Illegal use	If the DMA contains metered non-households which could potentially use large volumes of water, a survey of these may find some illegal use.
11. Repairs	Check that repairs to reported leaks and bursts have been carried out.
12. Reconsider night use allowances	A list of un-metered non-households in the DMA should be examined to find large users who may not have been metered. When these are found, a meter should be installed, if possible, and night use monitored. Similarly, metered customers with potentially high night use should have their night use monitored. A physical survey of the DMA may be useful to find households with large night use. This may be true if, for example, there is a large proportion of shift workers in the DMA, or many large gardens which are watered at night.

2. Find the leakage

There are several methods available to find leakage, once it has been determined that the losses are real. These methods are detailed in Section 6. If these methods fail to find the leakage, then further investigation must use a technique to pin down the location(s) of the leakage to allow further leak detection to be more precisely targeted. This may be done by:

— step tests, or
— sub-metering.

Step-testing can be done in most DMAs, using one or more of the zone meters. This method is described in Section 9. However, there may be differences when using the technique in a problem DMA. This is because the leakage is obviously difficult to find. Therefore the leakage should be pinpointed as closely as possible. A more intensive approach could therefore include the following points:

— The customer night use should be assessed for each step as if it were a mini DMA.
— Records should be kept of the drop in night flow and the estimated night-flow losses in each step.
— Small steps should be used, down to individual streets if possible.
— Main feeds within the DMA should be covered in as much detail as the valving allows.

Sub-metering is only likely to be necessary where step tests cannot easily be carried out with the DMA meters, or the DMA is too large to allow accurate results to be gained, or the supply must be maintained to a customer and an alternative cannot be found during step-testing. There are also some supply systems where sub-meters are already in place.

As a result of step-testing or sub-metering, several lengths of main may be found with high night-flow losses. The lengths of main identified should be subjected to leak detection. The sum of these losses should be compared to the excess losses in the DMA. If there is a discrepancy, then any mains missing from the survey should be subjected to the same leak detection.

There are several other useful methods, which could be used to find leaks if they have not been used in the DMA. These include using pressure logging within the DMA to identify mains where large total head changes occur over short lengths of main. These data may be available from fieldwork for network modelling. Network models may also be used to model the effect on pressures of a leak. This might be used to give some guidance to leak detection crews.

3. Remediation

Any leaks detected above should be repaired. The date and time of the repair should be noted. The repair should be seen so that a gross estimate of the size of the leak can be made. The change in flow into the DMA and the minimum night flow before and after the repair should be noted. The AZNP should be monitored. The night flow should be monitored for several weeks after the repair.

As a result of the intensive leak detection and repair described above, there are several possible outcomes. These are shown in Table 7.9.

Table 7.9 **Outcomes from leak repair**

Outcome	Further actions
1. Leaks detected and repaired: night flow drops after repair by the same amount as step	No further action necessary
2. Leaks detected and repaired: night flow drops but by a smaller amount than expected	Further investigation of night use in step, investigate pressure reduction possibilities
3. Leaks detected and repaired: no drop in night flow or an increase	Look for new leak in DMA, investigate pressure reduction, consider service and/or mains replacement
4. Leaks detected and repaired: night flow drops but rises again	Look for new leak in DMA, investigate pressure reduction, consider service and/or mains replacement
5. Leaks not detected in length of main with high night-flow losses	Further investigation of night use in step, investigate pressure reduction, consider service and/or mains replacement

In all cases where the leakage does not drop substantially, pressure reduction should be considered, because of its effects on both burst frequency and losses from existing bursts and leaks. If the AZNP increases after the repair, this may give enough additional pressure at the critical point to allow some pressure reduction. This should be considered even if the AZNP reduction is only a few metres.

Mains and/or service replacement is probably the most reliable method to remove the short-term leakage problem. However, pressure reduction should be considered in parallel, because replacement of part of the infrastructure will probably lead to increased pressures on the remaining old infrastructure.

4. Burst frequency

In the case of DMAs where a problem of a high burst frequency exists (on mains, services or both), this frequently leads to a high incidence of water quality problems. The incidence of reported bursts does not appear to correlate well with high leakages at a street by street level. However, it may at a DMA level.

Two of the factors which influence burst frequency are pressure and variations in pressure. There is some evidence that burst frequency is approximately proportional to the cube of the AZNP. Therefore pressure reduction, as long as it can be permanently maintained, should be extremely effective at reducing burst frequency. It should also reduce the diurnal pressure variations.

References

1. Farley MR. *Leakage Control by District Metering*. WRC 1984.
2. Farley MR. *District Metering—System Design and Installation*. WRC Report ER 180, 1985.
3. Farley MR and Merrifield TE. *District Metering—System Operation*. WRC Report ER210E, 1987.
4. *Managing Leakage—Reports E and F.* 1994.
5. Farley MR. *Innovative ways to detect leakage*. IIR Conference—Water Pipelines and Network Management, UK, 1997.
6. *A Manual of DMA Practice.* UK Water Industry Research Ltd, 1998.

8. Pressure management

8.1 Design of pressure management areas (PMAs)

Selection of districts for pressure reduction should proceed hand-in-hand with the auditing of existing districts nd the setting up of new ones. Much of the district proving required for pressure reduction must also be carried out for the proving of DMAs. However, it may not always be possible to combine pressure reduction and DMA proving. Therefore this section can be used to set up pressure management areas (PMAs) independently of DMA proving.

The main objectives of pressure control in DMAs can be summarized as follows:

- reducing losses from existing and future leaks and bursts;
- reducing the frequency of bursts.

There are some subsidiary benefits, although schemes are rarely implemented within DMAs in order to achieve them, such as:

- reducing pressure to customers;
- reducing the pressure variations to customers;
- reducing pressure-dependent demand;
- protecting mains with low pressure ratings from bursts.

Selection and implementation of a PMA goes through the stages shown in Fig. 8.1. These stages are described in greater detail in the following subsections.

Initial scheme design

Schemes can be designed in two stages, with a selection process after the first stage, or in one process if no selection is to be carried out.

Schemes can include:

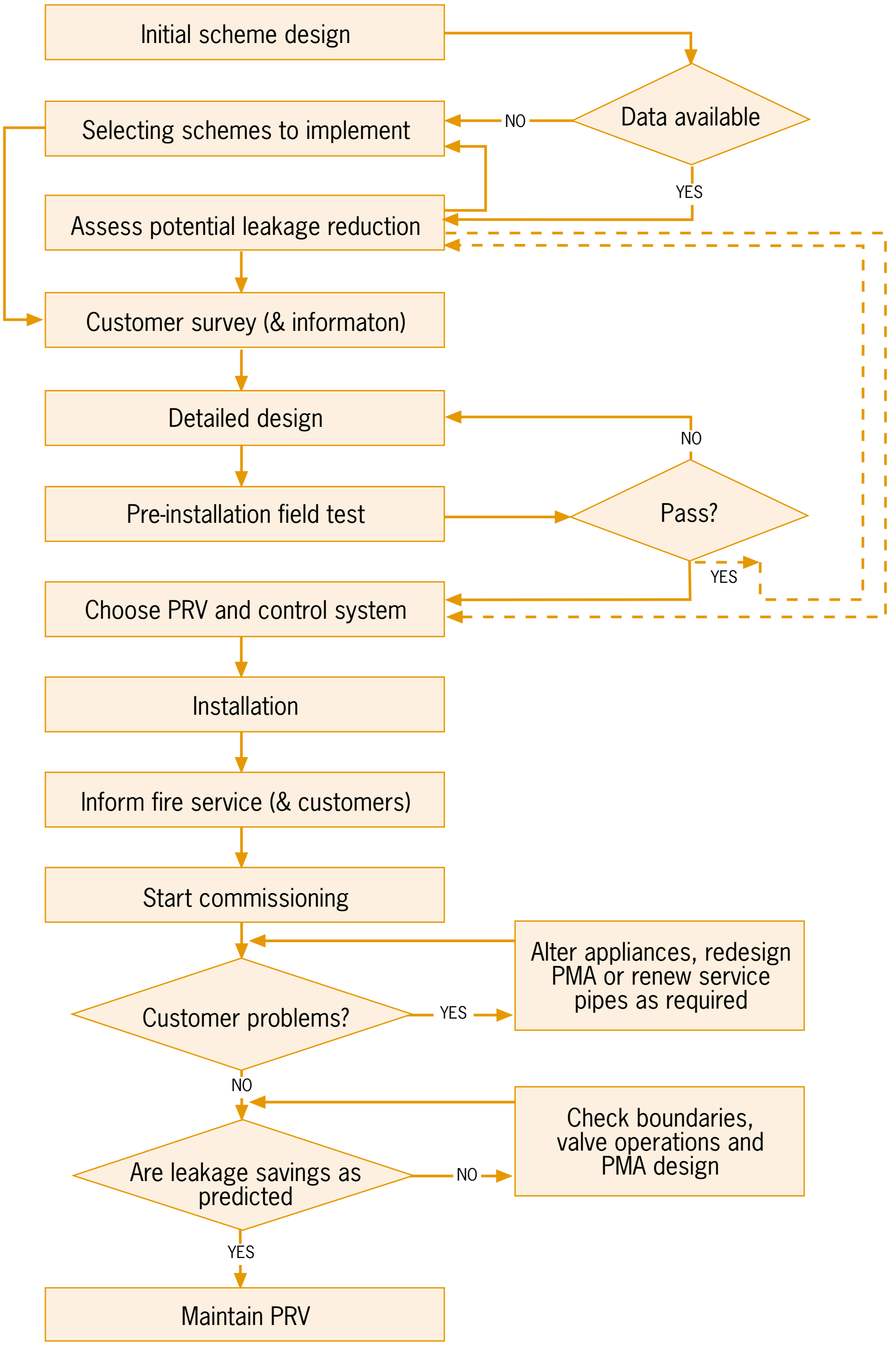
- new pressure-reduced areas;
- extensions to existing PMAs;
- existing PMAs with new control systems;
- boosters supplying one part of an existing or new PMA to allow further pressure reduction in another.

In a supply zone with several existing DMAs the potential for pressure reduction of whole DMAs can be examined by assessing pressures at critical points and AZNP points in zones.

Data from other sources can be used to assess schemes on a smaller scale. Data sources could include:

- asset management planning (AMP) studies;
- regulatory pressure monitoring points;
- network models and modelling field measurements;
- local knowledge;
- customer complaints;

Fig. 8.1 **Stages in PMA selection and design**

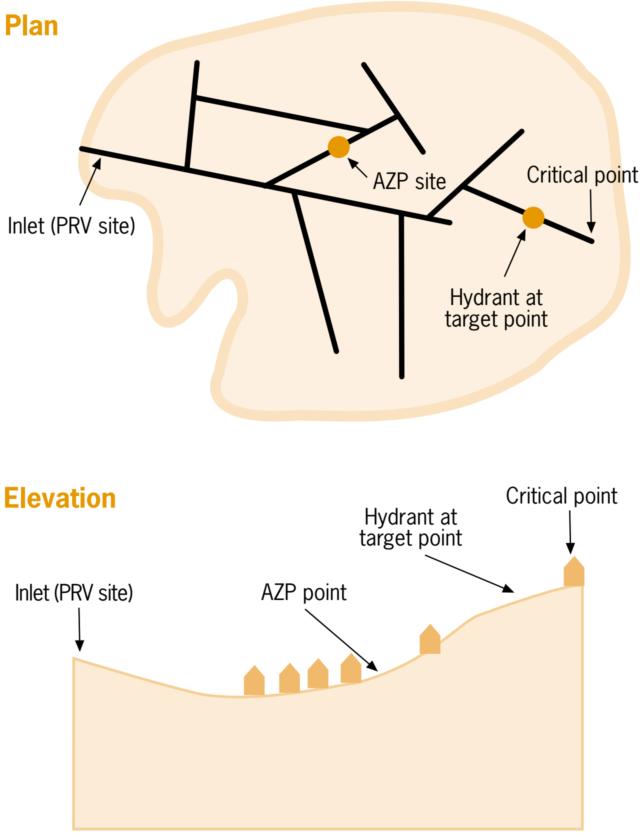


— GISs giving ground levels of properties. These can be combined with other system total head data, to identify potential schemes.

After the potential PMA has been identified, the boundary of the area should be defined. Basic data on the scheme should then be collected to allow schemes to be assessed. These data should include:

— the number of boundary valves identified from plans or GIS;
— the number of critical point(s) and elevations identified from plans or GIS;

Fig. 8.2 **A typical PMA**



— the pressure reduction potential at maximum flow identified from plans or GIS, using a best estimate of the current minimum pressure at the critical point(s);
— the total number of properties in the PMA, counted from GIS or plans;
— the number of PRV site(s) identified.

A typical PMA is illustrated in Fig. 8.2.

At this point the scheme could go through a selection stage, to compare its effectiveness with other schemes in the same supply zone, or to assess the scheme's effectiveness if the scheme is a one-off scheme.

Selecting schemes to implement

If potential schemes are to reduce pressure in all existing or new DMAs, most of the required data should be available to carry out a detailed assessment of the potential leakage reduction from the scheme. This is covered in more detail below.

If the scheme is small enough not to warrant DMA status, then an initial selection phase—with minimal data requirements—could be carried out on a comparative basis as part of a pressure-reduction project or on an individual scheme basis. Successful schemes could be assessed for potential leakage reduction when it is clear that it is worthwhile.

Comparative selection

Selection of schemes for pressure reduction may be done by assessing potential schemes throughout a supply zone. In this way, if marginal costs and headroom are equal across the zone, every scheme can be simply compared for its effectiveness on an equal footing. Possible methods are shown in Table 8.1 below.

Individual assessment

Individual schemes can be initially assessed for effectiveness in a number of ways, as shown in Table 8.1 below.

Table 8.1 **Assessment methods for selecting schemes to implement**

Method	Comments
Difference between the current minimum pressure at critical point and the minimum design pressure at target point	This is an assessment of the pressure reduction potential. A minimum value of 15 metres could be used as a cut-off. This method is excessively simple, and may exclude otherwise feasible schemes, especially where modulation could be used.
Ratio of maximum to minimum flows into the PMA	If this ratio is greater than 10, then the losses are likely to be small. Therefore this is a reasonable criterion to use. Another consideration is that the PRV may not be within its operating range at both flow rates. This requires flow rates to be known.
Effect of scheme on supply zone AZNP	This can be a useful measure when comparing PMA schemes within a supply zone.
Reduction in AZNP multiplied by the number of properties affected, also called 'property-metres'	A good simple reduction, but makes no allowance for burst reduction.
Cost per property metre	This gives a good measure of the benefit from each scheme. The cost per property metre should be minimized.

Assessment of potential leakage reduction

A system should be in place to assess the potential for leakage reduction in each scheme. This system should use the inlet, critical and AZP pressures and any flow data that are available to assess the potential leakage reduction and the cost per Ml/d of water saved. This assessment can be made at an early stage if the data are available, otherwise the schemes should be initially selected as described above, and then a more detailed assessment is made as the data become available.

The different control systems will each give a different saving, which can be assessed from the effect of the control system on the AZP over the day. A cost can be associated with each control system. This can be used to find the most cost-effective control system in a given PMA. There are several different methods used to make this assessment. There are a few software manuals available which will help in the selection and assessment of schemes.

Customer survey

If the selection stage has been completed, then the schemes selected must be designed in more detail. The customers who may be adversely affected by the scheme (both inside and outside the proposed PMA) should be surveyed. Customers who may be adversely affected include:

— occupiers of tall buildings. Supply should be maintained to the top floor of customer premises. Some industrial premises may have rooftop storage tanks. Very tall buildings will probably have their own pumps.

— industrial or commercial premises with sprinkler or fire-fighting equipment. The fire insurance cover is likely to be affected by a reduction in pressure, even if an adequate supply is maintained. The fire mains on these premises are likely to be fitted with low pressure alarms.

— customers with industrial processes dependent on mains pressure.
— customers requiring home dialysis. It should be ensured that these customers will receive adequate pressure and flow after pressure reduction.
— the fire service, to ensure that they know of the planned pressure reduction and ensure that adequate pressure and flow will exist at fire hydrants after pressure reduction. **Informing the fire service is a statutory obligation**.

As a result of this customer survey there are likely to be apparent limits to the pressures that customers are willing to accept. This will only affect the scheme if the customer pressure requirements would cause the minimum pressure at the existing critical point(s) to exceed the minimum pressure requirement. Whether to accede to such customer requirements is a matter for the company concerned to decide. If the company does, then the customer location may become a critical point.

If a customer with a particular pressure requirement exists, then it may be possible to redesign the scheme to put the customer outside the PMA.

Detailed design data requirements

The following data items will be required:

Item	Notes
1. The exact location and elevation of the proposed PRV(s)	The location(s) should be on a main(s) which will supply the proposed PMA at maximum flow. Power may be required to the site if telemetry or powered control systems are being considered. This should be considered during site selection.
2. The exact location and elevation of the target point(s)	The critical points will be those with the lowest minimum pressure. The target point will be a nearby pressure measurement point, normally a hydrant. There may be several critical points. These may be outside a critical customer premises (see above) or at the highest points or furthest points from the PRV. Allowance must be made when assessing pressures at the critical point if the target point is below or far from the critical point.
3. The minimum allowed daytime and night-time critical pressures	These should be defined by the company. They may be altered to fit local conditions
4. The property-weighted average zone elevation	This can be calculated from zone plans and contour maps.
5. A pseudo-AZP point location and elevation	This is a pressure measurement point which will give a pseudo-AZP. It should be at the average zone elevation and at a point of highest property density within the DMA. Alternatively, a point with the highest property density could be used, and the pressure corrected for the difference between the average elevation and the actual elevation.
6. Property counts, non-household counts and large metered customer data	This can be used to derive approximate customer use and losses for the PMA and to estimate night flow losses before and after pressure reduction.
7. Locations of boundary valves	These must be identified in the plans and found and marked on the ground.

Pre-installation field test

The next stage is to valve-in and test the PMA in the same way as a new DMA would be valved-in and tested. This is discussed in greater detail in Section 7.3. If the scheme consists of a whole DMA, then the boundary valves will still need to be confirmed as closed. The other checks, detailed in Section 7.3, will also be required unless the DMA has recently been audited.

The critical point pressures will be continually logged as the PMA boundary valves are closed. The critical point pressures will be checked after the valves are closed. The speed at which valving-in occurs depends on the local conditions and local policy. Pressures on each side of newly closed valves should be checked to ensure that there is no loss of supply due to unknown closed valves.

After valving-in, the flows and pressures can be measured, as shown below.

Item	Notes
Seven-day pressure records, at 15-minute intervals, at the PRV location, critical point(s), and pseudo-AZP point	These values can be logged for the exercise, or taken from recent fieldwork. However, it is important that the loggers are at the correct points, particularly for the PRV and critical point. In principle, the Average Zone Pressure could be derived from a suitable network model. A pseudo-AZP point has the advantage of allowing a measure of the effect of the pressure reduction after commissioning. Shorter logging intervals should be considered for critical points.
Seven-day flow records, at 15-minute intervals, at the PRV location (if a meter exists at that point)	This can be used to find losses and customer use for the PMA. If the PMA is part of a DMA, then DMA flows could be used to derive pseudo-PMA flows. Alternatively, property counts and AZNP could be used to estimate the losses.

Detailed assessment of the effectiveness of a pressure reduction scheme should be done at this stage if it has not yet been carried out. In PMAs which do not cover whole DMAs, the data will usually only become available at this stage.

8.2 Choice of PRV and control system

The criteria for PRV selection are as follows:

- — cost;
- — suitability for telemetry installation;
- — suitability for control systems;
- — ease of maintenance;
- — reliability:
- — availability;
- — operational range (flow and pressures);
- — stability of pressure output;
- — speed of reaction to flow changes.

The selection of a suitable valve should be made taking these criteria into consideration. The reduction in burst frequency from pressure reduction is only achieved if the pressure remains low. Therefore, stability of pressure output and speed of reaction to flow changes could be important. Stability is covered in greater detail elsewhere.

To maintain the outlet pressure during servicing, it is useful if the control system can be removed from service with the PRV still in service and maintaining a fixed setting.

The basic PRV designs fall into four categories:

- — spring-loaded diaphragm;
- — piston-operated;
- — diaphragm-operated;
- — flexible element.

Of these, the diaphragm-operated and flexible element PRVs are the most common designs for pressure reduction within DMAs. The spring-loaded diaphragm valves might be considered where the diurnal variations in inlet pressure and flow are small. Most diaphragm valves can be fitted with a range of control systems.

There are four basic types of control system:

- fixed outlet: this is the most common; the control system maintains a fixed set pressure downstream of the valve.
- flow controlled pressure modulation (mechanical or electronic): a modification to the control loop allows the valve to react to the changes in flow, so different outlet pressures can be set at different flow rates. This can be used either to maintain a pressure at a critical point or to switch between two outlet pressure settings at a threshold flow.
- time-controlled pressure modulation: this modification changes the downstream pressure according to the time. A common application is to reduce the outlet pressure at night and increase it during the day.
- remote-controlled pressure modulation: a telemetered signal from the critical point, or a control room, will control the downstream pressure. This can be used to maintain the pressure at a critical point at a given value.

These control systems can be fitted to a variety of basic pressure-reducing valves. In a PMA with only one feed, the remote-controlled modulation is unlikely to be required unless the diurnal pressure variation at the critical point(s) varies significantly from day to day.

The decision on which control system to use should be based upon the calculated savings from each one, compared to the cost of purchase, installation, maintenance and reliability.

The sizing of PRVs is determined using software or charts provided by the manufacturers. It is important to include the headlosses through the bypass assembly and to ensure that the full range of inlet pressures and flows (including peak summer flows and fire-fighting, for example) can be coped with. The process of calculating potential leakage reduction will determine the flow and pressure ranges required for the PRV sizing.

PRV installation

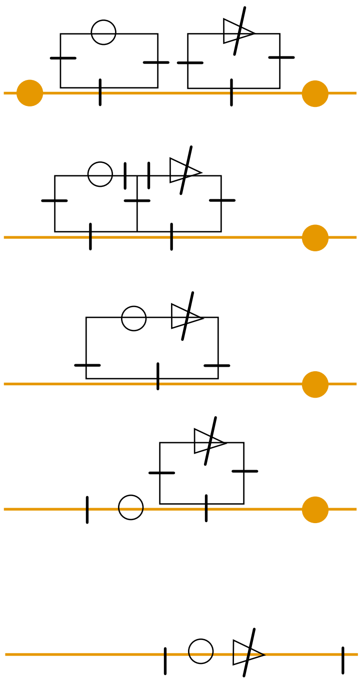
A PRV should usually be installed in a chamber so that maintenance, repair or modification can readily be carried out. Power may be required to the site if telemetry or powered control systems are being considered. This should be considered during site selection.

The cost of installing flow meters at the same time as a PRV is little more than the actual meter cost. The advantage is that the benefits of the pressure reduction can be measured and monitored. Some PRV control systems also require a meter. A disadvantage is that it is an extra asset to maintain. Whether to install a meter with a PRV is probably decided by the size of the PMA.

There are several options for installation design. The criteria which should used in selecting a design are:

- the cost;
- will the design interfere with the operation and accuracy of the meter and PRV?
- will the operation of the meter and PRV interfere with each other?
- ease of access for servicing and repair;
- ease of isolation for servicing and repair;
- is a strainer required to keep the meter and PRVs working effectively in the local water condition?
- can the cost be minimized without affecting the meter and PRV operation by the inclusion of a flow straightener?
- have the installation requirements of the meter and PRV been met?
- can the meter be calibrated in-situ?
- can the layout of pipe-work be easily understood from the layout of covers?

Fig. 8.3 **A selection of meter and PRV installation layouts**



Separate meter and PRV bypasses. High cost. allows meter and bypass to be separately isolated. Useful if no room for combined bypass on one site.

Combined bypasses. Allows meter and bypass to be separately isolated.

Low cost, with meter straight on to PRV. Flow straighteners are likely to be needed. Metered flows may not be accurate.

Meter in-line, where meter is low maintenance.

Low cost installation with meter straight on to PRV. Flow straighteners probably required. Low maintenance PRV and meter required. Metered flows may not be accurate.

A selection of potential meter and PRV layouts are shown in Fig. 8.3.

Commissioning

Before commissioning a PRV, the affected customers could be informed. This is a decision which must be made by the company concerned in the light of local conditions. The fire service must be informed before commissioning.

The PRV should be installed fully open at first. Commissioning of valves is carried out differently for different valve designs. The manufacturers provide guidance on commissioning.

Fixed outlet PRV

For a fixed outlet PRV, the valve should be commissioned and then the pressure reduced progressively towards the target pressure at peak demand over a period of days or weeks. The target point pressure should be monitored. The flow into the PMA should also be monitored.

Customers' complaints should be noted. If such complaints are received, the cause should be investigated. Further pressure reduction could be delayed until the causes are found and the pressure slightly increased, if it reduces the customer's problem. When the cause has been found and remedied, the pressure reduction should continue. Two of the most common causes of complaints are combination boilers failing and large headlosses down corroded service pipes. Discounted replacement or repair of these could be considered. When the customers' problems have been solved, pressure reduction should continue to the design target pressure.

If the reduction in flow into the PMA significantly exceeds the expected savings, this indicates that the PMA boundary may be breached. If this is the case, the boundary valves should be rechecked and unknown connections searched for.

Flow modulation

Where a modulation control unit is being installed, the valve should be commissioned in the same way as a fixed outlet valve. When the target minimum pressure has been achieved, the pressure profiles at the target point can be used to set up the modulation. From here the commissioning method will vary between systems.

Multi-feed PMAs

Multi-feed PMAs are fed by two or more PRVs, which are usually controlled by a telemetered reference to a critical point within the PMA. These systems are relatively rare at present, but the installation of more DMAs within cities makes their wider use inevitable.

Pressure-sustaining valves (PSVs)

Pressure-sustaining valves (PSVs) are used to sustain the pressure upstream of the valve above a given level by regulating the flow through the valve. The valve itself is identical to a PRV, but with a control system which responds to the upstream pressure rather than the downstream pressure.

These valves can be used where the demand on the export from an area causes the pressure in the area to fall below an acceptable level. This may be due to a large customer using water intermittently, or a burst on a downstream main. The PSV can be installed to maintain an acceptable pressure in the area. Before installing a PSV there are several effects to be considered:

— the effect on customers downstream in normal conditions;
— the fire service downstream;
— the potential increase in leakage upstream.

The treatment of customers in this situation should be similar to that when installing a PRV.

Pump control

Pumps could be considered in PMAs in two circumstances:

— where installation of a pump would allow further pressure reduction within a PMA. For example where a single property on a hill can only be supplied through a PMA;
— where changing an existing pumping regime would reduce the losses within a PMA. This could be the reduction of the pumping head, or modulation of the pumping head so that at low flows the AZP is reduced.

References

1. *Managing Leakage—Report G.* 1994.
2. *A Manual of DMA Practice.* UK Water Industry Research Ltd, 1998.

9. Leak detection and location

This Section describes the techniques for leak detection and location, and, where appropriate, the range of equipment to support each technique. The equipment is described in more detail in Section 10.

Definitions

There is a clear distinction between leak detection and leak location.

Leak **detection** is the "narrowing down" of a leak or leaks to a section of the pipe network. Leak detection activities may be carried out routinely, i.e. as a "blanket" survey of the network, or in precise areas of the network, guided by the analysis of DMA data.

Leak **location** is the identification of the position of a leak prior to excavation and repair, although finding the exact location cannot be guaranteed. Location surveys can be carried out with or without prior leak detection activity.

9.1 Leak detection techniques

There are a number of techniques to detect where leakage is taking place in the network, including:

- — sub-division of DMAs into smaller areas by temporarily closing valves or by installing meters;
- — variations of the traditional step-test;
- — the use of leak localizers;
- — sounding surveys.

All the techniques are explained in the following sections.

Sub-division of DMAs by internal valving

When monitoring shows that leakage has increased in a DMA, internal valving can be carried out to temporarily subdivide the DMA into smaller areas. If daytime closure of the valves causes supply problems they can be closed at night, and opened again before the morning high demand.

Each sub-area is monitored in turn using the DMA meter. The result of each subdivision can be monitored by installing flow data loggers at each input meter in advance of the test. In large DMAs further sub-division can take place over several nights (see step-testing). At the end of the test the logged flow rates can be compared with the sequence of sub-division of the DMA. Leaky sub-areas are inspected and "normal" subareas left alone. Fig. 9.1 shows a DMA being fed by three DMA meters, with internal valving to sub-divide the DMA.

Sub-division of DMAs by metering

In DMAs where sub-dividing would cause too much disruption, consideration can be given to installing a meter or meters on an internal boundary, as shown in Fig. 9.2. In

Fig. 9.1 **DMA sub-division by valving**

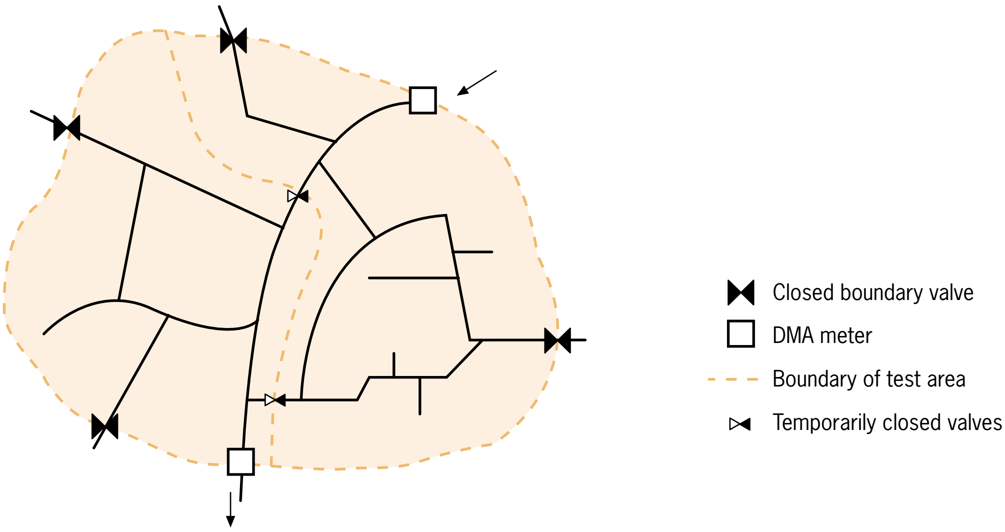
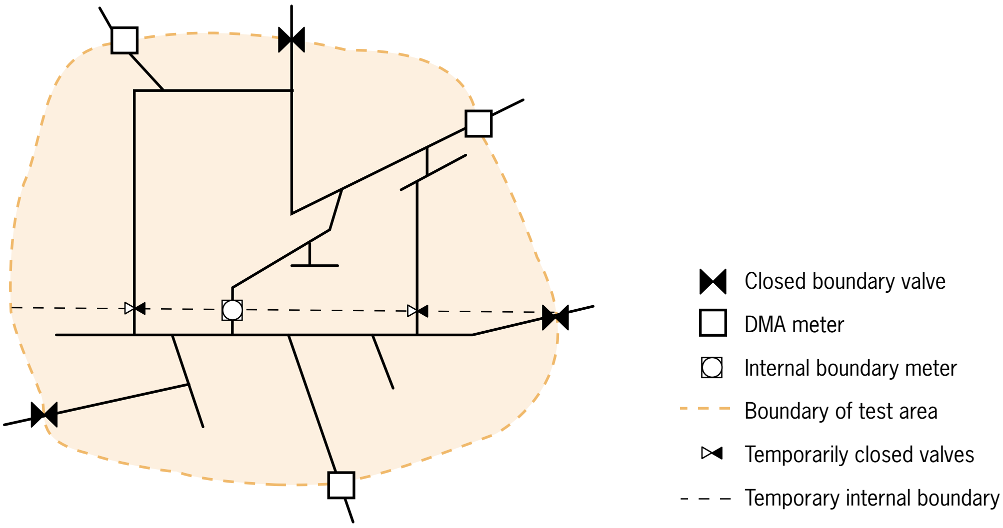


Fig. 9.2 **DMA sub-division by metering**



effect this creates two DMAs, one cascading into another.

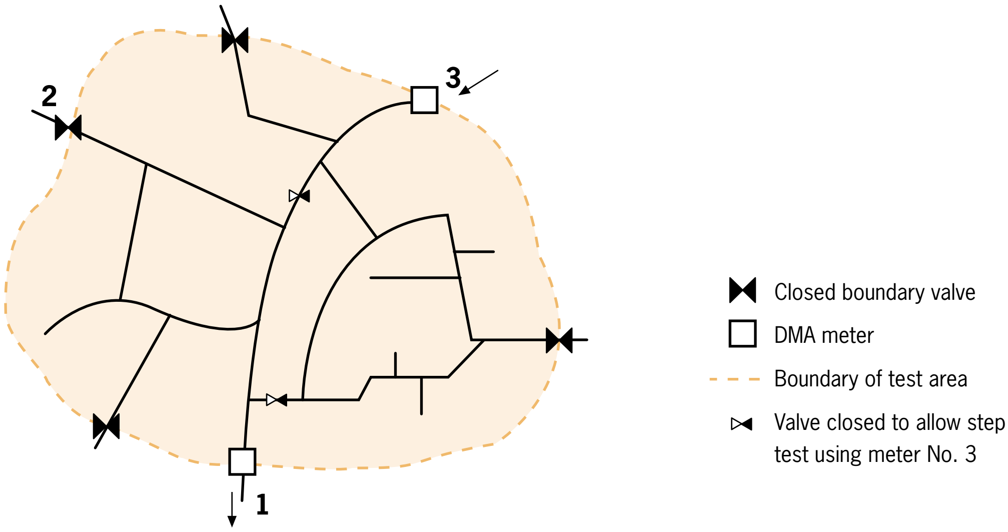
These meters would not normally be read, until DMA monitoring shows an increase in night flow. Internal valving may be carried out in conjunction with metering for further sub-division.

Step-testing

This technique has been used by the UK water industry for many years. It involves some advance work to design step test areas and to identify sections of pipework and valves. A flowmeter is installed on the input main to each area. The principle of the technique is to systematically reduce the size of the area by closing valves on each section of pipe in turn, at the same time noting changes in flow rate at the meter. A large drop in flow rate indicates a leak in the section of pipe which has just been closed.

There are two main types of step-test. The traditional technique is to progressively

Fig. 9.3 **DMA valved for step-testing**



shut valves, working back towards the meter, and then returning to open valves when the test is completed. This technique is less popular now because of interruptions to supply and the possibility of dirty water problems. A more recent technique, helped by improvement of flowmeter and data logger technology, is to use a series of short steps, isolating sections of the DMA for a short time only. This technique requires a remote meter reading device, either a radio or mobile phone, positioned at the meter. Flow rates are transmitted to the site operators, enabling them to see the results of the valve closure immediately, speed up the operation, and reduce the time the valves are left open. One man operation is also feasible, within the limits of health and safety guidelines (i.e. always two men operation at night)

This step-test principle is illustrated in Fig. 9.3.

The techniques of step-testing are well documented in Report 26. The procedures for setting up and operating step-test areas are still valid today. However, the technology for both monitoring and recording flows has advanced since the report was published. Step-test areas are now generally smaller (500–1000 properties), and are usually incorporated within larger DMAs, using the DMA meter for monitoring flows into the DMA and for carrying out step-tests in each area.

It should be noted, however, that some companies find that step-testing is no longer a viable technique, for the following reasons:

— step-tests require expensive overtime working, coupled with staff rest time for most of the following day;
— to comply with regulatory requirements, companies must warn customers of planned work, which is time- consuming and expensive (see Section 8);
— step-testing may cause bursts on weak mains and discoloured supplies.

The latter problem may be alleviated by flushing prior to the test.

Sections 7.36 to 7.44 of Report 26 contain a useful guide to establishing step-test areas within a DMA. The procedure is summarized below, with the terminology updated.

1. Establishing a step-test area

— Determine the number of properties in the area.
— Determine the number of metered customers who use water at night.
— Estimate the number of unmetered non-domestic customers, taking note of those

likely to use water at night (e.g. pubs, hotels, residential homes—see Sections 7.3 and 7.4).

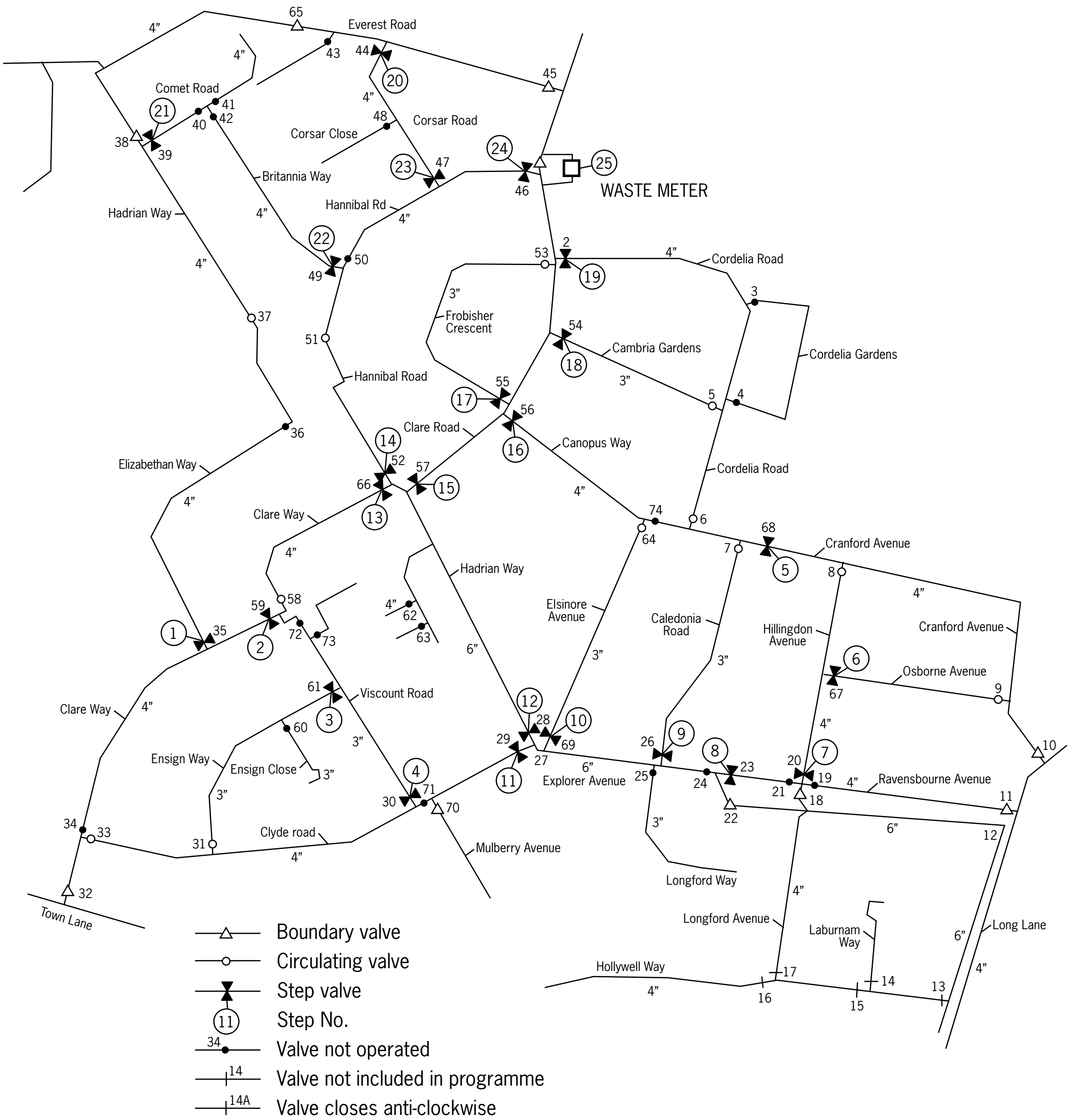
— Check the condition of valves to be operated during the test.
— Allocate numbers to the valves and note if they are closed clockwise or anti-clockwise.

2. Plans

Prepare a plan of the step-test area to show:

— road names and layout of pipes;
— meter installations and valves;
— boundary valves (closed to isolate the area from the DMA);
— circulating valves (closed to remove loops, to create a tree and branch network);

Fig. 9.4 **Plan of a step-test area** (reproduced from Report 26)



— step valves (operated during the step-test);
— all other valves, not used during the test, to avoid opening in error (e.g. DMA boundary valves);
— positions and details of commercial customers, with an estimate of their night use (to help later analysis of step- test data);
— valve numbers, status (closed or open), and direction of closing.

Plans should be kept waterproof in a clear plastic wallet. A detailed plan of a step-test area, reproduced from Report 26, is shown in Fig. 9.4 (note that "DMA meter" has replaced "waste meter" in the terminology).

3. Preparation for the test

— Consider a flushing programme to reduce water quality problems.
— Close as many valves as possible during the day without disrupting the customers' supply.
— Close the remaining valves at night before starting the test.
— Take the initial night flow reading.
— Where possible, turn off large night users or premises with tanks that fill overnight.
— Read the meters of those users, which cannot be turned off, and subtract from night flow (install data loggers if practicable).
— Check that at-risk customers and those with special needs are not disrupted.

4. Step-test procedure

a) *Isolation method.* In this method, the sections of the area downstream of the closed valve are without water during the test.

— Close the circulating valves.
— Starting with the step valve furthest from the meter, close the valves in succession so that less and less of the area is supplied via the meter.
— If any step valve is not drop tight, there will be no change to the flowrate until the next valve is closed.
— Follow the sequence of closing valves right up to the meter, when the flow should be zero.

b) *Close and open method.* In this method, the valves are closed at each step but re-opened once the meter reading has been noted. This overcomes the disadvantage of the isolation method, which can inconvenience night users. However, if a burst is identified on one of the steps, care should be taken when restoring the supply to avoid aerated or discoloured water.

c) *Backfeed method.* This method uses the same sequence of closing as the isolation method, but each time a valve is closed, another is opened behind it, starting with the boundary valves. This allows the water to backfeed from another part of the network, maintaining supplies to the area. However, while this method may have been acceptable in the early days of "waste metering", when step-test areas were closed in specifically for a test, it may not be acceptable now, when DMA boundary valves should be kept closed to maintain the accuracy of DMA flow data.

Appendix B of Report 26 gives a detailed check-list of procedures and equipment for preparing and carrying out a step test operation. Although the references to "waste meters" are no longer relevant, the Appendix provides a useful guide.

A typical sequence, practised by one water company, is as follows:

— step-test at night, unless during the day is unavoidable;
— close all boundary valves prior to the test;
— attach logger to the meter, programmed for 1-minute intervals;
— start at the point furthest away from the meter, recording the time of closure and valve details;
— sound each valve for tightness;
— work back towards the meter;
— each step is shut long enough to see the impact at the meter (typically 10 minutes);
— if an urban area with bulk users (e.g. hospitals), back-feed the area as each section is shut;
— re-open in reverse order, opening each valve slowly to avoid bursts;
— sound leaky sections during the day.

A typical time requirement for DMA with 25 steps is 4 hours 10 minutes (25 x 10 min.) plus operating time.

Leak localizing (noise logging)

This technique has become popular over the last few years, and practitioners are increasingly using the technique as an alternative to step-testing. The technique can also be used as a routine survey to "sweep" a zone. The equipment is supplied by several manufacturers (see Section 9 and Annex 5), and usually consists of a set of 5 or 6 microphones, each incorporating a logger. The units are magnetized to ensure contact between the sensor and the metal. Units are installed on a group of adjacent fittings (usually valves or hydrants), and are set to switch on automatically at a predetermined time. The loggers listen for and record the constant source of noise generated by a leak, usually over a 2-hour period. Because they are set out during the day and record the noise levels automatically at night, they have an advantage in busy or dangerous areas. The readings are analysed by comparison of sound levels and sound spreads recorded at each logger. This indicates whether there is a consistent anomaly at one or more of the fittings, requiring closer inspection in the vicinity of that hydrant. Proximity to a leak is typically represented by a high decibel level and narrow noise spread. However, when analysing logger results they should be compared with each other and not in isolation, in order to compare the significance of the results from the group.

Some manufacturers supply a hydrophone version of the logger, to give better sensitivity in the trunk mains.

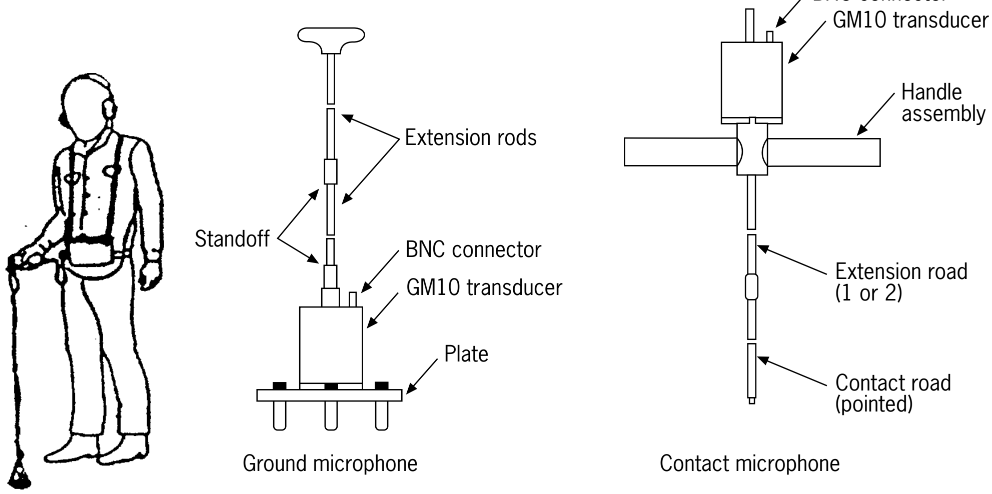
Case studies of the use of leak localizers by various water companies have been published by one of the manufacturers (Palmer Environmental—sales literature). The papers describe in detail the deployment of the loggers, and are illustrated with screen dumps of the results from logging exercises—these clearly show the variation in noise level and spread.

Sounding survey

Sounding is the systematic survey of a DMA, listening for leak noises on valves, hydrants, stop-taps or at the ground surface above the line of the pipe. A sounding survey can be carried out either as the follow-up stage to a leak detection exercise, or as a blanket survey of the whole DMA.

Although blanket sounding can be inefficient in terms of focusing on leaky areas, it does provide a systematic examination of the DMA, such as when a DMA is first commissioned. It also allows other non-leak faults to be identified.

Fig. 9.5 **Microphone in ground and contact modes**



Sounding surveys are carried out using various types of equipment, such as:

— a basic listening stick;
— an electronic listening stick;
— a ground microphone;
— a leak noise correlator (survey mode).

The basic instrument is the **sounding stick**, which is used either as a simple acoustic instrument or 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).

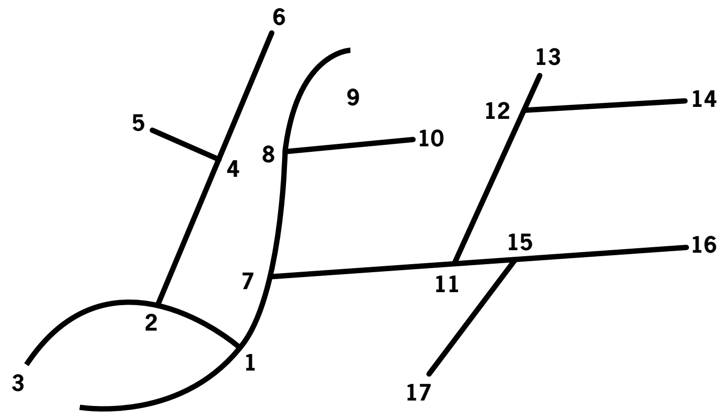
The **ground microphone** can be assembled for use in either of two modes, contact mode and survey mode. The contact mode is for sounding on fittings, similar to an electronic listening stick. The survey mode is used to search for leaks on lengths of pipeline between fittings. The technique involves placing the microphone on the ground at intervals along the pipe and noting the 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. Fig. 9.5 shows the assembly of the equipment in both modes.

Leak noise correlator

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 (maximum 500 m apart). 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 metre) in most sizes of pipe. The instrument is portable and can be operated by one man, and it has the capability for frequency selection and filtering. However, there are some leaks which the correlator has difficulty in locating, notably pipes which are low pressure, large diameter, non-metallic, and with infrequent contact points for microphone placement.

Fig. 9.6 **Correlator survey plan**



The correlator can be used in two modes:

— as a survey tool to detect leaks in sections of the pipeline;
— as a location tool to identify the leak position.

When using the correlator as a survey tool, a correlation peak shows that a leak noise is present. Before carrying out a correlator survey, a plan of the DMA should be prepared, showing the location of all valves and hydrants to be used in the survey. These should be numbered on the plan, and a Table prepared showing lengths of pipe by end numbers, and the estimated distance between locations.

An example of a two-man correlator survey is as follows: one operator carries the correlator and microphone and a copy of the plan. The other operator carries the second microphone. Both operators carry radios or mobile phones. The sequence is as follows:

— Operator 1 attaches the correlator and microphone to the first fitting.
— Operator 2 attaches the microphone to the second fitting and informs operator 1.
— Operator 1 carries out a correlation run and any resulting leaks are noted in the Table.
— Operator 1 informs operator 2 by radio to say when to move on to the next fitting.
— Operator 1 repositions the correlator for the next run.
— The sequence is repeated until the area is complete.

The correlator is used in location mode on those sections which appear to have leaks. The advantages of the correlator survey are:

— it is unaffected by ambient noise;
— unlike step-testing, it can be done during the day;
— the procedure takes only a little more time than valve and hydrant sounding.

Fig. 9.6 shows a plan for a typical correlator survey.

9.2 Leak location techniques

Leak location is the pin-pointing of a leak position once its has been identified from one of the detection techniques explained in section 9.2. The sounding stick, ground microphone, or leak noise correlator are used in exactly the same way as for leak detection, except that they are used more intensively in smaller areas of the network to track down the leak position. In the case of the correlator, “location” mode is used instead of “survey” mode.

There are also a number of other acoustic and non-acoustic location methods, which are usually used when acoustic methods fail to find the leak. Besides the well established gas-tracing technology, several new technologies are being developed and tested in trials by the water industry.

Gas injection

Gas injection and tracing techniques are used less frequently for leak location, mainly because the other techniques are successful in most cases. For the difficult leaks, however, particularly those in low-pressure, non-metallic trunk mains, gas injection is the next choice. An inert gas is injected into the pipeline, and is traced as it comes out of solution at the leak point. Because of the equipment needed to inject and trace the gas, however, it is more cumbersome than correlation, and is usually carried out by a specialist contractor. The most common tracer gases used are sulfur hexafluoride (SF_6) and industrial hydrogen (95% nitrogen, 5% hydrogen). The main disadvantage of the SF_6 technique is that bar-holes have to be made in the ground, at 1.0-metre intervals along the line of the pipe, to allow the gas to collect and be traced.

The main advantage of the hydrogen technique is the speed of tracing. The gas diffuses through the soil (and asphalt and concrete, but less quickly) as it comes out of solution, and rises to the surface, eliminating the need for bar-holing. From practical experience the main applications of the H_2 technique are:

— finding multiple small background leaks in a single section of pipe, e.g. during a step test;
— finding leaks in service pipes, which are relatively close to the surface, and which can contain unexpected loops and bends making accurate correlation difficult.

The tracer gas is injected into the network via a hydrant upstream of the suspected leak. The operator walks along the line of the pipe with a sensor, which is either hand-held or a surface probe. The sensor is microelectronic, and the manufacturer claims that no maintenance is required. The hand-held sensor is used for tracing on accessible pipes or fittings, the surface probe for tracing the gas close to the ground, along the line of the pipe. Details of manufacturers of the H_2 and SF_6 tracing equipment are contained in the Annex.

Other techniques

Several innovative techniques have been tried by the water industry as an alternative to the conventional techniques described above, usually to find difficult leaks, especially in trunk mains. The techniques include ground radar, thermal imaging, and in-pipe acoustic technology (e.g. WRc's "Sahara"). Some of the techniques are fully developed but are currently being tested in trials by the industry. Several water companies claim success with ground radar, and with thermal imaging, using an aircraft mounted camera to overfly rural trunk mains. Other techniques, like the "Sahara" are still being developed and tested by companies, and are not yet commercially available. A review of these innovative techniques was presented to a water industry seminar in 1997, and sets out case studies for the use of ground radar and thermal imaging techniques.

A review of leak detection and location techniques used by U.K. water industry practitioners was carried out for the National Leakage Initiative in 1994. This was reported in *Managing Leakage*—Report J.

Detailed operating procedures for leak detection and location equipment are contained in the manufacturers' operating manuals. A list of leading manufacturers of equipment are given at the end of this Section (see below).

Some manufacturers also give training courses in techniques and equipment for leak detection and location.

Procedures for planning and implementing leak detection, location and repair activities

A typical procedure practised by one water company consists of three stages:

- Planning
- Leak detection and location
- Leak repair

The planning stage includes the principles of DMA monitoring and analysis:

— review nightline;
— identify the DMA with the highest nightline;
— check that the nightlines are not high for other reasons (flushing exercise, outstanding mains or service pipe repairs);
— access plans of DMA, and identify boundary valves and metered users, customers with special needs, etc.;
— check PRV operation if applicable;
— check boundary valves and carry out a zero pressure test on anomalies;
— close the open boundary valves and check that all valves are tight;
— check the nightline again and if still high, calculate the ESPBs (equivalent service pipe bursts);
— go to leak detection and location procedure.

The leak detection and location procedure is summarized in Fig. 9.7.

Case Study 1. Leak detection and location survey

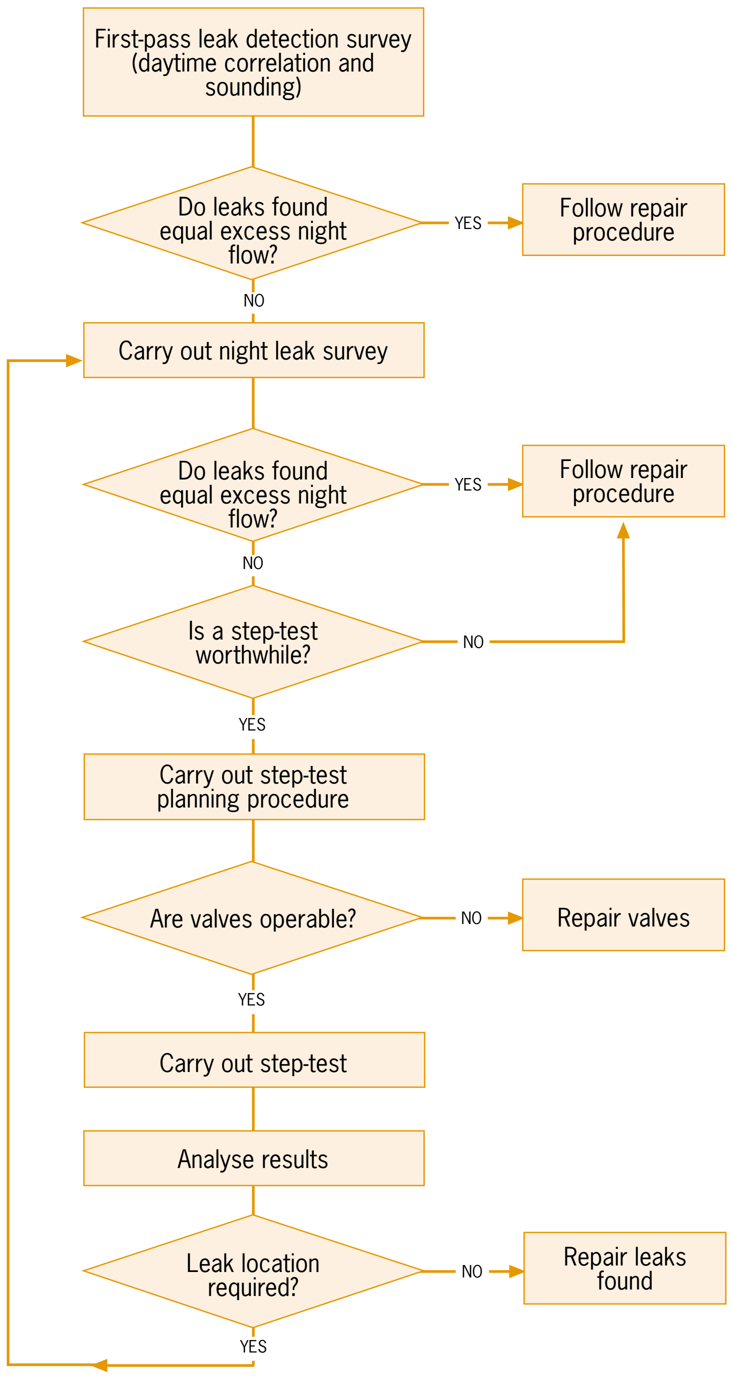
This case study describes leak detection and location activities carried out by one water company, following analysis of nightline data. It highlights how a leak detection survey is complemented by daytime location, and discusses the relative advantages and disadvantages of daytime and night sounding.

Sounding at night

This technique is practised mainly in urban areas. The company uses six-man teams of "night surveyors" who carry out a sounding survey. Each team surveys sluice valves, fire hydrants and stop taps equivalent to about 2500 properties per week (including time for gaining access to chambers). All leak sounds discovered during the night survey are passed to a core of skilled daytime inspectors who carry out full leak location. The use of night teams for surveying only has the following advantages:

— less ambient noise at night (easier to identify leak sounds);
— less customer use (fewer draw-off sounds);
— leak sounds are checked twice, once at night and once during the day (confirming leaks rather than use);
— night teams are dedicated to sounding survey and not leak location (survey rate maintained at 2500 properties per week);
— the day team is fully utilized in leak location rather than detection surveys (better use of skills and equipment);
— areas with high volumes of road traffic can be surveyed at night, followed by the location team in the early hours of the same morning (eliminates the need for work on accumulated leaks, usually carried out in the early hours of Sunday morning).

Fig. 9.7 **A typical leak detection and location procedure**



Daytime leak location

It is not always practicable to use night survey teams, e.g. when there are few access points in the network, as in some rural areas. Other methods of leak detection and location are used in these circumstances, such as:

— correlation surveys on lengths of main;
— sounding of distribution fittings by day inspectors;
— use of acoustic data loggers which can be deployed as required.

Case Study 2. Technique determined by area

This study describes how a water company chooses techniques for urban/rural and large/small DMAs. Table 9.1 summarizes the techniques used by DMA type.

Town centres. Town centre investigations are normally carried out by the night team. In exceptional circumstances the day inspectors may be used on overtime.

Larger urban areas. Some of these may incorporate old "waste districts". Data loggers are temporarily fitted to the meters and the district is split into sub-areas to highlight high flows. An Aqualog and/or correlator survey is carried out to break the area into manageable sections. This is followed up with stick sounding and/or correlation to identify leaks.

Larger rural areas. Large areas—typically with long lengths of main and fewer properties—are normally step-tested. An Aqualog or correlator survey is carried out on sections which recorded large drops. The area is progressively broken down into smaller sections which are then sounded or correlated.

Small urban/small rural areas. In these areas the leakage inspector usually decides the technique.

First-pass survey. For all types of area, first-pass techniques are usually instigated by the supervisor in charge of leakage inspectors. A step-test, correlator survey or Aqualog survey may be carried out in the DMA prior to carrying out more detailed investigation. This applies particularly to larger DMAs. In small DMAs the inspector takes responsibility for the technique used.

Table 9.1 **Techniques used by DMA type**

DMA type	First-pass investigation	Second-pass investigation	Follow-up	Comments
Town centre	LNC	Sounding	LNC survey	Investigations normally carried out at night
Large urban	Run waste districts/ Aqualog or LNC survey	Stick sounding/leak noise correlation to pinpoint leaks	LNC survey	
Small urban	Sounding	LNC/stick sounding	LNC survey/stick sounding	
Large rural	Step-test/Aqualogs	Aqualogs/LNC	Check NFN	
Small rural	Sounding	LNC/sounding	LNC survey/stick sounding	

References and further reading

1. *District Metering—System Operation.* M. Farley, WRc Report ER210E, UK, 1986, Pub WRc.
2. *Leakage control, policy and practice* (Report 26), cited before in Section 1.3.
3. *The Use of Aqualog Noise Loggers to Solve a Difficult Urban Leakage Problem* (Palmer Environmental sales literature).
4. *Innovative Ways to Detect Leakage.* M. Farley, IIR Seminar, London, UK, 1997, Pub IIR.
5. *Managing Leakage*, Report J—Leakage management techniques, technology and training (see Section 1.3).

9.3 Equipment for leak detection and location

A review of the equipment

Table 9.2 presents one water company's review of currently available equipment for leak detection and location.

Table 9.2 **Equipment for leak detection and location**

Equipment	Comments/Application	Limitations
'Basic' listening stick	Rudimentary sounding of SVs, FHs, MSTs, etc.	Some smaller leak sounds may go undetected (inspector must have a good ear)
'Electronic' listening stick	General sounding of SVs, FHs, MSTs, etc. Better than 'Basic' stick due to sound amplification. Is sometimes used to confirm 'best leak sound' position after correlation	Few limitations, generally useful part of the inspector's 'tool kit'. Better than 'Basic' stick; not as good as ground microphone (see below)
Electronic ground microphone	More sensitive than the electronic stick. Generally used to confirm 'best leak sound' after correlation. Powerful enough to listen to leak sounds through 'made roadways'. Can be used for general sounding with a probe screwed into the microphone	More 'cumbersome' to use than the listening stick. Some inspectors do not like to use microphones, but prefer the electronic stick
Electronic ground microphone with sound frequency filters	As sensitive as the ground microphone, with the added advantage of the inspector being able to adjust filters and remove some unwanted sounds. Generally used to confirm 'best leak sound' after correlation. Powerful enough to listen to leak sounds through 'made roadways'. Can be used for general sounding with a probe screwed into the microphone	More cumbersome to use than the listening stick. Some inspectors do not like to use microphones, but prefer the electronic stick
Acoustic detection loggers	'Stores' sounds within the distribution system usually between 02:00 and 04:00. Loggers are set up and downloaded using a PC. Leak sounds are identified by the 'range' of sounds recorded by the logger. Useful for areas where normal leak location activities cannot be used	Does not locate actual leak position, can give identification that leak is taking place
Step-test unit	Mobile Advanced Step Tester (MAST) system. Used for remote monitoring of flows while carrying out step-tests within distribution networks. Allows almost instant results of valve closure leading to minimum disruption to customers. Leak location activity can be carried out quickly rather than waiting for 'office-based' analysis of step-tests using data loggers. Can also be used for remote monitoring of pressure during valve closure (critical node monitoring while setting up PMAs or DMAs)	Valve closure required, may cause discoloration/water quality problems. Difficult to use during the day as some disruption to supplies will take place (unless areas are 'back fed' when valve closure takes place). Step-tests need to be planned to gain best results

Equipment	Comments/Application	Limitations
Leak noise correlators (various)	Used for general 'surveying' of lengths of main for leak sounds followed by more accurate leak location. Various 'models' available from easy-to-use menu-driven machines to PC-controlled FFT machines for more 'difficult' jobs. Sensitive enough for quiet leak sounds. Can survey long lengths of main rather than manual sounding of individual valves. PC-based correlator can be used for other applications including on-site interrogation of flow/ pressure data loggers, acoustic data loggers. PCs can be loaded with 'mobile' graphical information systems providing inspectors with distribution system drawings	Very accurate when all data inputs can be guaranteed. Limited to the fact that main material, length, and velocities can cause errors in calculations if not accurately entered. A reasonable level of inspector training, skill and experi ence are required for use. The better the information, the better the result
Hydrogen gas detection method	Identifies leak position by detecting the location of hydrogen gas which has been introduced into the water supply. The hydrogen gas (carried in 95% nitrogen) rises to the surface above the leak position. Due to the small size of hydrogen molecules the gas can permeate concrete, asphalt, etc. Provides accurate leak location as the gas rises above the break in the pipe	Best suited to locating leaks on smaller pipes (ideal for difficult supply pipe leak locations). Pipework is de-watered by the introduction of the gas. Gas needs to be introduced by using either a boundary meter box and forcing the gas towards the property or closing the boundary connection and introducing the gas through the customers internal stop tap. Can take some time to set up and for the gas to rise to the surface for detection
'Flexi Trace'	Enables non-metallic pipework to be located by the insertion of a flexible 'wire'. Once inserted in the pipe a signal is induced either at the leading point of the trace wire or throughout its length. This signal can then be traced using a cable avoidance tool	The trace wire has to be inserted into the bore of the pipe, leading to a possible contamination risk. Hygiene care needs to be taken when using the trace. Trace will not pass sharp bends or T bends. When obstructions are met, the pipe has to be excavated, the pipe cut and trace re-inserted
Pipe & cable locating/avoiding tools	Used for locating cables and pipework	Not suitable for plastic pipes unless 'flexi' trace is used
Other pipe-tracing equipment	A 'vibrating' sound can be induced in the pipe to be traced via equipment attached to a hydrant. The pipe is traced by listening on the surface for the sound being transmitted down the pipe	There could be complaints about noise in the pipes when in use. Some argument about possible damage to the pipe by vibration

Equipment manufacturers

This section summarizes the equipment for leak detection and location commonly used by the water industry in the United Kingdom. It lists the current models supplied, and approximate prices (as at March 1998).

Leak detection equipment	Approx. cost (£ sterling)
■ Step test units	
Biwater Spectrascan "Aqualink"	4600
Palmer "Mobile Advanced Step Test" unit (MAST)	6000
Wessex Electronics "Tele-link/Tele-log"	4500–5500
■ Leak localizers	
Biwater Spectrascan "Spectralisten"	6000
Palmer "Aqualog 40"/"Aqualog 50"	7000
Sewerin (PCL) SePem	4500

Leak location equipment	Approx. cost (£ sterling)
■ Simple sounding stick	
Palmer "ST 20"	80
Commercial Industrial Gauges (wooden)	
■ Electronic sounding stick	
Biwater Spectrascan "Stethaphone"	280
Fuji Tecom FSD-7D	280
Palmer "LS 5"	400
Sewerin (PCL) Stethophon	195–250
■ Ground microphone	
Biwater Spectrascan (for use with Aquacorr)	750
Fuji Tecom HG-10	1200
Palmer "MK5"	1700
Sewerin (PCL) Aquaphon Memotech	2000
■ Leak noise correlator	
Biwater Spectrascan "Aquacorr"	6350
Palmer "MicroCorr 6"	12000–14000
Palmer "MicroCall" (portable PC-based correlator)	13000–16000
Palmer "Corralog Leak Manager" (incorporates flow/pressure loggers and step-test unit and ground microphone)	6000
Primayer "Eureka"	5000
Sewerin (PCL) SeCorr 03	6000–6500
Sewerin (PCL) SeCorr 04 (portable PC-based)	9000–11000

References

1. Farley MR and Merrifield TE. *District Metering—System Operation*. WRC Report ER210E, 1987.
2. *Managing Leakage—Report J*. 1994.
3. Farley MR. *Innovative ways to detect leakage*. IIR Conference—Water Pipelines and Network Management, UK, 1997.
4. *A Manual of DMA Practice*. UK Water Industry Research Ltd, 1998.

ANNEX 1

Example of a workshop programme to demonstrate strategy development

A planned strategy and trained staff are required before a project to reduce water losses can be implemented. This example of a workshop programme, which was presented to the Chonburi Public Waterworks Authority (PWA) in Thailand, describes both these aspects—strategy development and staff training.

1. Objectives and scope of the project

The PWA's goal is to reduce Non-Revenue Water (NRW) to a level of 25% (or less) of the Distribution Input (DI) by introducing a water loss management strategy, using system monitoring facilities and management support tools.

Current losses in the Chonburi PWA, estimated at 33% (*Bangkok Post*, 17 November 1997—data from *Water* magazine), are due to physical losses from an aging pipe network and non-physical losses such as theft from illegal connections, meter errors and under-collection of revenue. This estimate is almost certainly on the low side. However, the strategy set out in the terms of reference of PWA provides a sound plan for (i) assessing the relative significance of physical and non-physical losses, (ii) monitoring leakages in the distribution network, and (iii) transferring skills to PWA staff so that the project can be sustained.

The first task—the strategy study—is to verify the true figures for production and consumption, and to make a detailed analysis of the causes of water loss. A programme to achieve reductions in both physical and non-physical losses will then be designed. This will help the PWA to set accurate and achievable targets for leakage control in individual zones, which are a realistic goal for the company based on the true figures.

2. Training and transfer of skills

The principal aim of the programme is to put in place a leakage management strategy which will reduce water loss from the present level down to 25%. It is acknowledged in the terms of reference that one of the essential tools of the strategy is training of local staff in the skills and techniques of leakage management, which include:

— measurement and estimation of water loss and leakage;
— designation of leakage monitoring districts;
— analysis and interpretation of leakage data;
— detection, location and repair of leaks;
— plans for rehabilitation of pipework;
— operation and maintenance of the plant and equipment.

Staff training includes motivation and transfer of skills in the techniques and technology of leakage management, and in system operation and maintenance. The following sections describe the basic principles and approach for meeting these objectives, and for ensuring a sustainable leakage management strategy.

3. Approach

The tasks, problems and constraints associated with introducing a leakage management programme are the concern of all levels within the PWA project team. The senior management level should support all the tasks involved and see that workers at the operations level fully understand the programme's principles and design, and the steps in implementation of the project. The training programme will therefore include awareness seminars for senior staff (and for raising public awareness), training workshops for engineering and technical staff, and continuous practical training for operations staff.

Awareness seminars. A carefully planned and targeted awareness seminar is the first step in the training programme. The main aim of the seminar should be to brief the senior managers and decision-makers on the aims of the project, the steps required to implement it, and the plans for staff training. Once perception has been raised at the top, motivation will be enhanced at all levels of the organization. The participants will be given an overview of the issues and methodologies, the objectives and cost-benefits of a leakage management policy, and the steps required to introduce one. While they may be more interested in the financial and institutional aspects of the programme and in the benefits of increased operational efficiency, they will also be given an overview of the technical aspects.

Training workshops. The aim of these workshops is to ensure that within the constraints of the system, recommendations for best practice are made, and skills are transferred to the engineers and technical staff responsible for managing and controlling leakage. It is unlikely that one workshop will be able to raise the awareness of the whole range of PWA staff. Workshops will therefore be tailored to serve each category of staff—for example, engineers will be made aware of management issues, in addition to benefiting from those modules with a practical and technical approach. Technical and operational staff would be made aware of the programme's stages and requirements, followed by hands-on skills training. Workshops for operational staff would be modular, covering particular aspects of leakage management, such as meter calibration, flow measurement, and pressure control (data logging) as a precursor to the field training programme.

Continuous practical training. This is for operational staff who are responsible for leakage management in the field. It is structured in modules, each module covering a particular task or skill to reinforce the workshop training. Training in the field requires a long-term view, with continuous repetitive exercises.

It is important to integrate continuous training with the ongoing leakage management programme, so that trainees will work alongside contractors and consultants at selected times. This on-the-job training will result in an efficient transfer of skills and an understanding of the day-to-day operational tasks with their own problems and solutions.

Programmes for the seminars, workshops and continuous practical training will be designed, bearing in mind the needs of the various groups of staff and their respective requirements.

National seminar. A national leakage seminar should be held to raise the government's and public awareness of the PWA's goals and achievements. The timing of this seminar will depend on the project's milestones, but a suitable time would be at the end of the project after the strategy has been implemented, data have been gathered, and the targets have been attained.

In summary, the integrated approach comprises:

1. Carefully planned awareness seminars and training workshops for all the staff.
2. Practical training, both formal courses and while on the job, to acquire the skills for all leakage management tasks.
3. Coordination of practical on-the-job training with key stages of the programme.
4. A national seminar, and other events contributing to raise the PWA profile.

4. The Programme

The preliminary seminars and workshops are conducted at the start of the programme to explain the concepts and principles of leakage management. The seminar at the end of the programme will update all the staff on the results of implementing the strategy.

Practical training courses and on-the-job training will be phased—following the initial seminars and workshops to help develop the skills for leakage management and continuing, with repetitions to reinforce the learning process, throughout the project. The training items will be complementary to each stage of the project; for example, training concerned with the design of district meter areas (DMAs), pressure management, flow meter installation, and data capture will coincide with the implementation stage, while training in DMA management, records management, and equipment maintenance will be appropriate during the later maintenance stage. However, some overlap is inevitable, as maintenance training for certain elements of the system will need to be in place during the implementation stage. Field training in pipe and leak detection techniques can start immediately to maximize leakage reduction, but will span all stages.

Continuous practical training will proceed throughout the life of the programme. At first, training will be intensive and repetitive, until the trainees reach a standard of competence and confidence to take over responsibility. Their supervision will gradually be replaced by monitoring, and selected project staff will eventually be in a position to become trainers themselves.

4.1 Programme content

Awareness seminars (1 day). A typical seminar programme provides an overview of:

- — the principles and concepts of leakage management (DMAs and night flow monitoring);
- — the latest research findings from the UK National Leakage Initiative and the *Managing Leakage* reports;
- — water balance components and calculation;
- — economic principles (leakage targets, optimum levels, alternative strategies).

Training workshops (5 days each). Specific tasks for managing the strategy will be encompassed in the areas covered by the four workshop modules, as follows:

- *Module 1* (1 day)
  - — Principles and concepts of leakage management
  - — Choosing a strategy (economic analysis)
  - — Optimum leakage levels and targets
  - — Understanding the components of water balance.
- *Module 2* (1 day)
  - — Advantages of continual night flow monitoring
  - — Design of district meter areas (DMAs)
  - — Design of pressure management schemes.
- *Module 3* (1 day)
  - — Flow measurement and data capture
  - — Data analysis and interpretation
  - — Prioritization of leak detection activities.
- *Module 4* (2 days)
  - — Principles of leak detection: techniques and equipment
  - — Practical training in pipe location and leak detection
  - — Managing and operating a DMA scheme
  - — Requirements for operation and maintenance.

Practical skills training (continuous training)

1. Flow monitoring
   — Understanding metering principles
   — Flow data capture (data logging)
   — Data analysis and interpretation (prioritizing leak location work).
2. Leak detection techniques and technology
   — Location of pipes and fittings
   — Leak detection techniques and equipment (e.g. step-testing)
   — Leak location techniques and equipment (e.g. ground microphone, correlator).
3. Operation and maintenance of a leakage management system
   — Keeping records of plans and data
   — Maintaining a DMA system
   — Maintenance of meters and equipment.

In addition, the continuous training will include tasks while on the job for selected project staff guided by their counterparts (among the consultants and contractors) at certain stages of the study. These tasks include:

— calculating water balance and analysing the components;
— meter audit and calibration procedures;
— leakage studies:
— pressure management studies and PRV installation;
— DMA design and implementation;
— network rehabilitation studies and techniques;
— pipe repair techniques.

5. Staffing

A training consultant and a trainer, whose roles are described below, will be provided for the duration of the project.

Training consultant

At the start of the project, the training consultant will liaise with the PWA project team to identify and allocate PWA staff to appropriate tasks for training, and to agree on timings, venues, etc. of all the training sessions. The consultant's specific duties will be to:

— liaise with the PWA project team;
— organize and conduct the awareness seminars and training workshops;
— organize and monitor the continuous practical training;
— supervise the work of the trainer (see below);
— identify milestones and targets against which trainees can be assessed;
— implement a suitable certification scheme for trainees;
— ensure coordination by integrating the continuous training with the steps of the ongoing leakage management programme;
— provide the PWA project team with regular progress reports;
— advise the PWA project team on the organization of a national seminar and other profile-raising measures.

The consultant would receive continuous inputs during the first 3–4 weeks of the programme, with intermittent advisory, supervisory and monitoring inputs during the implementation stages of the project.

Trainer

The trainer's role will be to:

— assist the training consultant in designing and implementing the training courses;
— organize all practical field training and transfer of skills;
— ensure that the continuous hands-on training is integrated with the stages of the ongoing leakage management programme;
— liaise with PWA leakage control teams to ensure consistent practice and continuity;
— assess the progress and achievements of trainees against agreed targets and standards;
— deputise for the training consultant when necessary, particularly for liaison with the PWA project team.

It is expected that the trainer would receive continuous inputs for the life of the project.

6. Implementation of a strategy study (months 1–3)

Review of components of water loss and inception report

This review would entail measurement of water into supply and water consumed by a number of different methods ("within the constraints of practically achievable and realistic measurements and assessments") to calculate an accurate figure for the components of water loss, and in particular to determine the significance of leakage and the other components through the following:

— calibrate or check existing production meters;
— check existing bulk meters;
— carry out reservoir drop tests;
— check pump curves or unmeasured production with insertion meters;
— check the metered consumption (sample of consumer meters checked for accuracy and under-registration at low flows);
— check illegal use, operational use, unmeasured supplies, and reservoir overflows;
— carry out night flow measurements in sample zones (1000 households) to determine leakage levels in the distribution system;
— achieve water balance and recalculate the total volume of non-revenue water (NRW);
— estimate leakage;
— measure the system pressures;
— write the inception report;
— advise on the type of equipment required, and assist with quotations, purchase, and installation.

The review would include an assessment of the water company's current water loss management practices, system features and characteristics, local political, social, and economic influences, etc. This would be achieved by:

a) Discussions with 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, demand, topography, supply arrangements);
— drawings and records, billing data;
— estimates of total water loss;
— estimates of leakage and other water loss components (illegal connections);

— current practice (staffing structure, staff numbers and skills);
— techniques and equipment;
— repair programme;
— economic data (cost of production, etc.).

c) Field visits to appraise current practice and skills.

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

7. Design and implementation of district metering (months 6–10)

Pilot areas

Two or three pilot zones are designed, where the results and benefits of water loss and leakage reduction can be demonstrated early on in the project. These also serve as a data collection area and a training /demonstration ground for a range of leakage control methodologies and equipment. Cost data and benefits can be calculated so that the most economic option for the company can be chosen. The pilot areas could also be used to test the efficacy of a range of pipe renovation methods on leakage reduction.

Implementation of leakage monitoring

Network models are used to design and implement district meter areas (DMAs)—discrete zones of 1000 to 3000 households, each with a permanent boundary—monitored via flowmeters, so that increases in night flow can be observed and the zones prioritized for leak detection activity. Pilot areas may be used to get experience of design implementation. Each DMA will have its own operational target night flow, derived from night flow measurements and estimates of background and bursts losses.

ANNEX 2

Workshop case study

Guidance notes for trainers

This case study is based on a consultant's report of a training workshop, sponsored by the World Bank, in Hanoi, Vietnam, in 1995 for participants from the Vietnamese water industry. The format of this workshop has successfully been used for other World Bank projects, as well as WHO projects in Pakistan, Vietnam, and Samoa and the Cook Islands in the South Pacific. The participants were first instructed in the principles for developing action plans and then asked to develop their own plans.

This case study should be used by the trainer, together with section 7.3 (DMA management), to advise the participants on the preparation of action plans.

1. Course objectives and format

The course was attended by 27 participants representing 17 water supply companies in the north of Vietnam. The majority were Directors, Vice Directors, and Heads of Departments (Technical, Financial, and Planning).

The primary objective of the course was to enable each participant to design a short-term and medium-term programme to reduce water loss in his or her particular company. This was achieved by bringing together persons from different water companies, with common problems, so that ideas could be developed during group discussions using examples of successes, which some participants had achieved in pilot projects of their company. The Consultant's task was to be a facilitator—the aim was not to compare Vietnamese practice with other countries, nor to dwell too much on the technology of leakage monitoring and detection because the Vietnamese water industry was currently practising the lowest level of leakage control activity (i.e. repair of visible leaks only). The aim was to encourage the participants to develop their own sustainable solutions, and to build on what they have rather than devise solutions which are unworkable or unaffordable. Thus, during the course the participants had to:

- examine the scale of water loss;
- identify the causal factors;
- assess the relative significance of non-physical and physical losses;
- review appropriate tools, methodologies, and equipment to support programmes to reduce water loss;
- design programmes which were feasible and sustainable for the Vietnamese economy, culture, and institutional organization.

The participants were encouraged to discuss openly the constraints and weaknesses (and also the strengths) of their system's characteristics and existing procedures, and to propose only those solutions or actions which could be realistically implemented.

The format of the course was designed to give the participants the opportunity to learn not only about water loss problems and solutions in countries outside Vietnam, but also—through discussions with colleagues, case study material, and results from pilot areas—to gain an understanding of what can be achieved in Vietnam. This would help them to select ideas and methodologies that could be tested in their own companies and could form the basis of an action plan. This was achieved by a mix of lectures, discussions in working groups, and case study examples. Each participant was also given a translation of the World Bank's *Working Guidelines on the Reduction and Control of Unaccounted-for Water.*

By the end of the course, the participants should be able to design, for their individual companies:

- An immediate action plan
- A two-year programme for non-physical losses
- A five-year plan for physical losses.

Some companies had already started programmes to reduce water loss, and these were consolidated and supported by the course material and discussions with colleagues during the week.

This training course was supported by the Ministry of Construction, which had previously announced its intention of encouraging and financing water loss control programmes.

2. Course programme

Day 1

The course was opened by Dr Pham Sy Liem, Vice-Minister for Construction, who emphasized the timeliness of the course, as the Ministry was now making water companies more accountable for water loss. Each company was required to present its programme to reduce water loss to the Ministry by the end of the year. A review of these programmes will therefore include a measure of the effectiveness of this training course. The government's support measures are discussed more fully in Session 1 of Day 5.

After the Minister's opening remarks, the course began with presentations from the Consultant which provided an introduction to unaccounted-for water.

Session 1. Components of Water Loss

The session began with a review of water loss figures for countries worldwide, comparisons between developed and developing countries, and the ratios of physical to non-physical losses contributing to the percentage of total water loss. Data from a recent survey by the International Water Supply Association were used for this presentation. This enabled the Vietnamese practitioners to compare their own company and national figures with those of other countries. The components of water loss were then addressed—these range from physical losses, like leakage and reservoir overflows, to non-physical losses, such as meter under-registration or misreading, illegal connections, consumer waste, and underestimates of use. Participants were divided into two discussion groups and asked to consider which components were most significant in the Vietnamese water industry. From the presentations that followed this exercise, a number of important points arose:

a) Water loss in Vietnamese water supply organizations ranges from 35% to 70% of production.

b) Non-physical losses are generally higher than leakage from the distribution system.

c) The main components of the non-physical losses are:
— meter under-registration caused by inaccurate recording at low flows;
— meters not working (broken, worn out or deliberately damaged);

— theft of water from illegal connections (also badly made, thereby increasing leakage) or from by-passed meters;
— waste of water from consumers on flat-rate tariff.

In addition, there is some loss of revenue from meter readers who do not bill the consumer for the full amount, or who do not pass on all the revenue collected.

Most companies had no means of accurately measuring production or consumption owing to:

— lack of production or bulk meters measuring flows into the distribution system;
— inadequate or inaccurate consumer meters.

The figure given by companies for % water loss were therefore based on estimates of production and consumption.

Two priority tasks identified by the participants for the immediate action plan were:

(i) to check production meters;
(ii) to address consumer metering policy.

Session 2. Factors influencing Water Loss

This Session examined the range and relative importance of factors contributing to water loss. These were grouped into four categories—Resources, Infrastructure, Institutional Policy, and Leakage Control Activity. Following a presentation by the Consultant on the influencing factors in each category, the participants were asked to form their discussion groups and identify the factors which influenced water loss control in Vietnam. The results of these discussions would be used to devise additional priorities and requirements for the immediate action plan and the 2- and 5-year programmes.

To facilitate their work the participants were given listed guidelines on a translated OHP slide and were directed to selected texts in the World Bank Guidelines.

At the end of this exercise each participant was asked to give a short presentation describing his or her own water company's supply and distribution system, highlighting particular characteristics, problem areas, reasons for water loss, and contributing factors. The presentations helped the participants to understand the range of problems and potential solutions experienced by colleagues with their systems, and also enabled the Consultant to pitch the rest of the course content at the appropriate level for conditions in Vietnam.

Day 2

Session 1. Non-physical Losses

This session gave participants the opportunity to discuss and consolidate the factors contributing to non-physical losses in Vietnam. These are:

— wasteful use by consumers on the flat-rate tariff;
— illegal connections;
— illegal use (deliberate damage to meters, by-passing meters, deliberate under-registration by low flowrate use);
— under-registration (meter oversizing, inaccurate meters);
— non-working meters (damage by particulate matter, poor quality meters).

In addition, there is widespread loss of revenue influenced by the dubious practice of meter reading, billing, and revenue collection all being performed by the same employee. This leads to misreading, misbilling or non-billing, and withholding of collected revenue. Some companies are trying to overcome this factor by imposing stricter controls and supervision on the meter readers.

Session 2. Physical Losses and Detection Techniques

Discussions with the participants established that physical losses are of secondary importance to non-physical losses. In common with distribution systems worldwide, physical losses in Vietnam are from leakage in the distribution system, from joints, flanges, gaskets, valve spindles, and ferrule connections on service pipes. Leakage is influenced by:

— poor quality materials and fittings—one company used thin-walled steel pipe previously used as an oil pipeline;
— poor mainlaying practice;
— shallow cover (damage from traffic vibration);
— damage during road-building, from subsidence, and from bombing during the war.

Leakage control policy in all companies is passive, i.e. only visible leaks are repaired. However, one company, Haiphong, has introduced pilot areas to demonstrate district metering, a methodology for monitoring night flows into a discrete area. The Consultant demonstrated alternative control methodologies, emphasizing the benefit of using simple sounding sticks to detect invisible leaks, although some participants felt that most leaks appeared at the surface and regular sounding is unnecessary. Flow metering principles, particularly the benefits of temporary insertion turbine meters for checking production and bulk meters, were also illustrated and discussed.

Session 3. Hanoi Case Study

In this session, Mr Hieta, from YME Group, described the long-term water loss reduction programme being carried out in Hanoi, supported by Finnida. Of particular significance was the public awareness campaign, which had heightened the perception of the community to the value of clean water and the damage caused by waste. The campaign strategy and results were expanded in more detail by Mr Salminen on Day 5.

Mr Hieta stressed the point that the problem of non-physical losses must be recognized by the authorities, as in the case of the Hanoi Peoples' Committee, and identified three stages to a water loss control programme:

a) Recognize the problem
b) Authorize funds
c) Design an action plan.

Public perception of the scale of the problem should be increased. In Hanoi, water loss is increasing (currently 160000 cubic metres/day) while the resource is being depleted (groundwater level is dropping by 1.0 m/year).

Only 32% of total production is billed. The 68% of water lost comprises 43% non-billed, 20% leakage, and 5% for the water company's own use.

The volume of billed water is decreasing (28% at the end of May 1994), despite the repair of 1000 leaks/year and disconnection of 2000 illegal connections/year. It is therefore assumed that the rate of increase of illegal connections is greater than the rate of leak repair.

Consumer studies were seen as an immediate requirement to identify or address the following:

— consumer waste;
— illegal connections;
— tariff charges;
— consumer contracts (only 50% of Hanoi's 200 000 consumers have contracts for revenue payment).

Addressing non-physical losses is clearly a priority. Solutions are linked with:

— improvements to the billing system, and meter reading /collection procedures;
— changes to metering policy (one tap dripping at 0.4 litre/minute wastes 600 litres/day) to install better meters;
— payment for the meters. If the company pays for the meter (130 000 dong), the payback on savings per consumer of 18 m_/month would be made in less than four months (144 000 dong).

Physical losses are also being addressed. One person has been nominated to lead a leak detection team. Sounding sticks have been issued, and staff are being trained in their use, and in the use of other leak detection equipment.

Conclusions from the study are:

— The campaign was effective in getting the message across: 90% of consumers were aware of it
— The campaign's aims were accepted by the local people
— The message of the campaign increased the peoples' understanding of the objectives, and created mutual good feelings between the water company and the consumers
— Better communication and understanding were established between the water company departments.

An estimated 10–20% water saving was made during the "Water Week", a cost saving of US$ 50 000. However, people are slow to change their habits, and campaigns should continue, supported by changes to the tariff and billing systems, which at present give no incentive to save water.

To further support the programme, the Hanoi water sector was reorganized in early 1994 into a new company called Hanoi Water Business Company. Ba Dinh Water Business Enterprise was selected as a model to monitor the progress with the following targets:

— 100% of consumers registered;
— 100% of meter installation;
— 85% or more of production collected as revenue;
— tariff fully enforced;
— 24-hour service level.

The lessons learned from the Hanoi experience provided valuable guidelines for the participants, who were asked to list the points in the Hanoi study which could be applied to their own company's action plans.

Day 3

Session 1. Immediate Action Plan

Previous sessions had guided the participants towards identifying problem areas and policies. This session consolidated the guidelines for some investigations and actions which could be carried out in the very short term.

It was accepted by all participants that the main source of water loss is due to illegal connections or illegal use, and under-registration of consumer meters. The points to address in an immediate action plan are therefore:

1) Ensure that all consumers are metered and remove the flat-rate tariff, which does not encourage wise use of water.
2) Stop illegal use by introducing more rigorous investigation of illegal connections, damaged and by-passed meters, and by ensuring that fines are imposed (sometimes with public "shaming").

Secondary actions would include the replacement of non-working meters, and a meter purchasing policy to ensure that only meters which can accurately measure low flows are used; the Chinese meters used by most companies are grossly inaccurate. One company is entering a joint venture with a French meter manufacturer to produce a low-cost locally made meter; other companies are using meters imported from Thailand.

Some companies are also introducing organizational changes to improve the accountability of the meter readers. It was agreed, however, that most institutional and organizational changes would be part of a longer term strategy.

Session 2. Case Studies

This session illustrated how water loss reduction programmes had been implemented in pilot areas in Vietnam and Peru.

(1) Haiphong, Vietnam

Mr Luy, Director of Haiphong Water Company, outlined the background to his company's water loss problems, and the pilot studies being carried out in three sub-districts. This is an example of where district metering is possible and has been successfully implemented. The case study demonstrated the importance of institutional support—the company receives a government subsidy, but has also changed its management structure, and now has a supportive and enthusiastic Director, whose philosophy is to reduce water loss, increase capacity, and improve management. An increased level of service and increased revenue would follow.

Losses had been about 70% of production in the past, 25% of which were due to leakage, the rest "institutional" or non-physical losses. While recognizing that the company must continue to supply its consumers, the only way to reduce losses is to progressively install new consumer meters and monitor and control the flow into and out of the network via small "management zones".

The study emphasized the importance of raising public awareness, with strong institutional support from the local authorities, the Peoples' Committees, and the police. The study contains a business plan, incorporating new solutions and techniques, such as:

- — working with the community via the Peoples' Committee, and with community management groups supervising meter reading and billing;
- — supervising main laying in new sections of the distribution system pipework;
- — checking population figures and drawing new network plans;
- — improving meter installation techniques, including protecting the meter from deliberate damage, sealing the meter to prevent tampering, and flushing the pipes to reduce damage from particulate matter;
- — disconnecting illegal connections after recouping retrospective payment;
- — strictly implementing fines and disconnections for interference with the meter.

Losses in the pilot area, after pipework rehabilitation, have been reduced to 20%. Payment is now collected from 99% of consumers, who pay their bills at a central office 5–10 days after being billed.

By 1996, the business plan described above was to be extended to six sub-districts, each with an average population of 100 000, at a cost of 900 000 dong (US$ 90) per connection.

(2) Arequipa, Peru

The Consultant described the stages in conducting a pilot study in Arequipa, Peru (population: 360 000).

The aims of the study were to:

— quantify water loss;
— identify a suitable control method;
— investigate pressure control;
— train staff.

Total water loss was 45% of production. Contributing factors were:

— asbestos cement pipes in poor condition;
— bulk meters not working;
— 50% of reservoir float valves not working;
— steeply sloping land, giving excessive pressures and sometimes little or no pressure;
— passive leakage control policy.

In contrast to Haiphong, however, water loss in Arequipa was largely due to leakage from the distribution system and from reservoir overflows—a total of 36% of production, with 9% due to mostly meter under-registration.

The Consultant described the stages involved and the equipment used in calculating the water loss figures, developing a work plan, and designing and setting up districts for monitoring leakage. An economic analysis had been carried out to determine the most effective and appropriate level of leakage control activity for Arequipa, which was district metering to monitor leakage, combined with an electronic sounding technique to detect noise from individual leaks. In the pilot zones, night flows were found to be 35 litres/connection/hour. Consumer night consumption tests showed that leakage and waste in houses amounted to 9 litres/connection/hour, and that leakage in the distribution system was only 26 litres/connection/hour. The pilot zone results for leakage control methodologies showed that leakage could be reduced to 11 litres/connection/hour using district metering and leak detection techniques.

The recommendations of the study were to:

— divide the town into 33 monitoring districts;
— install a further 12 insertion meter points to complement meters and points already installed during the study;
— organize two teams of two inspectors to sound for invisible leaks;
— sound districts which have night flows in excess of 20 litres/connection/hour;
— install ball valves on reservoir inlets;
— conduct a pressure survey to identify areas for pressure reduction.

It was estimated that for an initial expenditure of US$ 53 000, and an annual expenditure of US$ 22 000, annual savings would be US$ 200 000.

A follow-up visit a year later showed that while district metering had been implemented, a leakage control team had been appointed, and areas of high leakage had been identified, there was little success with detection of individual leaks using the equipment recommended. It was concluded that extra care must be given to training for the results and achievements to be sustainable.

Day 4 Medium- and Long-Term Plans

By this stage of the course the participants were well equipped to formulate a medium term (2–3 year) plan to reduce non-physical losses and a longer term (5 year) plan for physical losses.

Session 1. Two-to-Three-Year Plan

As with the Immediate Action Plan, the Consultant drew up a translated list of topics which could be discussed and expanded by the participants for inclusion in a medium-term plan.

After the discussions in working groups, six participants were invited to present their plans. As an example, the 3-year plan presented by Mr Du, Head of the Technical Department, Bac Thai Water Company, is summarized below.

Stage 1. Defining the problems
The main problem lies with meter error, exacerbated by current metering policy, which was due to:

— poor quality Chinese meters (low budget);
— no regular maintenance or calibration;
— some meters past their (10 year) life;
— interruption of supply when large meters had to be removed for calibration;
— removal of meters by some consumers, with temporary re-installation for reading;
— some illegal connections, but only two or three cases per year;
— the same person reading the meter and also giving out the bill and collecting the money.

Stage 2. Planning
a) Meter replacement policy:
— identification of consumers who can afford to buy a higher quality meter;
— concentration on large consumers, whose revenue equals several hundred private consumers;
— the pace of replacement directly linked to the number of willing consumers found;
— this policy will eventually eliminate poor quality meters.

b) Meter type:
— a new meter currently being made in Hanoi under a joint venture agreement with a French manufacturer;
— the cost of 100 000 dong (US$ 10) is thought to be reasonable, in addition to all the advantages of local supply and support.

c) Installation procedure:
— this depends on the nature of the consumer, but it is intended to construct meter chambers for the protection of both domestic and large consumer meters;
— filters to be considered for large meters, as long as they do not suppress the flowrate too much in low pressure areas.

d) Staffing organization:
— three or four people in charge of meter maintenance, for a total of 6000 meters of all sizes, maintained on site or in the workshop.

e) Communication:
— use the media to discourage illegal connections.

f) Leakage control:
— zone the network into pilot areas, as in the Haiphong study.

g) Recalculate non-physical losses after the planned replacement of 250 meters (50–200 mm) over three years.

h) Retain one person for meter reading and revenue collection, but with supervision and checking.

The cost of Mr Du's plan was estimated to be 200 000 000 dong (US$ 20 000), 70% of which would be raised from the consumers.

Session 2. Five-Year Plan

As in Session 1, the participants were given translated guidelines to help them formulate their own longer term plans to reduce physical losses. These are seen by most water companies as being less significant than non-physical losses. One exception, however, is Thanh Hoa, where most of the losses are physical. Ms Oanh, Head of the Technical Department, presented a plan which was started in 1992, and provides a good example of a staged approach to reducing physical losses.

Stage 1. 1992–94

This stage included:

a) Staffing organization—the setting up of a water loss reduction division, headed by a Director, and supported by finance, technical, and legal departments.

b) Analysis of losses—most losses are physical, caused by:
— leaks from joints;
— leaks from house connections;
— poor quality pipe material (thin steel pipe designed for the oil industry).

c) Analysis of problem system characteristics:
— although the pipework is in poor condition, low pressures suppress leaks;
— valves are mostly buried, hampering leak detection;
— some pipework is laid in sewers;
— about 2 km of pipework is buried under houses;
— low pressures also lead to meter under-registration.

By the end of 1992, the network had been remapped and a list of registered consumers compiled, both metered and flat rate.

Stage 2. 1994–96

The tasks in this stage include:

— checking all visible leaks, and repairing immediately;
— technical training;
— replacing all large meters (with a smaller size);
— carrying out valve maintenance, and installing new valves to facilitate zoning for district metering;
— cleaning the pipes (flushing);
— repairing ferrules at house connections;
— raising pipelines from sewers;
— installing two booster stations to improve supply;
— drafting regulations for the Peoples' Committee to authorize removal of houses built over pipelines;
— replacing all the steel (ex oil pipeline) pipes;
— installing all consumer meters (after June 1992) in a protective box.

Day 5

Session 1. Economic Considerations

Following the completion of the participants' presentations of their five-year plans, the Consultant discussed the cost-benefits of alternative methods of leakage control. The importance of achieving the optimum level of leakage for any system was emphasized—the higher the cost of water, the more active (and expensive) the methodology which can be justified, and vice versa. The participants were encouraged to identify the components of water cost in Vietnam, and were shown a simple method for calculating the volume cost of production in cubic metres.

The Consultant's discussion session was complemented by a presentation from Mr Quyen, Deputy Director of the Ministry of Construction's Department of Urban and Rural Management, who outlined the government's policy on water loss control and pricing.

Mr Quyen circulated to the participants a copy of the order which had been sent to every water company by the government, and used this document as a basis for his presentation.

The quoted range of water loss is 45–70%, and although figures are mostly estimates, it is likely that the average figure exceeds 50%, which means that water companies have doubled their production costs. Companies are facing the problem of increasing production to satisfy demand. They are concerned with raising funds for projects like building new treatment works, but are not addressing the control of water losses.

There are social as well as economic aspects of water loss control—local politics can interfere, one example being where a provincial organization takes over control of a water company project. In Haiphong, the two organizations work together as a team, and Hanoi is now achieving more success by integrating the organization. Other social/political pressures come from the consumers. If they are dissatisfied with the supply, they will complain to the Peoples' Committee, who will put pressure on the company.

The main task facing a water company is to increase its revenue, and there are concerns over tariff structures. Although the company is run as a business, it has no powers to decide the tariff or the volume of production, but the production costs are linked to market prices. The government has decided to subsidize water production, but subsidies are rarely equitable, often benefiting the rich.

The order issued by the government reviews the present situation and gives guidelines for water companies to follow. The government's aim is to reduce losses by 50% in the coming years. Haiphong has saved 5% in one year, equivalent to the cost of building a new treatment works.

Guidelines in the order advise companies to:

- review losses, particularly in urban areas;
- identify components;
- calculate the cost of control (e.g. how much investment is required to save 10% loss);
- gradually eliminate flat-rate consumers, because the flat rate is inequitable;
- improve public awareness and motivate the whole community;
- empower representatives of women's associations.

The Ministry has set up a special division to control the work and give guidelines on tariffs, publicity, and awareness campaigns. Discussions on water tariff policy and production subsidies are now taking place between the Construction and Finance ministries. The aim is to define a tariff for each company, and change the institutional structure to that of a business company.

At the end of 1994, the Ministry would be reviewing the actions implemented by the water companies.

Session 2. Public Awareness and Education

In this session, Mr Salminen, sponsored by Finnadia, highlighted the stages in the public awareness campaign carried out in Hanoi. He illustrated his presentation with pamphlets and stickers produced for the campaign.

The campaign had been launched in August 1998, with a PR consultant from Hong Kong who had been engaged to assist in developing the strategy and design. The campaign aimed to convey four clear messages:

— how water is brought from the source to the tap
— how water is wasted
— the excellent value of clean water
— paying for water is necessary for investment and upgrading.

There was good media coverage for the launch of the campaign, with regular media statements. At the opening ceremony a consumer "hotline" was opened. A total of 200 000 leaflets were distributed, one to every household. Fourteen vehicles were kept on standby to answer hotline calls. In the first week there were 421 calls, of which 281 supplied correct information about loss or waste of water. In that week 258 repairs were made, and 133 non-urgent repairs recorded. Broken public taps (167) were the biggest component.

Advertisements were placed in eight different newspapers, using cartoon-style graphics. Stickers were produced for cars, taxis and buses. Water company vehicles carried large versions of the sticker.

During the water week there was a slight increase in system pressure and a slight decrease in consumption.

Results of a follow-up questionnaire showed that 90% of people were aware of the campaign. The total cost of the 1993 campaign was US$ 73 000. An estimated water saving of 10–20% was made during water week, with a saving of US$ 50 000. The cost of this year's (1999 Au: ?OK) campaign will be less (US$ 20 000) because local resources will be used rather than professional PR consultants.

Conclusions from the campaign were:

— the campaign was effective in getting the message across;
— the campaign's aims were accepted by the people of Hanoi;
— the message increased the understanding of the objectives;
— mutually good feelings were created between consumers and the water company and between the different water company departments.

However, people are slow to change their habits, so the campaign needs to continue. The campaign should also be supplemented by changes to the tariff structure and billing system, which do not provide an incentive for saving water.

After Mr Salminen's presentation, the participants were asked to form working groups and discuss public awareness campaigns, and then return with comments, points for further discussion, and ideas which could be used in their own companies' campaigns.

Mr Phong, Deputy Director of Haiphong Water Company, described his Company's campaign. He thought that communication through TV and radio is better than leaflets, and thought the Hanoi leaflet too "wordy". Haiphong TV showed a 30-second film spot each day which costs 4 500 000 dong (US$ 450) per month. TV is also used to "shame" illegal users.

In contrast, companies in the rural provinces, with limited budgets, cannot use mass campaigns and must use other means to get messages across to the people. Some examples of these were given by the participants:

— placing messages in local newspapers once a week;
— targeting the community via local committees, to inform them of the Company's regulations;
— publicizing examples of wise water use and bad water use.

It was agreed by all participants that self-respect and self-control by individuals and the community were essential for the success of public awareness campaigns, also maintaining good links with the Peoples' Committees.

Day 6

Session 1. Institutional Aspects

The aim of this session was to bring together all the institutional factors influencing a water loss control programme. Using a translated OHP slide as a basis for discussion, the Consultant outlined three key institutional elements, the factors which influence them, and the way they are interlinked. These were:

- the business
- the staffing organization
- the community.

The success of the business is influenced by its constitution, i.e. whether it is private or public, whether its direction is strong or weak, and whether decisions can be made by the Director or are influenced by organizations outside the water company.

The effect the staff have on the business is affected by the culture of the country and the working practice of the organization. The attitude of the staff is governed by career development, salary, incentives, and competition.

The community is integral to the water loss programme by its attitude to waste, damage, and illegal connections. The community is influenced by public awareness, community management and policing, and self-discipline.

Following discussion in working groups, Mr Phong outlined the staffing organization at the Haiphong Water Company and the changes which had been made to ensure that the water loss programmes were carried out in the pilot sub-districts.

Session 2. Course Review and Close

Mr Thanh led this final session of the course, which allowed the participabts to air their views on the course content and material, and on the value of the course in helping them design their water loss programmes. This session has been reported by Mr Thanh.

The course closed with a presentation by the Vice-Minister, Dr Pham Sy Liem, who exhorted the delegates to use the information they had gained to complete the review of their systems, as requested by the Ministry.

3. Conclusions

The participants were attentive throughout the course, and applied themselves with willingness and enthusiasm to the tasks and discussion group sessions set by the Consultant. They gave the impression that now that the government had initiated a “wind of change”, they wished to be empowered to activate action plans. The course concentrated on the programmes to reduce non-physical losses, because in most companies this is where the majority of losses occur. Although the time for the introduction of advanced technology is still some years away, there are a number of techniques (like district metering) and some technologies (like flowmeters, insertion meters, and equipment for listening for leak noise), which were of interest to the participants and which are wholly appropriate to the Vietnam water industry.

The course was extremely well organized and coordinated by the National Country Officer, Mr Thanh, who brought together a good mix of visiting speakers whose presentations were fully appreciated.

ANNEX 3

Case studies: Implementation of the strategy

Case study 1. The South West Water (UK) Leakage and Network Strategy

South West Water (SWW) is one of the ten major water service companies in England and Wales. This Company serves 700 000 households in the counties of Devon and Cornwall, in the south-west of England, via a 15 000 km mains network. In the summer months the 1.5 million resident population increases to 2.0 million by the influx of tourists. The Company's area is entirely bounded by the coastline, and sewage treatment and disposal have to be maintained to high standards to ensure clean bathing beaches. This adds considerably to the costs and to customers' water bills, which are the highest in England and Wales. The Company, which is currently spending £4.5 million (US$ 6.4 million) each year on active leakage management, employs 100 leak detection staff, about a third of whom are SWW staff—the rest are contract staff working on a 'payment by results' basis. The Company has had an active leakage control policy for many years, but in 1992, in response to the growing interest in leakage and the demands of the regulators, the Company began to develop an integrated leakage and network management strategy. The aim of the strategy was to combine all the elements of distribution system management, and to complement the leakage control activities that were already being practised. The strategy would draw on the wealth of data and specialist knowledge existing within the Company to develop better methods for measuring and understanding the scale and significance of leakage and the other components of water balance, at all points within the distribution network. Once the mechanisms were in place, the Company could then begin to address the demands of the regulator—by achieving good quality data and by meeting leakage targets. The strategy has three main goals:

- To ensure that flow measurements are **accurate**
- To ensure that leakage is **monitored**
- To reduce losses to an **economic** optimum level.

A number of tasks and studies support the strategy. They include:

— a rigorous calibration programme for the 'super-key' meters, which measure supply;
— dividing the Company into water into supply (WIS) zones and DMAs;
— a system for ensuring that DMA boundaries remain "tight";
— a survey of metered non-households to quantify average night use for each category of customer;
— studies to analyse losses from reservoirs and raw water mains;
— studies to identify average zone night pressure and the factor required to convert nightflow rate into daily leakage, taking into account the diurnal variation in pressure (the hour to day factor);
— development of customized software for calculating the costs of active leakage management, and for setting economic leakage targets.

The Company's supply area is divided into 65 water into supply (WIS) zones and 19 sub-WIS zones (large WIS zones which are subdivided). These zones form the first stage of the metering hierarchy. The Company has a total of 147 super-key (production) meters and 205 key (WIS-zone and sub-WIS zone) bulk meters. All super-key and key meters report flow data to the company telemetry system via modems and outstations. All WIS zones and sub-WIS zones are divided into District Meter Areas (DMAs) to enable continual night flow monitoring (CNFM). The whole of the SWW distribution network is divided into DMAs, each of which has a boundary consisting of permanently closed valves. Night flows into (and out of) each DMA are continually monitored by fixed flowmeters and data loggers. All 84 of the Company's WIS and sub-WIS zones are covered by DMAs, 471 in total. The complete monitoring system contains some 2050 meters (key and DMA). Flows into (and out of) each DMA are logged by a permanently installed meter and data logger. An average DMA contains 1500 properties, with a range of 92 to 4998 properties—urban DMAs contain larger numbers of properties than rural ones. The number of meters in each DMA varies, depending on the DMA size and its hydraulic characteristics, but the average across the Company is 4.56 meters per DMA. Some WIS zones contain large mains, and in this case **trunk main DMAs** are formed by metering branch connections from the large main, and at each end of the main. The largest consumers, particularly those using water at night, are also permanently logged, creating in effect a **large user DMA**.

A rigorous meter calibration and replacement policy has been adopted for the 147 super-key meters. Of these, 94 are electromagnetic or differential pressure, and 53 are mechanical. The mechanical meters are changed every five years. The Company has carried out a survey and evaluation of calibration techniques, from which it has developed its current meter calibration policy. Non-mechanical meters are calibrated once a year, with their secondary instrumentation and set-up being checked every six months. The Company considers that the key benefits from zoning and from monitoring the network are:

— ensuring the accuracy of flow data and consumption;
— understanding losses in each component part of the distribution system;
— enabling the Company to record the costs of each operational task;
— setting and achieving economic leakage targets.

Within weeks of coming to power in 1997, the new Labour Government convened a Water Summit specifically to address the leakage issue. The UK Government ordered that mandatory leakage targets be set for each of the water companies of England and Wales. Targets were set in October 1997, and meeting them remains a high priority task. South West Water's mandatory targets are 110 Ml/day for 1997/98 and 96 Ml/day for 1998/99. In the six years since South West Water introduced its leakage and network strategy, the Company has made good progress in **understanding** leakage, which is the first step in a policy to reduce leakage and meet the set targets. The Company set its own leakage target at 15% of distribution input, to be achieved by 2000. This is equivalent to 84 Ml/day (4.8 l/p/h). Since mandatory targets were introduced, the Company has already achieved its 1997/98 target. Current losses are 101 Ml/day, and if the current trend continues, the Company will soon achieve its 1998/99 target of 96 Ml/day. Fig. 1 illustrates the decline in leakage levels since 1995 against the Government's mandatory targets and the Company's own target for 2000. The reduction of customer leakage has been partly influenced by the introduction of a free repair policy, and the Company's leakage figures reflect the increase in investment in active leakage control. The graph also shows the gradual reduction of balancing error from 5.0% in 1995 to 0.5% in 1998. Fig. 2 shows how the total daily demand has dropped from 510 Ml/day in 1995 to 430 Ml/day in 1998, a reduction of 15.7%.

South West Water attributes its successes and achievements to its integrated management strategy. External consultants have been extensively used to support the Company's own in-house experts, working as a team to write software, conduct field studies, and to publicize the Company's achievements.

Fig. 1 Bar graph of targets and achieved total leakage level, 1995–1998

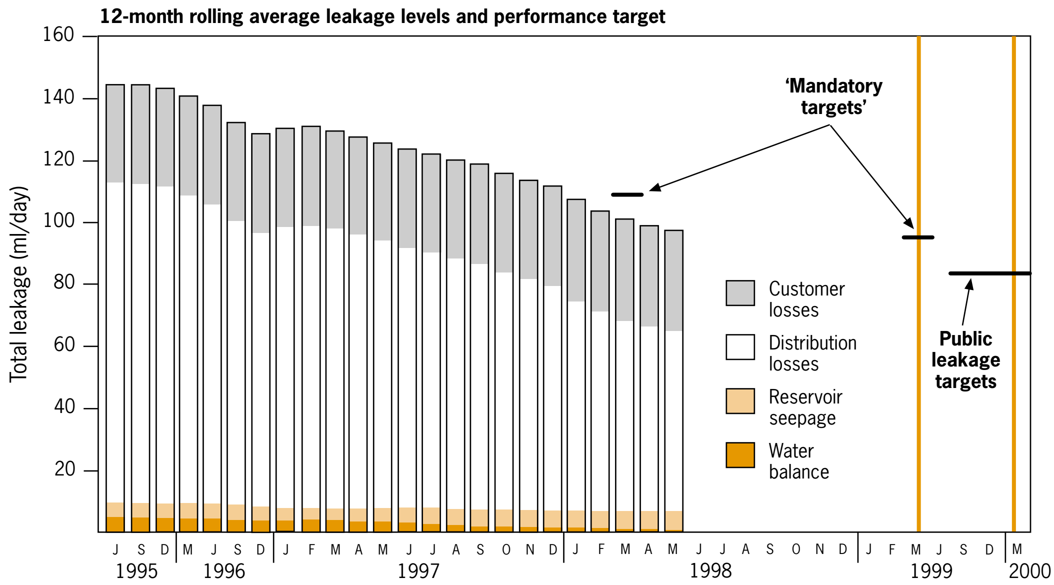
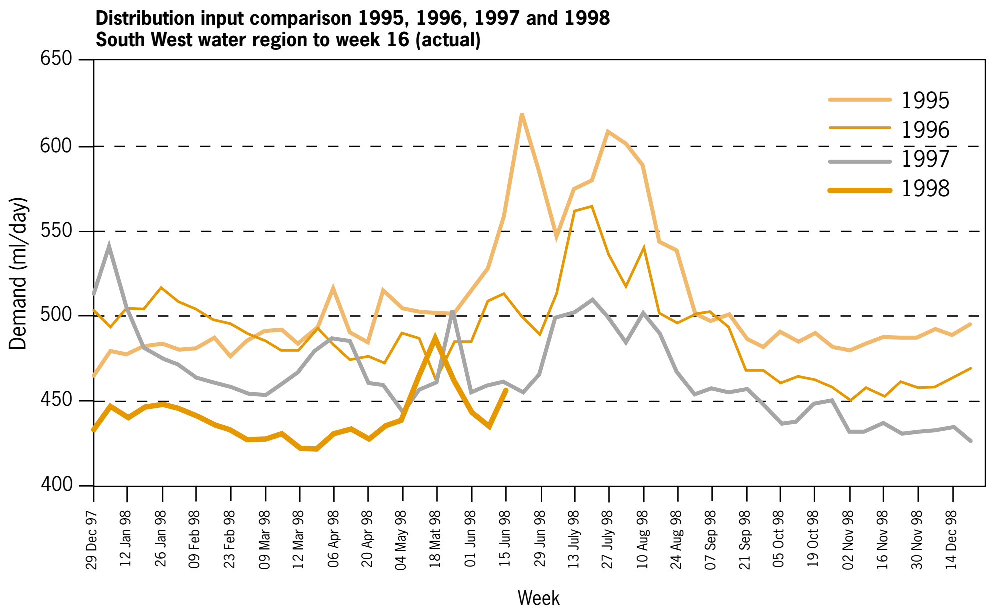


Fig. 2 Graphs showing reduction in demand, 1995–1998



References

1. Arscott A and Farley MR. *Dealing with leakage—The South West Water (UK) Integrated Management Strategy*. International Water Supply Symposium, Tokyo, 1987.

Case study 2. Experiences in the South Pacific

1. Introduction

The concept of strategy development was put into practice in two countries in the South Pacific—Samoa and Cook Islands—in late 1997. The author was engaged by WHO to appraise the operating practices of the Western Samoa Water Authority, and the Waterworks of Rarotonga, Cook Islands. The purpose of each project was to:

— review operating practices and documentation relating to the water supply and distribution networks;
— develop action plans for a water loss reduction programme, including advice on community education programmes and water conservation policy;
— produce procedural guidelines for future water loss management operations;
— conduct field training in leak detection and location techniques.

The two countries have similar characteristics and local influencing factors. Both have water shortage problems due to the unusually high customer demand. In Samoa demand is 400–500 litres per head per day. The Samoans have traditionally used river sources for washing and drinking water, and the story goes that even now when they have piped supplies, they treat the supply like a river—allowing the water to run continuously! This demand is almost double the design capacity of the treatment works, and treated water is augmented with raw water in part of the network to maintain supplies. Some customers are without water for part of the day, and others receive their supply at very low pressure. This scenario is a flash-point for disease epidemics, both from drinking untreated water, and from polluted water entering the network through back-siphonage or seepage through leak points and broken joints. The significance of customer waste and misuse of water, as well as leakage from the pipework and illegal connections, was acknowledged in the reports of consultants previously. These referred to taps left running all day, and house tanks, which are filled at night when the pressure is higher, being allowed to overflow. These factors highlight the greater influence of local culture and social habits on total water loss than physical losses from the network. Because of the volcanic nature of the soil, digging trenches is difficult and some sections of pipe are laid on the surface. This makes it easier to spot leaks but brings in other problems. For example, one enterprising shop owner in a remote village had used 50 mm galvanized water pipes as convenient supports for his shop's porch. The villagers clearly thought this was in no way connected to their loss of water supply and complained vigorously to the Water Authority—a case of unaccounted-for water pipes!

A plan to revise customer metering policy and introduce a tariff structure is under review. A community education policy is also being considered, to encourage householders to conserve water and report leaks. As in many developing countries, a shortage of funds for equipment invariably means there is no active leakage detection, and sometimes even visible bursts are not reported or repaired. Yet the importance of leak detection and repair is well recognized by the Water Authority engineers. One of the corner-stone actions of the strategy was therefore to:

a) get the team some form of transport (sharing with other departments if necessary);
b) develop some basic home-made listening devices to locate leaks;
c) provide training in the use of pipe location and leak detection equipment which had been supplied by consultants two years previously but had never been used.

However, the main thrust was the empowerment of the team and the motivation brought about by being given such a high-profile job.

A similar situation exists in Rarotonga, the main island of the Cook Islands. A study by

Rarotonga's Tourism Task Force in 1995 estimated that, by the year 2000, water demand for the following categories of customer would be:

— visitors in resort accommodation:	1000	litres/head/day
— visitors in self-catering accommodation:	600	litres/head/day
— resident population:	330	litres/head/day
— agriculture (total):	750 000	litres/day.

The reasons for such excessive use are:

- — growers using drip-feed irrigation systems which are left running 24 hours a day;
- — domestic customers using unnecessarily high volumes of water;
- — a totally subsidized water supply, which does not encourage customers to reduce daily consumption or stop wasteful practices.

However, tariff reviews are notoriously political, and a new tariff structure is not expected in the short term. But a programme to inform customers, particularly growers, of the need to stop using excessive amounts of water has been initiated. The programme included encouraging growers to develop and use alternative sources like shallow wells.

A study by the New Zealand Geological Survey in 1988 had assessed the potential for large-capacity valley storage reservoirs. Although this was considered as a long-term measure, requiring large-scale investment, the Waterworks was considering increasinA she upland resources to meet increasing demand. Rarotonga therefore provided an ideal pilot area for testing the process of developing a water loss strategy. The aim was to demonstrate that a sustained programme of demand management and water loss reduction could provide the extra resources to meet the demand without the need for valley storage.

As in Samoa, leak detection is passive, i.e. only visible leaks are repaired. Although two leak locators (ground microphones) had been left behind by previous consultants, both have fallen into disrepair. The Waterworks operations staff had been taught no skills in leak detection techniques or equipment use. Repairs to the pipework were being held up by a lack of repair clamps. Rubber strips made from tyre inner tubes were being used to bind the leak.

In late 1997, when the WHO project took place, the Rarotonga Waterworks was suffering from a legacy of piecemeal inputs from a succession of well-meaning but uncoordinated consultants from different organizations. Because of the financial situation in the country, the Cook Islands Government relies heavily on donor aid and the good but misplaced intentions were not always implemented in consultation with the Waterworks. A paper by an independent consultant, in 1994, reviewed the work and recommendations of previous consultants. Referring to the failure of the strategy, the consultant concluded that "the situation can be reversed by a combination of local knowledge, low cost and low technology measuring techniques, and user conservation habits, without relying on expensive outside consultants".

With the island experiencing its fifth drought in 15 years, the severity of water shortage was uppermost in the minds of the Waterworks and its customers alike. Flow in the streams at almost every intake was reduced to a trickle, and there was no better time for introducing a practically viable and achievable water loss management strategy. From the review of previous projects, and from an appraisal of current practice, including plans to upgrade the distribution system, it was possible to suggest an action plan for the Waterworks. During the project, four Waterworks staff were assigned to a leak detection team and given practical field training in pipe location and leak detection techniques. As part of their training and skills reinforcement, the team began implementing a pipe survey and asset register, as well as finding significant numbers of leaks.

Although the Waterworks was suffering from a legacy of failed or defunct plant and equipment inherited from a previous project, the basis of a sound strategy for managing the network had started. This included the installation of bulk meters at the intakes, a design for zoning the network and using zone meters for leakage monitoring. Although many of these meters were defunct, and zoning had never been implemented, the Waterworks engineers were familiar with the concept.

Recommendations were made for a number of improvements to current and future operating practices. Some of these are short term and low cost, requiring little extra investment. Other improvements are for the longer term, requiring some capital investment. Water shortages and drought measures could be addressed in the short term by an active policy of leakage reduction and demand management, and in the medium term by investment in upgrading the existing catchment intakes and providing extra reservoir storage capacity. Funds would be better invested in these projects than in deep valley storage.

Specific action plans, together with procedural guidelines, were drawn up for the Waterworks staff to follow. These were accompanied by a specification for recommended equipment to support the action plans. Most importantly, recommendations were made to WHO, as the funding agency, for a further project to support the Waterworks in their implementation of the action plans. This support would consist of further training, demonstration of techniques, and regular monitoring.

The short-term action plan (up to 3 months) contained actions that could be carried out immediately, at little or no cost to the Waterworks, to start improving supplies. Examples of these actions are:

— modification of intake screens to reduce fouling by debris;
— preparation of zone plans;
— pressure monitoring to identify critical areas;
— an active programme of pipe location and leak detection using repaired equipment and sounding sticks;
— improvement of pipe repair techniques.

The medium-term and long-term action plans (3 months to 3 years) address those elements for upgrading the network, for repairing or replacing bulk meters, and for extending the zoning and monitoring systems. Pilot study areas to demonstrate zonal monitoring and leak detection techniques are an essential feature of this stage. Others included addressing the non-physical losses in the network and the excessive use of water by customers.

In January 1999, a little over one year after the WHO mission, WHO sent a questionnaire to the Waterworks to ask which of the actions had been implemented. Although some of the short-term actions had been completed (intake screens, pressure monitoring), very little of the strategy had been implemented due to lack of funds, staff, equipment, and support. A follow-up study in 1999 reviewed the strategy and reinforced staff training, using equipment loaned by WHO for the mission. There were clearly added benefits from implementing the strategy in the pilot study areas and from purchasing essential leak detection equipment, and leaving it behind for the operations team to use.

2. Main activities and findings

The consultants' programme of activities is detailed in Annex 1. The main findings are described below.

Source intakes

A review of the stream intakes showed that all are well maintained by a weekly inspection and maintenance programme. Intake pipes are fitted with filters to prevent leaves and debris from entering the distribution network. The Water Works has reinforced the concrete support walls to the weirs and filter beds at some of the intakes, and has a planned programme of renovation in hand for the others.

The catchments are unprotected from pollution by residents or walkers, but the logistics of protecting them by physical means are almost impossible. The Water Works relies on education and awareness programmes to stop the resident population and tourists from polluting the catchments.

There is little storage at the intakes or elsewhere in the distribution system. This makes the population more vulnerable to short-term increases in demand and drought conditions.

There is suspected leakage from the 2.5 megalitre storage reservoir at Takuvaine—the ground on one side of the reservoir is continuously wet, with an absence of vegetation, typical of waterlogged soil. The level of the reservoir is controlled by a Savoy pressure valve, which is currently activating at 3.0 metres instead of the 4.0 metres top water line, reducing the storage capacity of the reservoir. The level in the 45 m3 storage tank at Takuvaine is controlled by a ball-valve, which is thought to be working efficiently.

Flowmeters

Bulk flowmeters have been installed on the trunk mains downstream of each intake. The majority of meters are the mechanical helix type, mostly of French manufacture (Farnier), but some have been replaced with Kent helix meters. Of the 13 intake meters, five are not working. Data loggers supplied by the French firm to record meter flows are no longer used, mainly due to lack of operation and maintenance, but also because the software for programming the loggers has been lost.

A portable ultrasonic flowmeter was left by the French. There are no operating instructions, and the WHO consultants were unable to repair it. Some of the components may be missing.

Approximately 550 Farnier consumer meters were installed by the French. These are no longer read regularly, and their condition and working order is unknown. They could, however, become a useful feature of a pilot study to assess consumer demand and the effects of a water awareness programme.

The distribution network

The distribution network consists of a coastal ring main, fed by the intake trunk mains, and the network of sub-mains connected to the ring main. Individual consumers are supplied from connections to the sub-mains. The total length of the distribution network is approximately 120 km, and the number of house connections is approximately 3500.

The pipe material is a mixture of galvanized iron (GI), asbestos cement (AC) and some PVC. PVC is used for new connections and replacements. New and replacement service connections are PVC, original connections are GI. The GI pipes are old and leaking. The sub-main system in the NE sector of the island is scheduled for replacement in early 1998.

Pressure monitoring

There are 13 pressure monitoring points in the network. Pressures are monitored daily as a routine measure of system performance. This is particularly important as sources diminish and pressures fall during the drought. Pressures in the network range from 5.0 metres at critical points in the system to 60.0 metres near certain of the intakes.

There is no method currently for reducing high pressures to ease the strain on the network.

Pipe survey and network records

Two sets of pipe-locating equipment and one metal detector (valve box locator) were left behind by the French. The pipe locators are the Radiodetection RD400 type, for metallic pipes. Of the two sets only one is complete, i.e. containing both transmitter and receiver. The transmitter was not working when the WHO consultants arrived, and the Water Works staff had been using the receiver to trace pipes. The transmitter only required new batteries to restore it to full working order. One major advantage of the RD400 is its capacity to measure pipe depth when the transmitter and receiver are used together. The Water Works staff are now aware of this facility, which will be a significant advantage for the pipe survey and GIS (geographical information system) update. The transmitter for the second set has been lost, but the receiver is working. The box locator was not working at the start of the mission, but has now been repaired by changing the broken battery holders.

The Water Works has competent in-house surveyors, although it was difficult to find working survey equipment for the pipe survey during the mission. The operational staff are competent at working with pipe location equipment and the team is currently starting a survey programme, in conjunction with the leak detection programme, to verify the company's GIS.

For outline planning of monitoring zones, the consultants used drawings made for the Water Works during a previous WHO mission.

The Water Works has developed its own geographical information system (GIS), using base maps from the Government survey department. Pipework details have been entered using historical records and operator knowledge. The Water Works is now justifying and updating the GIS records, using fixed reference points for positions of pipes and fittings. The survey is being carried out as an integral part of the leak detection training and survey programme for the mission.

Leakage detection activities

Leak detection practice is currently passive, i.e. only visible leakages are repaired. Although two Metrovib leak locators (ground microphones) were left behind by the French, both have fallen into disrepair and are not working. Therefore, up to now the Water Works operations staff have had no skills in leak detection techniques or equipment. The method used for locating a leak is to excavate the area where water is showing, unless the leak point is clearly visible on mains or fittings above the ground.

Four operations staff have been appointed to form a leak detection team, and have been working with the training consultant during the mission. During the training programme the team was able to begin implementing a pipe survey and asset register, as well as finding a significant number of leaks.

Repairs to the network are currently held up by a lack of repair clamps. Rubber strips made from car tyre inner tubes are used to bind the leak. This method is not satisfactory as it only effects a temporary repair. However, many of the leaks repaired in this way are on sections of pipe scheduled for replacement in the mains renewal programme. The programme will also include a new stock of repair clamps.

Repairs are usually carried out as soon as leaks are reported. There is no pump available for clearing water from the excavation, and repairs are often carried out under water.

Water awareness and education programme

The consultants found that the main reason why the population of Rarotonga use excessive amounts of water is because water is totally subsidized. This does nothing to encourage wise water use or conservation. However, a review of the tariff structure is planned to take place during the next two years.

A programme to inform customers of the need to use water wisely has recently been resurrected. A consultant has been appointed to design a strategy for getting the message across to the public and the growers to stop using excessive amounts of water. Media to be used are TV, radio, and newspapers, and, in the case of the growers, their trade associations. The consultants believe that the awareness programme is an integral part of the distribution management and demand management programme.

Training workshop

The consultants conducted a one-day training and awareness workshop for all Water Works staff during the first week of the mission. The workshop covered the principles of leakage management and the techniques and equipment for leak detection. The major part of the training consisted in a field demonstration of the equipment brought by the WHO consultants, so that all staff will become familiar with its use. The consultants identified further training needs, which are listed in the recommendations.

Pilot study areas

In consultation with the Director, the consultants drew up zoning guidelines for one intake zone and three sub-main zones for monitoring flows and demand patterns.

The pilot areas will be used to demonstrate:

- the feasibility of zoning areas of the network while maintaining consumer demand and levels of pressure service;
- the design and installation of meter sites for zonal monitoring;
- selection of meter flow range and size;
- the principles of pressure monitoring to assess the potential for pressure control;
- the principles of leakage monitoring by recording night flows at the meter with a data logger;
- the technique for analysing and interpreting flow data, and for prioritizing leak detection and repair;
- the techniques for leak detection.

Depending on time constraints and the availability of materials, the training consultant will attempt to create at least one sub-main pilot zone in the Rutaki area, by using a spare flowmeter from one of the lesser-used intakes, closing zone boundary valves, while monitoring the pressure at peak demand. Further pilot zones will be implemented during a follow-up project, when the bulk of the data collection and analysis will be carried out.

3. Conclusions

From the review of previous consultants' reports and from appraising current operational practice and plans for upgrading the distribution system, the principal consultant was able to make suggestions for a future strategy for the Water Works. The training consultant undertook a programme of practical field training in pipe location and leak detection techniques for the Water Works staff designated to the leak detection team. As part of their training and skills reinforcement the team was able to begin implementing a pipe survey and asset register, as well as finding a significant number of leaks.

The consultants found that a number of historical events have influenced the current leak detection programme. In 1992 a French firm of consulting engineers renewed certain sections of the pipework in Avarua. They also installed flowmeters at each of the source intakes, and provided a design for forming each source supply area into discrete zones. This provided a sound basis for future distribution system management and leakage monitoring. However, after the French had left the project, there was no follow-up to ensure that skills transfer was sustained or that equipment was maintained. When flowmeters and other equipment failed, there was no capacity for the repair, or purchase of spare parts, of the French-manufactured equipment. The unit of Water Works operations staff set up by the French to manage the project was disbanded.

The Water Works is suffering from this legacy of failed or defunct plant and equipment inherited from the French project, as well as from a lack of financial and technical resources. However, the WHO consultants believe that the French laid down the basis for a sound strategy for management of the distribution network, namely:

— installation of bulk meters at the source intakes;
— sectorization, or zoning, of the supply network;
— using zone meters for leakage monitoring;
— using consumer meters for demand studies.

There are certain aspects of the scheme designed and installed by the French, which the consultants felt could be built on. Zoning supply areas would considerably enhance the potential for leakage monitoring and pressure management. The consultants conclude that the implementation of the French zoning plan in a future project, with some adaptations and any necessary sub-main reinforcements, together with the repair or replacement of those source flowmeters which are no longer working, would be of great benefit to the management of the distribution system.

The Water Works has several items of equipment left by the French consultants. The WHO consultants were able to repair two items of this equipment, a pipe locator with depth gauge and a valve box locator. However, the leak location equipment and the ultrasonic flowmeter were beyond immediate repair.

The consultants were able to make recommendations for a number of improvements to current and future operational practice. Some of these are short term and low cost, requiring little extra investment. Other improvements are for the longer term, and require considerable capital investment. These are detailed in the action plans and the procedural guidelines prepared by the consultants for the Rarotonga Water Department.

The consultants strongly believed that water shortages and drought measures can be addressed in the short term by implementing an active policy of leakage reduction and demand management, and in the medium term by investment in upgrading the existing catchment intakes and providing extra reservoir storage capacity. The consultants concluded that funds would be better invested in these projects than in a project for deep valley storage.

Of crucial importance to the future success of the leak detection programme is further training and follow-up. The consultants concluded that, while the Water Works staff possess the required technical skills for day-to-day operational tasks, and are well motivated for implementing future pilot studies and leakage strategies, they would benefit from further training in certain areas such as network modelling, and in the design, implementation and management of zonal monitoring and pressure controlled areas.

4. Recommendations

The consultants recommended that certain actions were necessary to achieve an active and sustainable strategy for distribution system management and leakage control. These are listed in the following Action Plans, and the Procedural Guidelines describe the actions more fully. Where equipment purchase is suggested, a list of recommended equipment is provided. Further support to the Water Works is required to implement and follow up the strategy, and the consultants gave recommendations for the actions required in a further mission.

Action Plan: short term (0–3 months)

There are certain tasks and actions which can be implemented straightaway, at low or no cost to the Water Works. These are:

— postpone plans for large valley reservoirs;
— modify intake screens;
— repair Avatiu bulk meter;
— implement Avatiu zonal pilot study area;
— implement Rutaki sub-main pilot study area with under-used intake meter;
— conduct pressure monitoring programme;
— continue the pipe survey and leak detection programme;
— improve repair techniques, purchase submersible pump;
— continue equipment maintenance;
— perform drop-test on Takuvaine reservoir;
— adjust level of valve on Takuvaine reservoir;
— assess feasibility for repair of ultrasonic flowmeter and ground microphone;
— review future equipment needs and funding for procurement;
— design leakage/pressure management project requirements and pursue funding;
— design/adapt plans for sectorization of intakes.

Action Plan: medium term (3 months to 1 year)

The tasks are:

— upgrade intake catchments;
— repair/upgrade intake meters;
— implement the sectorization plan and network reinforcements;
— implement the water awareness campaign in the pilot study area;
— implement the pressure reduction programme;
— extend the sub-main zonal metering programme to all sub-main network.

Action Plan: long term (1–3 years)

The tasks are:

— extend intake storage reservoirs;
— examine the feasibility for alternative groundwater sources;
— consider the tariff structure and consumer metering;
— restrict excessive use by growers.

Further support to Rarotonga Water Works

The Director has a vision of the strategy he wishes to build for Rarotonga Water Works. The review of the current Water Works operating procedures, and an analysis of the strengths and weaknesses, has enabled the WHO consultants to build on this framework and make additional suggestions and recommendations to further improve the management of the distribution system. The Director and staff of the Water Works are well motivated to implement a distribution management strategy, and fully support the programme and action plan suggested by the WHO consultants.

An essential feature of the strategy is institutional strengthening and capacity-building. Only by making extra financial and staffing resources available to the Water

Works, together with further training of key staff, can the strategy be fully implemented. Another essential feature is monitoring and follow-up to ensure the strategy is sustained. This is a feature which has been notably lacking in previous project management.

The consultants therefore recommend that WHO approve a second mission to ensure sustainability. The mission would incorporate both training and project implementation elements.

Training and project implementation support is required for:

1. Network analysis
   — Building and calibrating a computer model of the Rarotonga network
   — Using the model to test zonal boundary design and pressure control areas.

2. Zonal leakage monitoring and detection
   — Designing and implementing leakage monitoring zones
   — Designing and implementing pressure controlled areas
   — Selecting and installing zonal flowmeters
   — Monitoring flow meters and using data loggers
   — Data analysis and interpretation
   — Prioritizing zones for leak detection activities
   — Using alternative leak detection techniques and equipment.

One training consultant is required for a one-month input to train staff in the principles of network modelling, and to assist staff in building, calibrating, and using the model. The consultant would be required to recommend and provide a copy of network analysis software suitable for, and licensed for, the Water Works' use.

Two further consultants are required to share a six-week input for training and implementing zonal leakage monitoring and detection. The principal consultant would be required for two weeks to:

— prepare outline zonal designs;
— confirm designs with the network model;
— provide training and advice on the zonal implementation programme;
— train staff in data collection, data analysis, and interpretation techniques.

The training consultant would be required for four weeks to:

— provide field support for zonal implementation;
— continue project supervision and field training;
— demonstrate zonal leakage monitoring techniques;
— demonstrate new leak detection techniques and equipment (either purchased for the project or loaned by the consultant).

Certain items of equipment are also necessary for a sustainable pipe survey and leak detection programme. These should be purchased as soon as possible while the motivation of the Water Works staff remains high. Suggestions for the required equipment are given on page 157.

The Director of the Water Works understands that approval for funding is required from the WHO budget allocated jointly to the Ministry of Health and the Ministry of Works and Physical Planning (MOWEPP). The consultants advised the Director to make a case for funding a follow-up project, based on the consultants' recommendations, which he would submit to MOWEPP.

5. Procedural Guidelines

Source intakes

The consultants support the Water Works medium-term plans to:

— systematically upgrade the intake catchments;
— extend the system of intake storage reservoirs.

The consultants recommend that the long-term plan to invest in large valley reservoirs be postponed, while the effects and cost-benefits of the short- and medium-term alternative measures are assessed. These are:

— an active zonal leakage monitoring and detection programme;
— a consumer demand reduction programme;
— a pressure management programme.

The build-up of leaf debris on the intake screens could be reduced by slightly modifying the screens from the present cylinder to a conical shape, using a traffic cone as a former.

The Savoy pressure valve at the Takuvaine reservoir should be checked and adjusted to increase the storage capacity of the reservoir.

A drop-test should be conducted to assess the amount of leakage from Takuvaine reservoir. This can be carried out by closing both inlet and outlet valves to the reservoir and noting the drop in level. Provided the valves are drop-tight, the drop in level will be due to leakage. The difference in volume before and after the test is calculated from the diameter of the reservoir and the height of the water before and after the test. The flow rate is calculated from the duration of the test. Although the cost of repairing the reservoir may not be justified, the exercise will provide valuable information for a future water balance calculation.

Flowmeters

Bulk flowmeters, which are not working, should be repaired or replaced. The currently installed, French-manufactured Farnier meters are of an obsolete design and, when they fail, should be replaced with Kent meters for the following reasons:

— there is a Kent agency in New Zealand which is known to the Water Works;
— meters and spares are readily available;
— the flowmeter head can easily be removed from the meter body for replacement.

Future meter installations should include a by-pass, so that repairs can be made without shutting off the supply.

The portable ultrasonic meter could possibly be repaired by a local electronics engineer. It is unlikely that tracing the manufacturer and sending the meter away for repair would be cost-effective.

Zonal leakage monitoring

Zonal leakage monitoring involves installing flowmeters at certain points in the network to monitor flows into a discrete area bounded by closed valves. Monitoring flows into the zone, particularly at night when consumption should be at a minimum, gives a clear indication of excessive use, which is due to excessive consumption, or waste of water by consumers, or leakage.

Water use = consumption + waste + leakage

Two options exist in the Rarotonga network for zonal leakage monitoring:

1. Intake zones
The sectorization plan suggested by the French, and adapted by the Water Works, would divide the network into discrete zones each served by an intake. Each zone would contain the intake trunk main, a length of the coastal ring main, and an area consisting of sub-mains and consumer supply pipes.

The Avatiu intake has been identified as a pilot area to demonstrate the benefits of this type of zoning and zonal metering. The zone is already isolated by closed boundary valves. The zone is therefore ideal for demonstrating the effects of leakage detection and repair. The meter should first be repaired or replaced with a meter from one of the intakes which is seldom used. It is likely that this will take place during the mission. As part of a future project, a data logger should be purchased so that continuous diurnal flow measurements can conveniently be made. An active leak detection and repair programme should then be carried out. Logged night flow readings should be made after each repair to assess the effect on reduction in leakage. An audit of the consumer meters in this zone should be made. Those which are working should be noted and those which are repairable should be repaired. This will enable consumer demand to be monitored—reduction in demand by a water awareness programme would show up as suppression of the whole diurnal flow curve, whereas leakage reduction will be characterized by a drop in the night flow sector of the curve.

2. Sub-main zones
This type of zone is formed by metering at branch connections to the ring main, so that the trunk mains and the ring main are excluded from the monitoring zone. It is likely that the majority of leaks are on the sub-mains and supply pipes, and this type of monitoring would be the most beneficial in reducing leakage in the short term.

A potential pilot study area to demonstrate this type of zonal leakage monitoring is the Rutaki area. Plans for installing a flowmeter and closing zone boundary valves have been discussed with the Director and, subject to meter purchase, will be implemented during the mission.

It is recommended that funds be allocated to a follow-up project for the purchase of flowmeters and data loggers to extend zonal monitoring to the rest of the sub-mains. It is likely that the Rarotonga network would be divided into ten sub-main zones, and a range of meters—suitably sized for the pipe size and flow range of the zone—should be purchased. The outline zone plans should be used to identify the main size. As a rough guide, a meter 5 inches main diameter has a sufficient flow range for most distribution systems. The smallest meter possible to cope with peak flows should be chosen to accurately record minimum night flows. Meters can also be sized using a network model, or by conducting a 24-hour flow test with a portable clamp-on ultrasonic meter or a portable electromagnetic insertion meter. Both types of portable meter are listed on page 157.

The project may also require extra valves to form zone boundaries.

Pressure monitoring and management

Pressure monitoring has several functions:

- — to monitor the pressure level of service;
- — as a performance indicator for improvement after leak detection and repair;
- — to assess the potential for pressure reduction with a pressure-reducing valve.

Pressure monitoring points in the Rarotonga network should be extended to include critical points. Examples of these are:

— extremities of the pipe network;
— high spots;
— known areas of low pressure;
— at the zonal flowmeter.

In high-pressure areas, reduction via a pressure-reducing valve (PRV) is the single most effective means of reducing burst rates and leakage volume. There are several examples of excessively high pressures (>60m) in the Rarotonga network, and consideration should be given to the installation of PRVs in a future project. Where justified, PRVs could be installed at each zonal monitoring point, downstream of the zonal flowmeter.

Except in critical areas, pressure reduction would have little effect on the ordinary consumer, whose consumption is not pressure-dependent. However, it could have a profound effect on reducing the excessive use of water by those growers who practise 24-hour watering—because there would be less volume flow during the night hours, when pressure in the network normally rises, after PRV installation.

A pressure monitoring programme will identify critical points in the network, and those areas where pressures can safely be reduced. When PRVs are installed the outlet pressures should be gradually reduced (e.g. by 5.0 metres per week) to avoid complaints from consumers, who invariably notice a sudden large drop in pressure, but not a gradual reduction.

Pressure can be measured with a gauge or a pressure transducer and data logger. Existing points such as hydrants can be used, or new points installed. Transducers are installed via a modified hydrant cap, or directly on to the pipe via a push-fit connector.

Pipe survey

The Water Works has a programme to systematically survey and reference the positions of existing pipes, to record the positions of new pipes, and to verify or upgrade the geographical information system (GIS).

Although previously competent with pipe location equipment, Water Works staff have reinforced their skills during the mission. New skills for tracing pipe depths using the transmitter have been acquired.

The pipe locators owned by the Water Works are, however, only suitable for finding metallic pipes. It is therefore recommended that a non-metallic pipe locator is purchased for the project. A suitable instrument is the Radiodetection RD500. This consists of a mechanical transmitter which induces a vibration in the water column via a hydrant. The pipe is located when the seismic wave created by the transmitter is picked up by sweeping the area with a receiver. A suitable non-metallic pipe locator is listed on page 157.

The metal detector owned by the Water Works is suitable for finding buried valve covers up to a depth of around 0.3 metre.

There is no suitable survey equipment available to the Water Works. This is needed for accurately referencing and recording the positions of pipes and fittings. The consultants recommended that a total survey station be purchased for this purpose.

It is recommended that when laying new PVC pipes a metallic strip is laid alongside the pipe to make location easier. Although metallic tape is available for this purpose, a cheaper option is to use old electrical cable. To work effectively, however, the cable should make a continuous connection between fittings, to maintain a signal for pipe location.

Leakage survey

During the mission the leak detection team became fully conversant with the use of the leak detection equipment loaned to the mission. The equipment was an acoustic sounding stick and a ground microphone. The team, together with the training consultant, will continue to survey with this equipment until the end of the mission.

To continue leak detection activities after the mission, however, the Water Works will need to purchase their own ground microphone, as it is unlikely that the Metrovib leak detection equipment can be repaired.

A suitable ground microphone is given in the equipment list. There are two modes of use:

— contact mode, for sounding on valves, hydrants, consumer meters, and exposed sections of GI pipe;
— ground microphone mode, for sounding on the ground surface over the line of the pipe, when contact sounding indicates a noise between two fittings.

Leak noise correlator

Owing to several factors, sounding with a ground microphone is not always satisfactory. The sensitive microphone is easily influenced by traffic and other noise in the vicinity of the pipe. In addition, until the pipe survey has been completed, leaks on non-metallic pipes will be difficult to find because of the uncertainty of their position. For a future programme, consideration should therefore be given to the purchase of a leak noise correlator. Unlike the ground microphone, which depends on the volume of noise from the leak to pinpoint its position, the correlator uses the velocity of sound travelling through the pipe material towards each of two microphones placed on fittings along the pipeline. If there is a leak between the two microphones, it shows as a peak on the correlator's digital display. The display also gives the distance of the leak from each of the two microphones. The method requires precise measurement of the total distance between microphones, including hydrant tees and branch connections. The correlator can identify a leak position to within 0.5 m. Because the method does not depend on sound volume it is not affected by ambient noise such as traffic noise.

For successful operation the microphones of the noise correlator should be placed less than 500 m apart. There are adequate sounding points in the Rarotonga network (valves, hydrants, meters, exposed GI pipe sections) for this criterion to be met and for correlation to be successful. The instrument is, however, very expensive. The price is currently approx. NZ$ 30 000, although there are indications that another model at half this price will shortly be launched. The new model incorporates a data logger and step-test unit (a method for localizing leaks in a section of a monitored zone), and the consultants recommended that this model should be investigated.

The correlator would be extremely advantageous for the network conditions of Rarotonga, and consideration should be given to allocate funds for its purchase for the follow-up project.

Leak localizers

A method for localizing leaks, i.e. narrowing down the leak to a small area of the network, is becoming increasingly popular as a first step in the leak detection process. The Aqualog 40 equipment consists of a kit of six hydrophones, each of which has a data logger. The hydrophones are placed on adjacent hydrants, forming a cluster of sounding devices. Data loggers record the sound picked up at each hydrant. If any of the hydrophones displays a high volume and narrow frequency spread, this indicates a leak in the vicinity of that hydrophone. A ground microphone or correlator is then used to locate the leak. This equipment can be adapted for use in any network, and is particularly useful in networks with non-metallic pipes. Consideration should be given to testing this equipment in the pilot study areas.

Leak repairs

Although the present method of temporary leak repair is unsatisfactory, the consultants are aware that there are financial constraints. Repairs should ideally be done with repair clamps, which will effect a more permanent repair.

Waterproofing material, such as "Denzo" tape, should be wrapped around repair clamps, joints and fittings on GI pipes to slow down corrosion.

A submersible pump should be purchased to clear water from excavations during repair.

A plan showing grid references should be used by the leak detection team to help the repair team to locate leak repair sites.

Data loggers

Suitable data loggers for measuring flows and pressures in the Raratonga zonal metering project are the Technolog "Metrolog" or the Biwater Spectrascan "Water Spider". Both are low-cost British loggers and are similar in their function and ease of operation. They are both programmed via a Psion or similar laptop. The agency in New Zealand used by the Water Works, ADR-Kent, supplies Biwater Spectrascan equipment. The availability of Technolog should be investigated. The equipment list (see below) allows for sufficient data loggers for permanent installation in the meter chamber for each intake meter and each sub-main zone meter.

Equipment purchase

A list of recommended equipment for pilot zones and for full implementation of zonal leakage monitoring and detection has been compiled.

Brochures for most items of equipment have been left with the Director.

Costs of equipment for the follow-up project and pilot study areas is estimated at NZ$ 29000–44000. Costs for full implementation are estimated at NZ$ 73000–83000. Extra costs for optional equipment are estimated at NZ$ 22000–25000

6. Recommended equipment

Equipment considered essential for the follow-up project pilot study areas:

Item (number needed)	Manufacturer/Type	Approximate cost (NZ$)
Leak noise correlator	Palmer MicroCorr 6	15000–30000
Ground microphone	Palmer MK4	4000
Non-metallic pipe locator	Radiodetection RD500	4000
Data loggers (3)	Technolog Metrolog (NZ$ 1000) (or Spectrascan Water Spider)	3000
Sub-main zonal flowmeters (2 of 4 in./1 of 6 in.)	Kent Helix 4000 (NZ$ 1000)	3000

Equipment considered essential for full implementation of zonal monitoring:

Item (number needed)	Manufacturer/Type	Approximate cost (NZ$)
Sub-main zonal flowmeters (7 of various sizes)	Kent Helix 4000	7000
Intake zonal meters (12 of various sizes)	Kent Helix 4000	12000
Data loggers (19)	As above	19000
Pressure reducing valves (approx. 5)	Size and type to be selected (NZ$ 2000 each)	10000

References

1. Farley MR and Dakin M. *World Health Organization—Regional Office for the Western Pacific, Mission to the Cook Islands*. Report No. RS/97/0627, 1987.

ANNEX 4

Glossary of terms

1. Components of night flow

(For a full glossary, see *Managing Leakage*—Report B, Appendix F)

Minimum Night Flow (NFM), the measured rate of flow into any distribution network or DMA during the minimum demand period on a given night.

Night Flow Delivered (NFD), the flowrate into customers' premises at the point of delivery at the time when minimum night flow is measured

Distribution Losses Night Flow (NFLD) = NFM—NFD; the leakage in the distribution system

Customer Night Use (NFCU), the amount of NFD used by the customer

Total Night Flow Losses (NFLT) = NFM—NFCU; the leakage in the distribution system and on customers' supply pipes

Supply Pipe Night Flow Losses (NFLS) = NFD—NFCU

Exceptional Night Use (NFCUE), night flows to customers >500 litres/hour

Net Night Flow (NFN) = NFM—NFCUE

2. Technical terms

(For a full glossary, see *Managing Leakage*—Report G, Appendix A, and Report J, Appendix A)

AZP Average Zone Pressure, the pressure in a Pressure Managed Area (PMA), which is calculated or measured at a surrogate point, and deemed to be the average of all the pressures in the DMA

AZNP Average Zone Night Pressure; like AZP, but for the minimum night flow period. *Managing Leakage*—Report G, Appendix D.1.2, explains the calculation of AZP and AZNP

DMA District Meter Area, an area which has a defined and permanent boundary, usually containing 500–3000 properties, into which flows are continually monitored

ESPB Equivalent Supply Pipe Bursts, a term for expressing excess night flow as an indicator of the maximum number of bursts to be located (a mains burst is equivalent to several supply pipe bursts), and used to set intervention policy

Hour to Day Factor The factor to convert night flow rate into a daily volume of leakage, taking into account the pressure variations which occur during the 24-hour period

ICF Infrastructure Condition Factor; a factor to indicate the relative condition of the infrastructure (0.5 = good condition, 2.0 = poor condition), used in the calculation of background losses

PCF Pressure Correction Factor; a factor to correct the AZNP to a standard 50m, used in the calculation of background losses

PMA Pressure Managed Area. Part of a DMA (or the whole DMA) which is subject to pressure management

ANNEX 5

Equipment manufacturers

Description of the equipment and contact details in the United Kingdom

Manufacturer	Products	Contact details
1. Flowmeters		
ABB Kent Taylor	Magmaster EM meter Aquaprobe EM insertion meter	Old Ends Lane Stonehouse Glos. GL10 3TA
Kent Meters	Helix 4000	Pondwicks Road Luton Beds. LU1 3LJ
BTR Ltd	SOCAM, Meinecke & Sensus Meters	Davenport House Davenport Gate West Portway Ind. Est. Andover Hants. SP10 3SQ
2. Data loggers/Telemetry		
Biwater Spectrascan Products	Microlog Hydrolog Spectralog Microlog T 507 (telemetry)	24/25 Hussar Court Westside View Waterlooville Hants PO7 7SQ
Kent Meters	LRP pulse generator (10 pulses/rev) HRP pulse generator (100 pulses/rev)	Address as above
Primayer Ltd	Socrates (auto-correlating flow analyser)	2 The Spinney Parklands Business Park Denmead Hants. PO7 6AR
Radcom (Technologies) Ltd	Lolog Sentry Centurion/Senator Monitor PSTN Centurion (telemetry) Centurion GSM (telemetry) Senator (telemetry)	2 Venture Road Chilworth Research Centre Southampton SO16 7NP

This list of equipment and manufacturers should be viewed as an example of available equipment. By no means is it implied that the World Health Organization recommends this equipment in preference to others of a similar nature that are not mentioned.

Manufacturer	Products	Contact details
Technolog Ltd.	Baby Newlog Metrolog Newlog 3 (low power telemetry) Utilog (PSTN telemetry)	Technolog House Ravenstor Road Wirksworth Matlock Derbyshire DE4 4FY Tel: 01629 823611
Wessex Electronics Consultants Ltd	Metermate (pulse generator) Loggermate series (inc. telemetry option)	Unit 2 Home Farm Lockersley Hall Estate Romsey Hants. SO51 0JT

3. Leak detection and location equipment

See Section 9.3 for details of equipment.

Biwater Spectrascan Products		Address as above
Commercial Industrial	Wooden Sounding Stick Gauges	The Drill Hall Llay New Road Llay Wrexham LL12 0PT
Gorseline Ltd	SF6 gas detection	16 High Street Hatfield Doncaster S. Yorkshire DN7 6RY
Palmer Environmental Ltd		Ty Coch House Llantarnam Park Way Cwmbran Gwent NP44 3AW
Pipeline Consultants Ltd	Sewerin leak localizers and leak location equipment	Bickenhill Lane Solihull Birmingham B37 7JQ
Primayer		Address as above
Radiodetection Ltd	Sensistor H2 gas detection	Western Drive Bristol BS14 0AZ

ANNEX 6

BABE and associated software

RPS Water Services Ltd, Block 4, Mountjoy Research Centre, Stockton Road, Durham, DH1 3UU, England.

Description of software

BABE Model RPS version of the Annual Water Balance Model

Pressman Predict the financial and volumetric results of pressure reduction

CelloRI Calculates economic levels of leakage in regularly inspected areas

CelloNI Calculates economic levels of leakage in night flow inspected areas

CostLoss Fits a 4-parameter equation to a curve and determines the slope of that curve at a point

Hour-Day Calculates the hour-day factor for a DMA. A version was released as part of the UKWIR research

CUSP Calculation of underground supply pipe losses

No Flows Prediction of volumetric savings from pressure reduction. This is a version of Pressman which does not need flow data

ALC Calculation of the economic level of leakage. Released as part of the UKWIR research

PMRural Prediction of volumetric savings from pressure reduction. This is a version of Pressman which only requires a 24-hour AZNP pressure profile

MELLONI Calculation of economic levels of leakage for a company, by summation of individual supply zones. Released to North West Water only

LIMES Calculation of economic levels of leakage for a company, by summation of individual supply zones. Supersedes MELLONI, and is the basis of several UTS contracts

MPRESS Multiple feed version of Pressman

FORECAST Long-term forecasting of supply/demand requirements

ELLRINI Calculation of economic levels of leakage, and predicts the benefit of moving from regular sounding to night flow monitoring

DJNFIS Night flow analysis programme for a district. Based on NFA.

ECONSS (EIPISD) Calculation of Economic Intervention Policy for small districts. Based on Kliene Okowva (in French)

Night Use Calculation of customer night use based on Report E classifications.

NFA Night flow analysis programme for a district.

Okowva	Calculation if the economic level of leakage for regular sounding (in German)
Kliene Okowva	Calculation of the economic intervention level for municipalities with small numbers of bursts (in German)
EMA	Analysis of pressures and flows using temporary hose connections during the day (in German)
CelloMan	Calculation of the economic level of leakage for night flow monitoring. A cut down version of Celloni with variable burst sizes
MustcatPR	Predicts the financial and volumetric results of pressure reduction, based on Pressman
OmanND	Calculates the night-day factors for a DMA. Based on hour-day
OmanNFA	Night flow analysis programme for a district
Scears	Calculation of economic levels of leakage for regular sounding, simplified version of CelloRI
Schdpm	Calculation of hour-day factors for the Santa Cruz distribution system and estimation of the reduction in losses from pressure control
Scmnfa	Analysis of minimum night flows for Santa Cruz for multiple zones
Scnfsz	Night flow analysis programme for a district
Amsis	Seasonal intermittent supply model for Amman. Calculates losses, and estimates the effects of different parameters. Used to predict the effects of different leakage contracts
Amnfa	Night flow analysis programme for individual zones. This programme is the basis for all other NFA programmes
Ampress	Predicts the financial and volumetric results of pressure reduction. This programme is the basis of Pressman, and also leads to the development of the hour-day programmes
Ammhd	Calculation of hour-day factors
Sapress	Predicts the financial and volumetric results of pressure reduction
Sanfa	Night flow analysis programme for individual zones
USACNU	Calculation of customer night use
USAND	Calculation of night-day factors
JZNFA	Night flow analysis programme
JWUND	Calculation of night-day factors
JZPM	Predicts the financial and volumetric results of pressure reduction
JCAD	Calculation of the components of the Annual Water Balance
JMNF	Whole system night flow analysis programme
NCAB	Calculation of the components of the Annual Water Balance
NSZR	Sub-zone refill programme
MOFFS	Flood forecasting programme for the World Meteorological Organization