

# DEVELOPING A STRATEGY FOR LEAKAGE MANAGEMENT IN WATER DISTRIBUTION SYSTEMS

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## ABSTRACT

Much that has been written about leakage economics and strategies has been aimed at either the leakage specialist or the economic regulator. This paper aims to make the practitioner aware of the key messages from the theory, and the issues which have to be taken into account, when developing appropriate policies and practices. The tasks and solutions involved in developing a strategy are illustrated in figure 1.

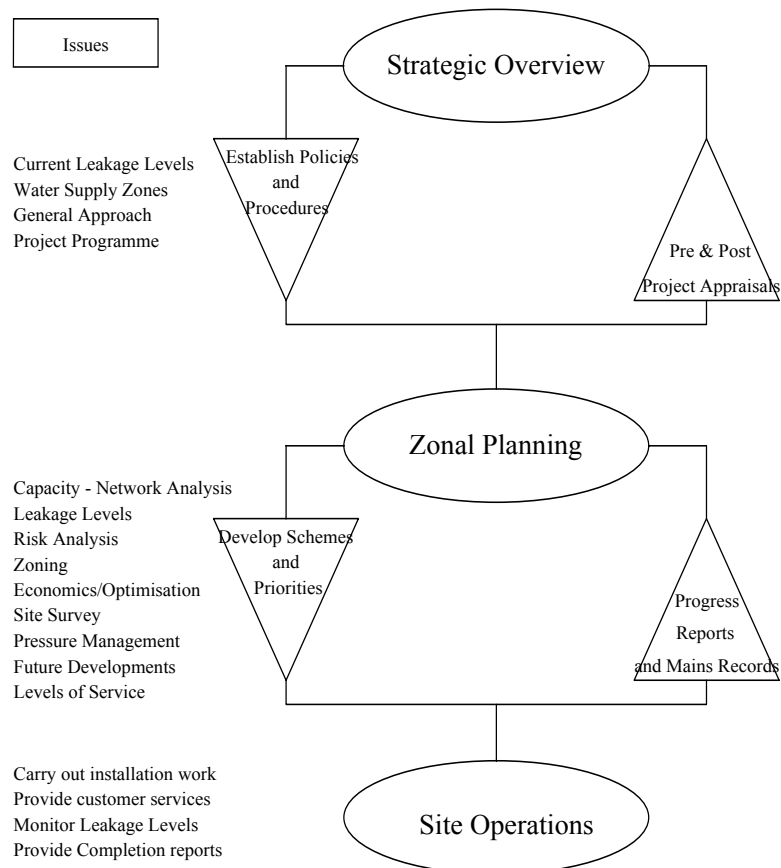


Fig. 1 - A Structured Approach to Leakage Management

The most important aspect of any leakage strategy is the leakage target. What level of leakage should the water supplier aim for, and what level should be maintained in the longer term? In an ideal world, every water supplier would like to eliminate leakage from water distribution systems. **However, there will always be a level of leakage which has to be tolerated, and which has to be managed.**

The paper gives an overview of the prime techniques for leakage management, which have been referred to as the four 'pillars'. Each of these follows a similar law of diminishing returns on investment to make savings in leakage. The key issues for introducing these four elements are discussed, together with the steps required to calculate the economic level of leakage.

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**INTRODUCTION**

**Water loss** occurs in all distribution systems - only the volume of loss varies. This depends on the characteristics of the pipe network and other local factors, the water company’s operational practice, and the level of technology and expertise applied to controlling it. The volume lost varies widely from country to country, and between regions of each country. The components of water loss, and their relative significance, also vary between countries. One of the cornerstones of a water loss strategy is therefore to understand the relative significance of each of the components, ensuring that each is measured or estimated as accurately as possible, so that priorities can be set via a series of action plans.

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

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

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

**STRATEGY**

It is difficult to be prescriptive as to the methodology which should be followed for setting leakage targets and for deriving an appropriate strategy for managing leakage.

The following sections set out a general series of steps to follow, whatever the nature of the water supply organisation. Figure 2 illustrates the generalised leakage management strategy.

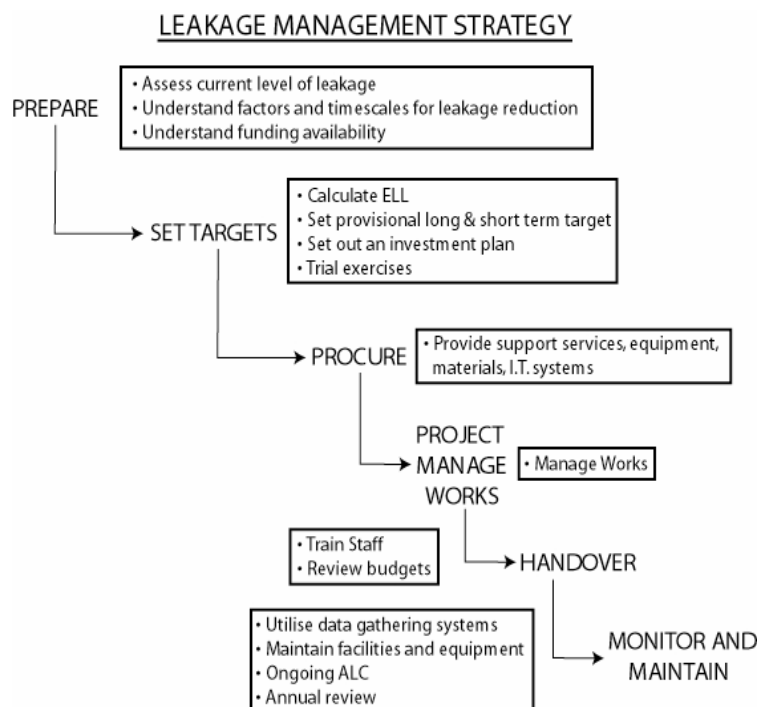


Fig.2 – Steps in a Leakage Management Strategy

**PREPARE:**

**Assessing water losses - The IWA International standard**

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

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

- System Input Volume is the annual volume input to that part of the water supply system
- Authorised Consumption is the annual volume of metered and/or non-metered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorised to do so.
- Non-Revenue Water (NRW) is the difference between System Input Volume and Billed Authorised Consumption.

System Input Volume (corrected for known errors)	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption (including water exported)	Revenue Water
			Billed Un-metered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water (NRW)
			Unbilled Un-metered Consumption	
	Water Losses	Apparent Losses	Unauthorised Consumption	
			Customer Metering Inaccuracies	
		Real Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility’s Storage Tanks	
		Leakage on Service Connections up to point of Customer metering		

Fig.3 IWA Standard International Water Balance and Terminology

- Water Losses is the difference between System Input Volume and Authorised Consumption, and consists of Apparent Losses and Real Losses
- Apparent Losses consists of Unauthorised Consumption and all types of metering inaccuracies
- Real Losses are the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

The components of the water balance should always be calculated as volumes before any attempt is made to calculate performance indicators. The separation of Non-Revenue Water into components – Unbilled Authorised Consumption, Apparent Losses and Real Losses – should always be attempted.

### **Understand Factors and Timescales**

All components of the Water Balance, and the Performance Indicators derived from it, are subject to errors in input data. The key to developing a water loss strategy is to gain a better **understanding** of the reasons for losses and the **factors** which influence them. Then **techniques** and **procedures** can be developed, and tailored to the specific characteristics of the network and local influencing factors, to tackle each of the causes in order of priority. Whilst there is no quick and easy answer to reducing losses, much can be learned from the recent experiences of the UK water industry. Urged on by the regulators to develop ‘more robust’ procedures for analysing and controlling losses, industry practitioners now have in place a number of techniques for understanding, measuring, and monitoring losses within the distribution network. Most companies have also introduced programmes to encourage customers to use less water. These experiences are referred to throughout the IWA book.

A diagnostic approach, followed by the practical implementation of solutions, which are **practicable** and **achievable**, can be applied to any water company, anywhere in the world, to develop a water loss management strategy. The first step in developing a strategy is to ask some questions about the network characteristics and the operating practices, and then use the available tools and mechanisms to suggest appropriate solutions, which are used to formulate the strategy. Typical questions (with the strategic answers) are;

- **How much** water is being lost? Calculate a WATER BALANCE
- **Where** is it being lost? Conduct a NETWORK AUDIT
- **Why** is it being lost? Review NETWORK PRACTICES
- **What** strategies can be introduced to **reduce** losses and **improve** performance? Develop APPROPRIATE STRATEGIES
- **How** can we **maintain** the strategy and **sustain** the achievements gained? Implement TRAINING and OPERATING procedures.

### **Establishing funding requirements**

An appropriate leakage reduction plan can only be set with due regard to the funding requirements. Even if leakage targets can be shown to be economic, the work has to be funded up front in order to achieve a pay back over a longer term – in some cases over 20 years. Funding could come from raising charges to customers, from government sources, from international grants and loans, or by accepting a lower level of profit during the leakage reduction work. It is important for the sponsors of the leakage programme to involve the water suppliers’ financial managers at a very early stage, as resolving the funding issues could take just as much time and effort as the technical aspects of the strategy

### **Reviewing the organisation structure and making changes to leakage programme management**

Where a major leakage reduction programme is planned, it will be not be efficient, is unlikely to be fully effective, unless the organisation structure is reviewed, and changed to take account of the new demands placed upon it. Whenever the workload warrants the appointment of a leakage manager, this is the preferred course of action. The leakage manager should then have responsibility for delivering the leakage reduction programme along the strategy agreed by the directors. It is essential that the leakage manager be given the support of the directors, and that if possible the same person remains in post during the leakage reduction stage. That person, who should be committed to the project, will become a focal point for leakage management activity and will be able to coordinate the various aspects of the programme.

There will inevitably be times when the programme is not going according to plan. During such periods it is important to differentiate between two stages of leakage management:

- Leakage reduction down towards a set target. This stage should be regarded as a project involving capital works, and other transitional costs, which can be managed as a project in a similar way to building a new treatment works. The project should be managed by someone with good project management skills, who does not necessarily have to be a leakage expert. However, the team should incorporate experts or external advisors, and also involve operational staff who will be responsible for maintaining leakage once it is reduced.
- Maintaining leakage at the target level. This stage should be incorporated into the ongoing management of the water supply organization, and managed in a similar way to the operation of the treatment works. During this stage there is less need for a dedicated leakage manager, but if the organisation is sufficiently large there is a case for a leakage coordinator to ensure consistency of approach across the region.

These two stages may run concurrently in the same organisation. A supply zone will be handed over from operational staff to the project management staff, and once the leakage reduction work is complete it will be handed back. Different zones will be at different stages during the overall project until work has been completed across the region.

### **SET TARGETS:**

The most important aspect of any leakage strategy is the leakage target. What level of leakage should the water supplier aim for, and what level should be maintained in the longer term? Leakage is synonymous with waste. Therefore, a company which wastes the product it is meant to supply, must come under scrutiny to investigate what else it wastes, for example customer income. This in turn can lead to prices for the product in excess of what is reasonable.

Every water supplier would like to eliminate leakage from water distribution systems. It serves no purpose, is wasteful, and has a deleterious effect on several aspects of the operation of a well-run water supply network. Leakage will add to the cost of producing and distributing water. It will add to the capacity requirement for storage systems, treatment works, and mains sizing. However, for the vast majority of water distribution systems, leakage is something which cannot be eliminated completely. **There will always be a level of leakage which has to be tolerated, and which has to be managed.**

When considering alternative ways of bridging the gap between the future need for water into an area, and the current availability of water, there are usually two principal methods:

- Supply augmentation. This may mean adding reservoir or pumping capacity, increasing treatment capacity, bringing in water from an adjacent area
- Reducing the future need for water by leakage reduction and demand management.

Each of these methods will increase the forecast 'headroom' i.e. the difference between the available supply and the projected demand, and therefore reduce the risk that supplies will become insufficient to meet customer demand. This is shown in figure 4. However, when comparing the economics of the two methods there is a general principle which should be appreciated.

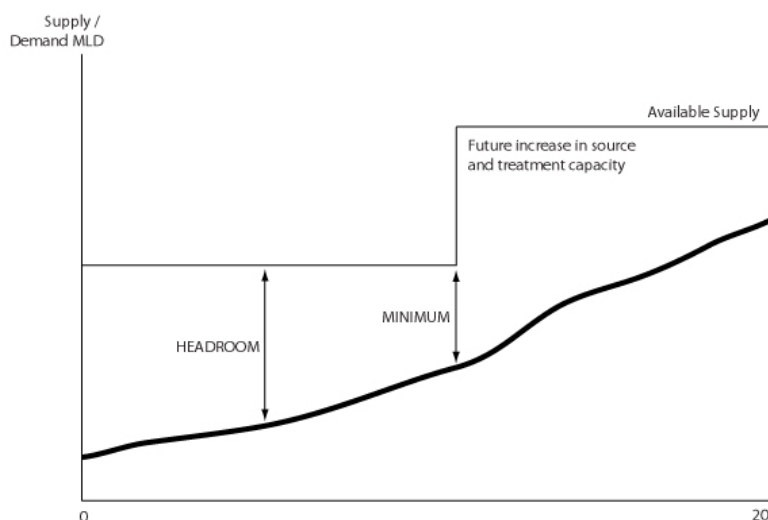


Fig. 4 – The effect of increasing demand and supply on available “headroom”

Reducing leakage costs money. However, unlike supply augmentation, there is less scope for economies of scale. In fact the reverse tends to be true. Everything to do with leakage reduction follows a law of diminishing returns; the more effort that is put in, the less will be the impact in terms of water saved.

Figure 5 shows the prime techniques for leakage management, which have been referred to as the four “pillars”. Each of these follows a similar law of diminishing returns (see figure 6):

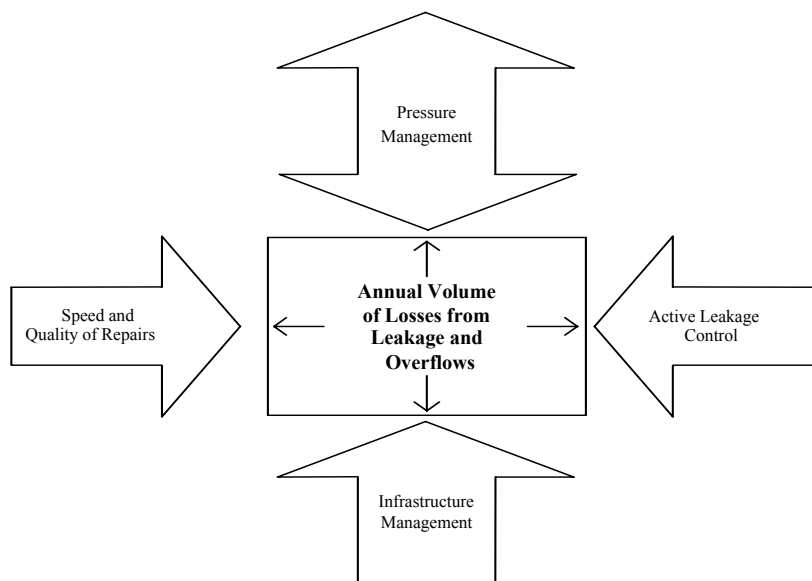


Fig. 5 The Four Pillars of Leakage Management

#### *Active Leakage Control*

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

#### *Pressure Management*

The most cost effective schemes are those which cover a large area, and which make a significant impact on average pressures. An example would be the installation of a pressure reducing valve on the branch from a trunk main to cover a whole town. Once such schemes have been completed, the next stage may be to install PRVs in conjunction with district metering. In the extreme, some water suppliers have installed PRVs on supplies to districts of less than 200 properties, or even on individual properties. The cost of the scheme reduces much less than the benefit obtained due to the reduction in the area covered, and so the schemes become less cost effective.

#### *District metering*

When installing zonal and district metering there is a tendency to favour areas which can be metered without the need for additional facilities to be installed in the network. Areas will be created using natural breaks in the network, along the lines of main roads, rivers and canals, and over undeveloped land.

The aim is to provide single feed district meter areas (DMAs) which are supplied through only one meter installation. This will tend to minimise the number of valves which have to be shut in order to create a discrete area. The number of areas which can be created in this way will depend on the layout of the

distribution network. The cost and the benefit will be similar. As the number of properties contained within DMAs increases, there will come a point at which adding further properties incurs a higher unit cost.

*Mains and service renewal.*

Replacing an old water main with a new installation will reduce leakage on the main. If water mains are being replaced for reasons other than leakage control, for example water quality problems, then the benefit to the leakage engineer should also be taken into account. When mains replacement is being used as a primary measure for leakage reduction, targeting studies should be carried out to determine which areas, and which mains within those areas, have the highest burst frequency (number per kilometre per year) and which have the highest levels of background leakage. If targeting is carried out effectively, it is inevitable that the initial schemes will be more cost effective than the later ones. So, mains replacement will also follow a law of diminishing returns.

*Speed of repairs*

Reducing the time it takes to repair a leak will reduce the volume of leakage. However, once the repair time is reduced below a certain threshold, the unit repair cost will tend to rise due to standby, call out and overtime payments to staff, or supplementary payments to contractors to make additional repair teams available.

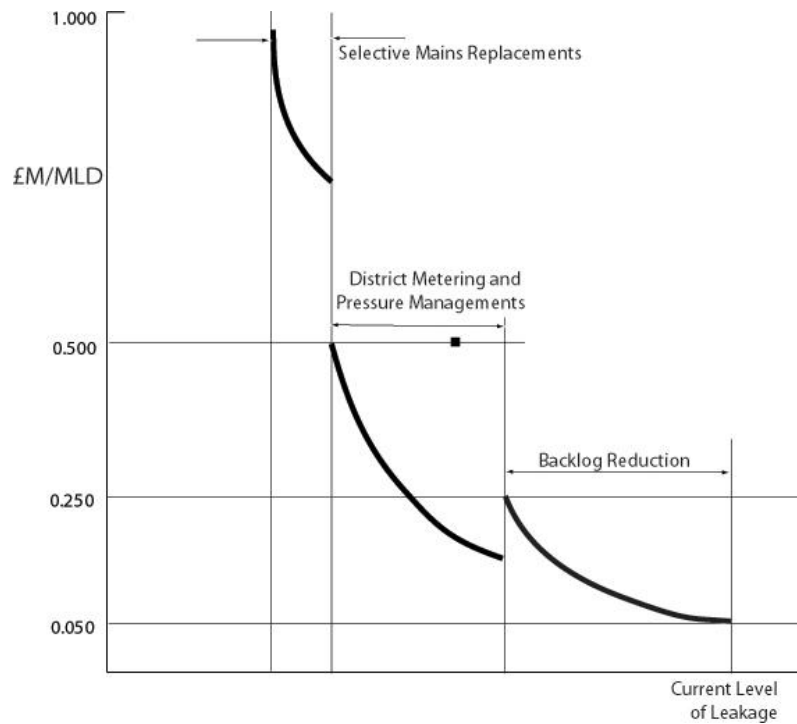


Figure 6 Diminishing Returns from Leakage Management Measures

**Economic Level of Leakage**

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

Figure 7 shows the generalised relationship between expenditure on leakage management operations, and the unit production costs of water as a function of the level of losses. The key to a successful strategy is to collect sufficient factual data to allow this relationship to be understood for each supply zone.

In order to understand the estimation of ELL, it is necessary to appreciate how water is valued. This will vary from one region to another, and also within areas of the same region.

### **Short term ELL**

In the short term there are a number of key parameters which govern the actual level of leakage. These are effectively fixed, and include:

- The average pressure in the system
- The condition of the mains and service pipes
- The facilities available for collecting data (i.e. district metering and telemetry)

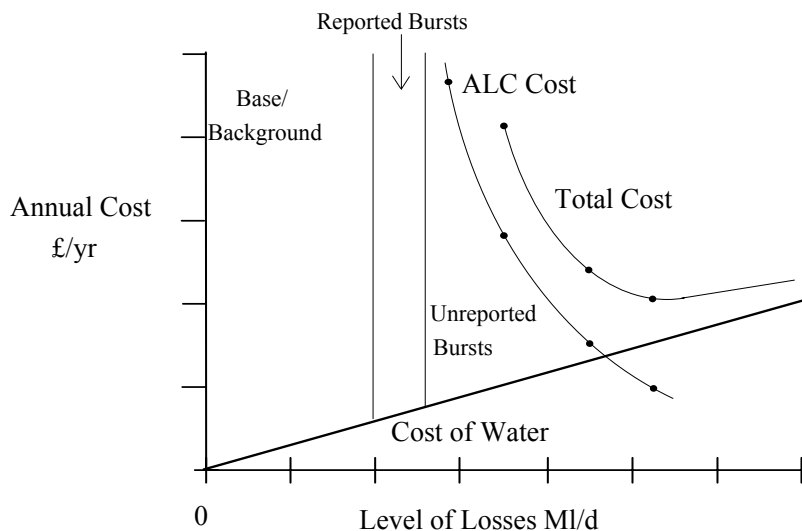


Figure 7 General relationship between operating costs and the level of losses

So, at any particular time, the only parameter which can be changed quickly to have an impact on the level of leakage, is the number of personnel out looking for leaks and then repairing them. Leak location and repair is sometimes called **active leakage control (ALC)**. There is a steady state situation in which the marginal cost of the ALC effort is equal to the marginal cost of the water saved by adopting that ALC policy.

### **Long Term ELL**

In the longer term, investment in facilities such as district metering, telemetry, pressure management and mains renewal will have an impact on the short term ELL. The reduction in the short term ELL and consequently the savings and costs associated with the change can be compared to the investment cost of making the change. Investment costs are sometimes called transitional costs, i.e. they represent the cost of making the transition from one steady state to another.

Short term ELL is based on an economic analysis which estimates the optimum level of ALC effort taking account of the costs of ALC and the short term value of the water in the supply zone. Long term ELL is based on a form of investment analysis taking account of the following questions:

- What is the current level of leakage?
- What is the short term ELL?
- How will the short term ELL change with the investment under consideration?
- What is the saving in water losses and the change in ALC resources from the proposed investment compared with the current policy?
- What is the cost of the proposed investment?
- What is the return on the investment?

The answers to these questions will allow the water supplier to decide an investment policy using normal investment decision criteria.

### **Provisional Targets for Leakage**

Setting leakage targets goes beyond the stage of calculating ELL. Targets must be specific to a particular supply zone, and the overall target for the water supplier should then be the aggregation of each zonal target. Different procedures based on the analysis of ELL will apply in each zone.

The other issue is the influence of external pressures which can significantly affect the target for leakage compared to the ELL. External factors include:

- Comparisons with similar water suppliers. It is inevitable that water suppliers will compare their current leakage level and their calculated ELL with that of other water suppliers working in the same country or within the same geographical region of that country
- International comparisons
- Political influences. The true ELL for a company with plentiful supplies and a poor infrastructure may equate for instance to 35% of total demand. However, the company may come under pressure from its customers or from government or peer pressure to reduce leakage because it is perceived to be too high.

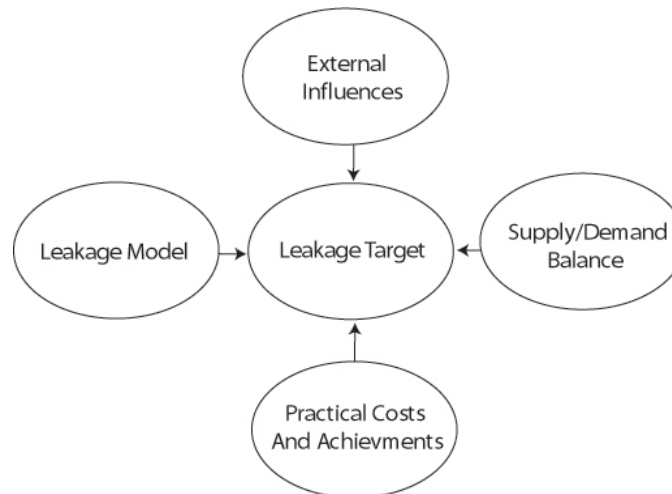


Fig. 8 - Factors influencing the target for leakage and losses

The most significant external factor affecting leakage targets is the impact of regulation on the water supplier. The nature of the regulation will depend on the general control and ownership of the water supply organization in a particular country. Regulation creates expectations from several parties which have to be managed:

- Customers expect the water supplier to control the prices they pay for their supply
- Government economic regulators also expect operating and investment costs to be justified
- Shareholders expect the water supplier to be managed efficiently and to produce a return on investment
- Environmental regulators and pressure groups seek to avoid further abstractions of raw water which deplete stream lakes and rivers, and the protest against the building of dams
- Drinking water inspectors protect supplies, and seek to control any works which may have an adverse effect on water quality.
- National governments aim to manage water supplies generally to ensure there is a general sufficiency for public health and for economic development.

Whilst targets may not be mandatory, there may be a requirement for leakage data to be submitted annually or at other regular intervals. If targets are set internally, without any external influence, there is a need to understand why targets have been set, i.e.

- is there a current water shortage generally, or in a particular region, or is a shortage forecast in the near future?
- have targets been set to bring the supplier into line with other similar organisations, or has the country as a whole become embarrassed about high leakage levels making it a political issue?

Whether targets have been set on external or internal influences, they will have a time-scale attached to them. A general target may be to reduce leakage by 20% within 5 years, or it may be to achieve a value for leakage

in litres per property per day by a given year, that year having some other significance. Time-scales must be realistic.

There is no easy solution to controlling leakage, even if substantial finance is made available for a one-off exercise within a constrained timescale. Leakage management is a painstaking process, and projects which aim to make a substantial reduction in leakage in a short space of time, are unlikely to succeed in the long term. Attempting to achieve too much too soon will lead to inefficiencies. There is a natural pace to a leakage reduction plan which varies from one region to another depending on a number of different parameters.

Where no particular internal or external influence exists and there is simply a general desire to reduce leakage down to an economic level, then it is recommended that a provisional long term target should be established as a goal to work towards. This goal should be ambitious, but it should not be impossible to achieve. The short term target should be set with reference to the long term target. A reasonable approach is to aim to achieve between 50% and 80% of the long term reduction within say 5 years. This time-scale is chosen as a reasonable one in which to set up the necessary facilities, to award contracts, and to carry out the initial works. A time-scale of between 4 and 7 years is reasonable; any less is too ambitious, and any more will not be as economic. The costs of leakage reduction will still be the same, but there is the cost of supplying the excess leakage after year 7.

Leakage will tend to be reduced over time following the “S” curve shape. The early leakage management expenditure may show little return on the investment, and there is a risk that staff will lose faith. However, if the effort is maintained (usually after 1 to 2 years), then leakage will begin to reduce quickly giving significant reductions in years 3 and 4. In the final stages, the rate of reduction will slow down due to the laws of diminishing returns explained earlier.

### **Setting up procedures to collect data**

Before any major expenditure is made on leakage reduction, it is very important that procedures should be established to collect all relevant data. Data collection should be established in a hierarchical way, so that by aggregating the data for DMAs within a supply zone, it is possible to provide average data for that zone. Similarly, supply zone data should aggregate to the company average values. In some cases it is necessary to create un-metered DMAs - these are areas which are not actually covered by a district meter, but for which the water supplier does have relevant data (e.g. number of properties and length of mains in the area) to make an estimate of leakage by other means. They usually have a defined boundary.

Leakage management is data hungry, and so investment in software systems and staff resources to manage the data can be significant. However, without such systems, there is a risk that investments will be targeted ineffectively and leak detection and repair operations will be carried out inefficiently. Therefore, although the cost of establishing good data management systems represents a high initial outlay, there will be a return on that investment in the longer run.

### **Establishing trial exercises**

These demonstrate benefits in a small area before introducing them company-wide. Whenever possible, demonstration exercises should be undertaken to show the techniques and also to deliver some early benefits in the leakage reduction programme. The exercises should not be regarded as separate from the mainstream programme. They should be planned as an integral part of it and carried out by the same team which will deliver the main body of work.

Pilot exercises may focus on a particular aspect of the leakage management programme, e.g. pressure control, or they may be all embracing to test the integrated strategy in a limited geographic area, e.g. a particular supply zone.

### **Importance of company specific data**

Whichever method is used to model leakage, or to derive a strategy, there is an inevitable dilemma. The strategy will be most important when the water supplier first embarks on a major leakage reduction exercise. To be accurate and reliable, the leakage made and the investment plan should be based on good quality data specific to that organization, and a well thought out investment programme in which there is a degree of

confidence that the expenditure planned will give the required benefits. However, if little or no work has been undertaken, then there will be no specific data. No data means that use has to be made of default values and assumptions and so there is less confidence in the modelled results.

Leakage modelling has been carried out over a number of years now, and the BABE concepts have been used in several countries around the world, with very different operating environments, and different policies, levels of service and configurations of their water distribution networks. As such, the original UK data have been enhanced, and the effect of these different global situations has resulted in a wealth of new data.

The solution is to take gradual steps, using data from each step to make changes to the model and to the strategy based on the lessons learnt. It is almost impossible to set out an effective leakage reduction plan and to stay with it from start to finish.

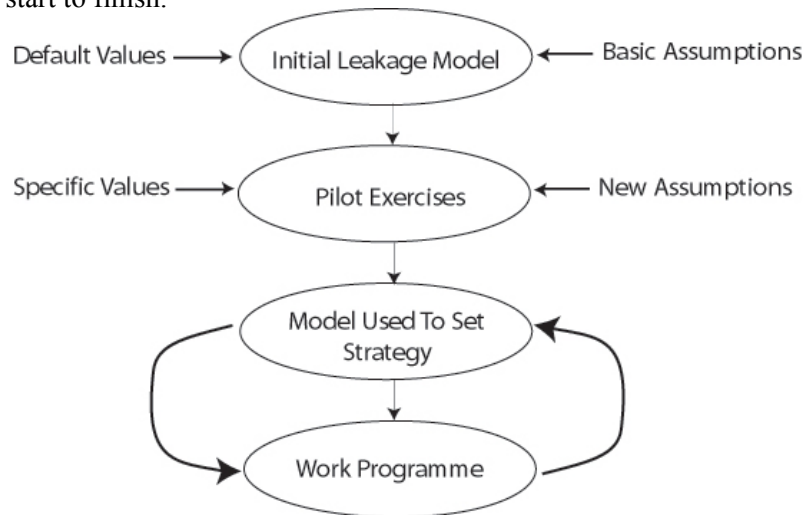


Figure 9 Using specific data to replace default values and assumptions

### **Introducing the strategy**

Perhaps the most important aspect of the leakage management strategy is that it is understood and followed by all parts of the water supply organization. There is a need to gain the commitment and cooperation of staff in a number of different departments, and in regional offices and depots of a large diverse organization. Effective leakage management requires an input from a number of different personnel, and unless they are all committed, the implementation of the programme will not be efficient, and it may then be difficult to maintain the infrastructure which has led to the lower leakage levels.

As an integral part of the strategy, careful consideration should be given to:

- A launch event such as a major seminar.
- Education and training of all staff, not just those directly involved with delivering the leakage management programme..
- A 'carrot and stick' approach has been found to be successful. Staff responsible for the ongoing operation of the water distribution system, are rewarded for proper maintenance of the leakage management infrastructure, whereas disciplinary action is taken against those who wilfully neglect to take account of the need to keep these systems in place.
- Public relations.

### ***PROCURE AND MANAGE WORKS:***

The leakage reduction works will comprise the four pillars of leakage management referred to earlier.

#### ***Active Leakage Control***

Leakage management can be classified into two groups;

- passive (reactive) leakage control

Passive control is reacting to reported bursts or a drop in pressure, usually reported by customers or noted by the company's own staff. The method can be justified in areas with plentiful or low cost supplies. Often practised in less developed supply systems where the occurrence of underground leakage is less well understood, it is the first step to improvement (i.e. to make sure all visible leaks are repaired)

- active leakage control (ALC)

The main methods of **ALC** are

- regular survey
- leakage monitoring

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

- listening for leaks on pipework and fittings
- reading metered flows into temporarily-zoned areas to identify high-volume night flows
- using clusters of noise loggers

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

The most appropriate leakage control policy will mainly be dictated by the characteristics of the network and local conditions, which may include financial constraints on equipment and other resources. Staffing resources are relevant, as a labour intensive methodology may be suitable if manpower is plentiful and cheap. Where leaks fail to appear at the surface, however, a more intensive policy of leakage monitoring is required.

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

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

The volume lost from a leak is a combination of the awareness time and the time taken for location and repair;

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

The main effect of an ALC policy is reducing the average **duration** of leaks, although repair times are unaffected by the choice of an active or passive policy. The awareness time is influenced by the data capture method;

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

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

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

Leakage monitoring requires the installation of flow meters at strategic points throughout the distribution system, each meter recording flows into a discrete district which has a defined and permanent boundary. Such a district is called a District Meter Area (DMA).

There is a clear distinction between leak detection and leak location. 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.

There are a number of techniques to detect where leakage is taking place in the network. These include;

- sub-dividing DMAs into smaller areas by temporarily closing valves or by installing meters (see Figure 10)
- variations of the traditional step-test
- the use of leak localisers
- sounding surveys

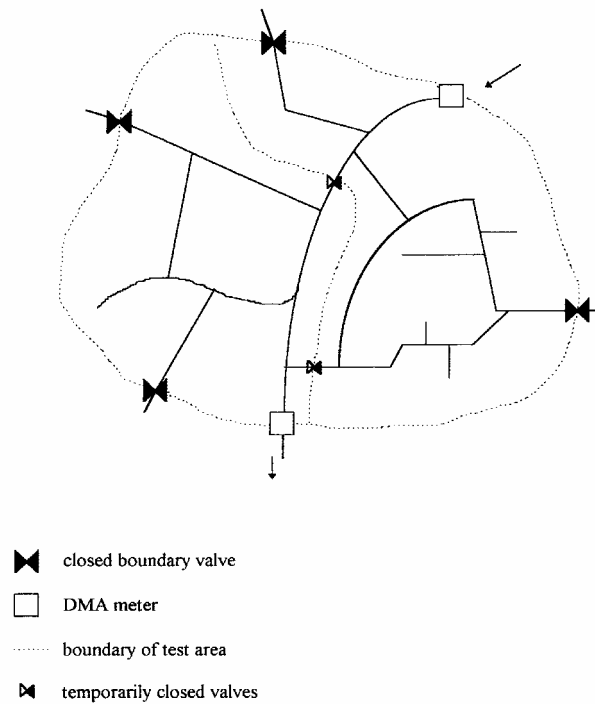


Figure 10 – A typical District Metered Area

There are two fundamental issues:

1. How often should areas be revisited?

The time period between inspection of a particular district is known as the intervention interval. The average intervention interval is a key element of the overall strategy. It should be set using economic considerations. It will have a major impact on the level of resources required

2. How much effort should be expended in each area before moving on to the next area?

Many aspects of leakage management follow laws of diminishing returns. This is also the case here. Once the initial leaks and bursts have been found, from what is often known as the first pass survey, then the more time which is spent in a district, the lower will be the return in terms of the number and quality of bursts which are found.

If the area in question is not covered by district metering, it may still be possible to apply the same principles at a supply zone level. The larger area will mean it is difficult to identify individual leaks, and it will make leak location more difficult. However, a balance has to be struck between the investment cost of the district metering, and the ongoing cost of meter reading, and the savings which result from a more efficient operation. These areas are subject to what is known as a policy of “regular sounding”, or regular survey. The frequency of the survey can be determined on economic principles and the strategy will include the number of staff required to maintain this inspection level. As it is difficult to estimate leakage in these areas they tend to be surveyed in rotation rather than on some form of prioritization. Economic frequencies of regular survey generally vary from a few weeks to about two years.

### Pressure Management

The rate of leakage in water distribution systems is a function of the pressure applied by pumps or by gravity head. There is a physical relationship between leakage flow rate and pressure, which has been proven by laboratory tests and by tests on underground systems. Burst rates are also a function of pressure. The strength of the relationship, and the quantification of it, is not as well understood as the relationship between flow rate and pressure. However, there is still considerable evidence to show that burst frequency is very sensitive to changes in pressure.

Pressure Management is one of the fundamental elements of a well-organised leakage management strategy. It should be an integral part of the strategy because it impacts on several other aspects:

- If pressure is reduced, the rate of increase in leakage will reduce. Therefore, there is an impact on the level of leak detection resources required.
- The flow rate from all leakage paths (bursts and background leaks) will reduce, as shown in Figure 11.

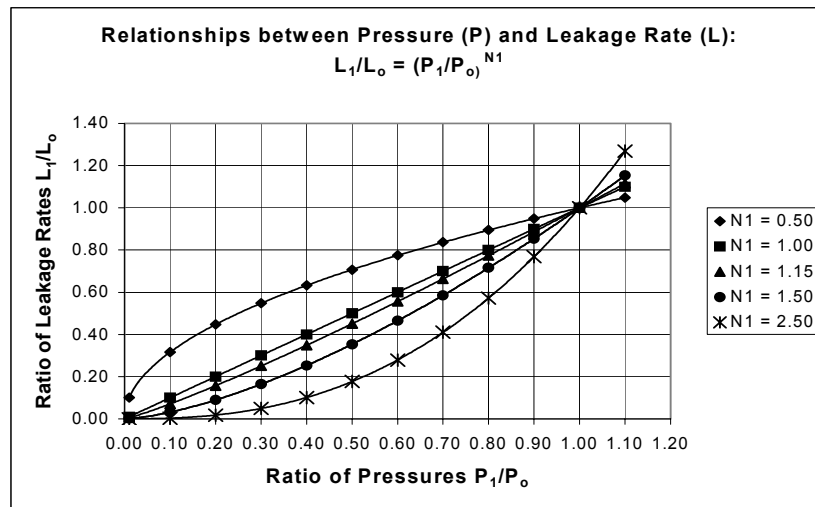


Figure 11 Relationship between pressure and leakage rate for different “N1” values. (N1 is determined from the proportion of fixed and expanding leakage paths in the distribution system).

- The data used to calculate leakage targets and economic levels of leakage should be revised when pressure management is introduced
- Reducing pressure may make existing leaks more difficult to find, because they make less noise, or do not come up to the surface.
- Reducing pressure can reduce some types of consumption. Any consumption from devices connected direct to mains pressure will give a reduced flow rate at reduced pressure.

There are several benefits of pressure management, and if it is designed and maintained well, there are few, if any, disadvantages.

### Benefits of Pressure Management

The benefits include:

- Reduction of frequency of bursts

Data from one UK water supply company (Figure 12) shows the reduction in burst frequency before and after pressure management was installed in an area. The data set is limited in size, but it indicates that a unit reduction in pressure will give a 3 or 4 times reduction in burst frequency e.g. reducing pressure from 80m to 40m (a 2:1 reduction) will reduce the burst rate from 7 bursts per 100 properties per year to only 1. Of course there are many other factors which affect the burst frequency of mains. Therefore, it is difficult to obtain good quality data to prove the strength of the relationship.

Burst frequencies will be more reliable in larger areas, e.g. supply zone, but at that scale it is more difficult to make significant changes in pressure. Therefore most data is available at DMA level, where the burst rate is more erratic, and so it may take several years to determine the true benefits.

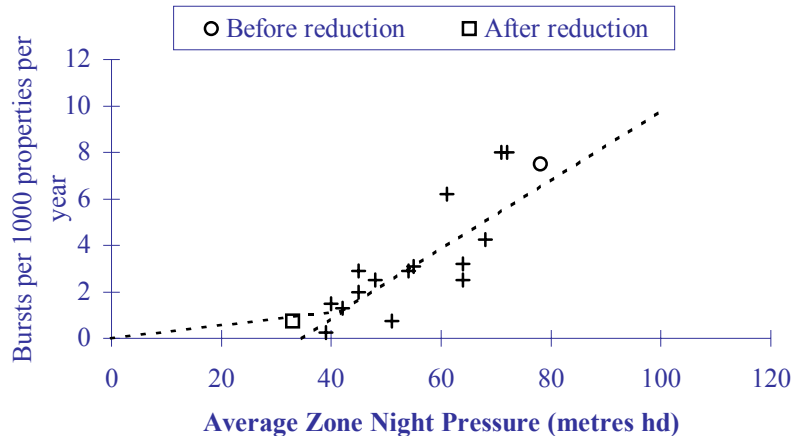


Figure 12 Relationship between Average Zone Night pressure (ANZP) and burst frequency for a sample of data from one UK water company

- Provision of more constant supply to customers

Without pressure management, the pressure at customers' premises will be a function of the pressure of water where it enters the distribution system, less the head loss through the underground pipe network. Well organized pressure management regimes will result in a better understanding of the factors affecting pressure at customer premises, and will allow systems to be put in place to maintain pressures within specified bounds.

- Increased fire fighting capability

In a similar way, lack of pressure management may result in inadequate supplies from fire hydrants for fire fighting. Many water supply organizations avoid pressure management because they are concerned that it will reduce availability of fire fighting water, and result in disputes with the fire authorities. However, with modern technology and design techniques it is possible to reduce pressure (and therefore leakage) and also provide adequate supplies for fire fighting.

- Protection of the long-term life of the assets

Daily variations in pressure place stresses and strains on the pipe network. Damage can occur at joints, and fittings, and pressure splits can occur in some types of pipe. Damage may be due to a fatigue effect which takes place over a long period of time. The higher and more frequent the variation, the greater the chance of damage caused by pressure fluctuations. Pressure management will tend to smooth out these variations, resulting in less damage to the network, and a longer asset life expectancy.

### ***Infrastructure Management***

The most significant factor affecting the level of leakage in a water network is the general condition of the mains and service pipes, and the service reservoirs. It is usually found that this is also the singularly most significant factor affecting the economic level of leakage for that network. The condition of the infrastructure

is something which is inherited from previous regimes and generations, and it cannot be improved significantly without major capital investment in renewal and refurbishment works. It has been shown that expenditure on infrastructure improvement, even if it is targeted to the areas most prone to high leakage, is not a particularly cost effective method of managing leakage. Where improvements are being made for other purposes, such as the need to meet water quality parameters, or customer standards of service for interruptions to supply or minimum pressure standards, then the impact on leakage levels should be taken into account. However, where leakage is the primary problem then it is difficult to cost justify mains renewal works.

The condition of the infrastructure can be assessed in two ways:

- its propensity to burst. This will be governed by factors such as pressure and ground conditions and weather as well as the condition of the mains and service pipe fabric.
- Its propensity for background leakage. Again this is governed by pressure.

At first sight it would seem that these two parameters would be linked, and that mains in poor condition would be susceptible to both effects. However, it does not follow that a high burst rate means high background leakage and vice versa. Therefore a separate judgment has to be taken on the two parameters. Most water supply organisations regularly carry out work to renew or rehabilitate their water distribution networks. If they did not, the pipe network would continue to age and deteriorate, resulting in increasingly higher maintenance costs to carry out repairs, in order to maintain levels of service to customers. The primary justification for main renewal and rehabilitation is usually one of the following:

- The internal condition of the main is affecting the quality of the water delivered through it. This is often the case with corrosion of cast or ductile iron pipes, which have no internal protection.
- The internal bore of the main has reduced due to corrosion, or a build up of deposits, so that it is no longer capable of carrying sufficient flow
- The pipe wall has weakened and is no longer capable of withstanding the internal pressure of water, or it has insufficient beam strength to withstand traffic loading. This is often the case with asbestos cement pipes laid in aggressive ground.
- Some external factor has resulted in the main being unable to fulfill its current duty

It is unusual for mains to be replaced solely on the grounds of leakage reduction. Customer levels of service and operating costs are the primary drivers. In all cases, however, the impact on leakage should be assessed as part of the justification process for each section of main.

The impact on leakage will depend entirely on the extent to which the old main was contributing to the overall leakage level, and then on the technique chosen to rehabilitate the network. If mains are replaced with new ones, then leakage on the main will be reduced significantly, although not eliminated altogether. However, unless the service connections are also renewed, there could actually be an adverse effect due to increased pressure (due to the extra carrying capacity) causing leaks on services to flow at a higher rate. Mains relining can also result in higher leakage due to the scraping process causing damage to pipe joints, service connections, and the pipe wall. If the main is slip lined with a new plastic pipe, then this will not be a problem, but if the main is coated with cement mortar or epoxy resin, then the rehabilitated main may leak at a higher rate than before.

In overall terms the experience of the author shows that unless main rehabilitation and renewal is targeted specifically to reduce leakage then it will have a neutral effect on leakage levels. The benefits gained in some projects, will be offset by the increased leakage caused by others, and in any event the small percentage of mains which are rehabilitated each year are statistically unlikely to be the source of the leakage problem.

It is often assumed that mains which are in poor condition, because they suffer from internal corrosion, or because they cause levels of service problems to customers, are also be the prime source of leakage. However, evidence from the UK suggests that this is not necessarily the case. Also, there is evidence to show that there is little or no correlation between burst frequency and background leakage. Areas with high burst frequency can have a low background leakage and vice versa. This may be due to the fact that high burst frequencies tend to occur in smaller diameter mains with low beam strength. Background leakage will tend to be more of a problem on larger diameter mains, and on service connections. Therefore, each section

of main has to be assessed, and any policy based on generalisations is unlikely to be cost effective, and could actually produce little or no leakage reduction.

If main rehabilitation is to be part of the leakage management strategy then it should be targeted. The aim is to identify those mains which make the major contribution to leakage levels in a supply zone, and then to find the most appropriate technique to renew them. This investigation has a cost, and therefore a balance has to be found between the expenditure on analysis and design, and on the actual cost of the main replacement. If insufficient effort is made on the preparatory stage, then mains will be replaced with little benefit, whereas too much investigation will add to the overall cost unnecessarily.

The following steps should be followed.

*1. Identify those mains clearly in need of replacement*

The first step is to examine records of mains failures and to consult with the local operations staff to identify those sections of main with a history of bursts and leaks, where repairs are carried out regularly. There will be a break even point depending on the value of the water, the frequency of bursts, the volume lost from each burst, and the cost of continuing-with repairs.

*2. Identify areas of high leakage*

The next step is to identify those areas which have a high level of leakage, after leakage detection and repair work has been carried out. This is best done for each DMA where they have been established. The areas should be prioritised according to their infrastructure condition factor, or simply in terms of the background leakage in litres/property/day or m<sup>3</sup>/km/day. Each area should then be investigated to determine the primary sources of leakage. Any leaks which can be detected by the usual location methods will have already been identified, so some form of step testing or sub-metering should be used. The aim is to measure the leakage on sections of main. Ideally each street should be examined, but if this is not possible, then the leakage should be narrowed down to as small an area as possible.

*3. Cost-benefit analysis*

Within the DMA, each sub area can be assessed to determine whether it is cost effective to replace the mains to remove the background leakage. The leakage rate will vary considerably from one section of main to another. In carrying out the investigation, a burst which was not located by other means may actually be found and repaired, eliminating the need to replace the whole section of main. Figure 5.3 shows an example of an economic range in which it is cost effective to carry out the replacement works solely justified on leakage reduction.

*4. Consider other benefits*

When carrying out the cost benefit analysis it may be possible to bring other benefits into the equation and to give them a value. For example, if the replacement is aimed to reduce bursts there will be a benefit from not having to carry on with repair costs, and there is a benefit in terms of customer service.

*5. Design the scheme*

A package should be produced including a plan and all other relevant data.

*6. Project management*

It is vitally important to ensure that the scheme realises the projected benefits by good project management

**MONITORING PERFORMANCE AND MAINTAINING PROGRESS:**

Once targets have been met, the key issue is then the ongoing maintenance and management of leakage at the reduced level. All aspects of leakage management requires constant effort if leakage is to be kept in a reduced state. Leakage never goes away, it is something which requires constant attention, otherwise leakage levels will rise and could return to the rate before the leakage reduction programme, wiping out much of the work and investment. If anything, leakage management becomes more difficult as this stage than during the reduction stage. The focus of attention on a major investment project has passed, further investment may be more difficult to obtain, and the ongoing work is seen as a cost burden which does not produce any benefit to the organisation.

An efficient and effective set of procedures must be put in place during the leakage reduction plan to ensure that once a set target has been reached, the leakage level is maintained at or near that target in future years. Leakage is like a spring, and unless downward force is maintained, it will bounce back. These procedures apply at three different levels:

- Strategic
- Tactical/Facilities
- Operational

Each of these is considered in turn.

### **Strategic Monitoring**

The overall indicator of performance on leakage management comes from the annual water balance calculation. However, the water supplier should not wait 12 months between carrying out these calculations. It is important that trends within the year are monitored, and that corrective action is taken if it appears that the annual target will not be met. The situation is similar to the financial management of a company, which has to file annual company accounts. Profit and loss figures will be produced more frequently to ensure the company is meeting monetary targets. It is recommended that water balance calculations be carried out every quarter, and possibly monthly where targets are critical or in areas where changes are being made to the regime which has applied in previous years.

Water balance calculations rely on accurate monitoring of distribution input, and

### **Facilities monitoring and maintenance**

The facilities which have been established during the reduction stage have to be maintained. This work tends to involve periodic inspections:

- District meters have to be calibrated or checked at regular intervals
- District boundaries have to be maintained
- Statistics such as property counts have to be kept up to date
- Pressure reducing valves will require monitoring and maintenance
- Equipment such as correlators will need regular calibration and periodic replacement

Records should be kept for each facility, and piece of equipment, similar to vehicle maintenance records, to show what maintenance work has been carried out and when. It is useful to maintain a file package for each DMA containing all relevant information which is updated with the results of the most recent survey work, changes to boundary valve positions, etc. Computer packages are available to store all this data electronically, possibly linked to the digitized mains records.

### **Operational Monitoring**

Day to day management of leakage is a painstaking task, which requires ongoing monitoring of large volumes of data and information. Computer systems are available to store meter readings, pressure data, consumption data etc., which produce leakage values for DMAs based on nightline information or regular (e.g. weekly) readings. These systems can also be developed to prioritise areas for leak detection surveys. While such systems help with the task of organizing leakage management operations, they also require maintenance

A key element of the ongoing monitoring is the assessment of productivity from the leak detection staff. During the reduction stage, it is possible to monitor expenditure in terms of the cost per Mld saved. However, when maintaining leakage at a set level then this is more difficult. Other measures have to be used, some of which are similar to those used in the reduction stage:

### **Use of new technology and operating practices**

During the leakage reduction phase, the primary management incentive is achieving the leakage target. Once it has been achieved and maintained for a period (say 1 to 2 years) the next strategic aim should be to continue to achieve the same level of leakage at an every reducing operational annual cost. This will require investment in research and development and use of new technology, in order to gradually reduce staffing levels. Efficiency savings come from:

- Use of techniques which make ongoing ALC operations more efficient, such that the same result can be achieved for less effort
- Review of data and assumptions which go into the leakage calculation, whether these be based on night flow estimates or annual water balances. In many cases, some of the demand which is initially thought to be leakage turns out to be hidden customer use, operational use, or is due to meter inaccuracies
- Review of practices and staff levels to cover seasonal variations. The tendency for leakage to increase is often a seasonal phenomenon, but it is common for the same number of staff to be employed all year round. By investigating seasonal variations, it is possible to make savings by making changes to working practices, and duties at different times of year, or by supplementing a permanent resource with contracted staff for a few weeks at a time when needed.
- Some companies monitor weather forecasts and use the data to predict the number of bursts which are likely to occur in the next few days. From this they decide how many leak location and repair staff to have on standby and for call out arrangements.

### **Undertaking an annual review to assess the effectiveness of the strategy**

It is recommended that the Leakage Management strategy be kept under constant review, and that it is subject to some form of annual audit. This could mean a review by senior management, or it could involve external consultants. The review should include the following elements:

- Progress against target
- Changes to target due to lessons learnt
- Changes to assumptions and default data
- Investment made

### **REFERENCE**

**'Losses in Water Distribution Networks - A Practitioner's Guide to Assessment, Monitoring and Control'**, by Macolm Farley and Stuart Trow. Published by IWA, April 2003.