



**Specialist Group**  
Efficient Operation  
and Management  
**Water Loss Task Force**

# District Metered Areas

# Guidance Notes

February 2007

Version 1

# DMA Management Guidance Notes

These guidance notes have been written by the DMA Team of the Water Loss Task Force. The Water Loss Task Force was set up at the IWA “Water Loss Management – A Practical Approach” Speciality Conference in Cyprus in 2002. At that conference the production of these guidance notes was also proposed in order to meet the need for information on best practice for DMA Management. The main authors were:

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# 1 Foreword

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The Water Loss Task Force (WLTF) is part of the International Water Association's Specialist Group on Efficient Operation and Management of Urban Water Distribution Systems. The vision of the WLTF is to *"provide leadership in the field of Water Loss Management through effective and sustainable international best practices"*.

The mission of the WLTF is accomplished by:

- its strong international membership,
- the dedication and commitment of its members, and
- the participation of the many research scientists and professionals in testing, verifying and challenging current and proposed techniques and practices.

It is evident that water is a limited resource in many parts of the world, a situation that has highlighted, amongst other things, the need to reduce leakage from urban water distribution systems to levels that are considered economically acceptable. We firmly believe that Water Loss Management is of fundamental importance to improving the efficiency of many water networks all over the world in order to ensure long-term environmental and societal sustainability.

The WLTF is continuously building and expanding on current and new initiatives such as:

- Utility Benchmarking and Performance Indicators,
- District Metered Areas and Pressure Management,
- Real and Apparent Losses,
- Leak Detection and Repair,
- Economic Level of Leakage,
- Active Leakage Control,
- Training and certification.

The practices promoted by the WLTF are well documented in articles, conference proceedings, software, manuals and text books. The WLTF will continue expanding Water Loss Management strategies and developing new research initiatives which can be universally applied.

Within the above context the WLTF has developed the District Metered Area (DMA) Guidance Notes, a comprehensive document on DMA management, a well proven technique which when implemented correctly in conjunction with other measurers can effectively assist in reducing and/or monitoring leakage levels in a distribution network.

The Guidance Notes is the result of endless hours of hard work by many dedicated people in an effort to put together in a simple, practical and easy to follow step by step methodology the technique of DMA management which has been practised around the world for many years with excellent results, examples of which are included in these Guidance Notes.

Furthering knowledge and promoting best practices internationally in the field of Water Loss Management is of the utmost importance to the WLTF. To this end it was decided that this document is made freely available to anyone who wishes to use it. The Guidance Notes can be downloaded free of charge from the web site of the Water Loss Task Force ( [www.iwaom.org/wltf](http://www.iwaom.org/wltf) ).

Bambos Charalambous

Chair,

Water Loss Task Force,

February 2007

## 2 Introduction

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### 2.1 Purpose

These Guidance Notes are intended as an introduction for leakage practitioners to the benefits, design and management of active leakage control activities based on the use of District Metered Areas (DMAs). It is part of a series of Guidance Notes prepared by the IWA Water Loss Task Force to cover all aspect of Water Loss Management.

### 2.2 Readership

The Guidance Notes are aimed at leakage practitioners that have little or no experience of leakage control using DMAs, and has drawn on the experience of leakage engineers all over the world to create a best practice for DMA management. The Guidance Notes should be seen as a general guide which must be adapted to local conditions.

### 2.3 Definition of DMA management

The concept of DMA management was first introduced to the UK water industry in the early 1980's in "Report 26 Leakage Control Policy & Practice, (UK Water Authorities Association (1980))". In this report, a DMA is defined as a discrete area of a distribution system usually created by the closure of valves or complete disconnection of pipe work in which the quantities of water entering and leaving the area are metered. The flow is analysed to quantify the level of leakage. In this way the leakage practitioner can determine more precisely where and when it is most beneficial to undertake leak location activities.

The process of leak identification, location and repair is known as Active Leakage Control, or ALC.

### 2.4 Management of DMAs

Leakage control by ALC has proved to be very successful as part of an overall plan to reduce and subsequently maintain leakage. Over the last quarter of a century, it has been applied with much success in networks all over the world. But the technique requires careful understanding and should not be considered as a quick fix. Instead, it is a tool to allow a more efficient management of leakage, as it requires robust management and appropriate manpower resources to be successful.

The introduction of leakage control using DMAs usually requires significant short and long term funding to be effective. In the short term it is necessary to fully understand the existing network configuration and to plan and

implement measures required for DMA management. In the long term it will be necessary to maintain the system both in terms of its operation, the analysis of data and location and repair of bursts.

## 2.5 Items covered by the Guidance Notes

The items covered by these Guidance Notes include the following:

- Design of DMAs;
- Analysis of flow measurement;
- Prioritising of leak location from DMA data;
- Management of DMAs.

Information from successful examples of DMA design and construction has been provided by various practitioners and is included in Appendix F.



## 3 Philosophy of Leakage Control by DMA management

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### 3.1 Introduction

As water networks deteriorate, they become prone to leakage. In addition, new networks frequently include leaks as a result of poor installation practice and incorrect materials. Where the distribution network comprises hundreds or thousands of kilometres of pipe work, it is not an easy task to locate the bursts and breakages, particularly as many are invisible. This situation progressively worsens until, in extreme cases, it becomes necessary to ration the water for part of the day by closing off the supply.

The solution is to create a permanent leakage control system by dividing the network into a number of sectors called DMA so that the leakage in each sector can be quantified and the detection activity can always be directed to the part of the network with the most leakage. Once an acceptable level of leakage is achieved, the flow into the area is usually monitored to enable new leaks to be identified immediately.

### 3.2 Control of leakage – why use DMAs?

The traditional approach to leakage control has been a passive one, whereby the leak is repaired only when it becomes visible. The development of acoustic instruments has significantly improved the situation, allowing invisible leaks to be located as well. But the application of such instruments over the whole of a large water network is an expensive and time-consuming activity. The solution is a permanent leakage control system whereby the network is divided into District Metered Areas (DMAs) supplied by a limited number of key mains, on which flow meters are installed. In this way it is possible to regularly quantify the leakage level in each DMA so that the leakage location activity is always directed to the worst parts of the network.

An important factor in lowering and subsequently maintaining a low level of leakage in a water network is pressure control. The division of the network into DMAs facilitates the creation of a permanent pressure control system, thus enabling pressure reduction in DMAs which reduces the level of background leakage, the rate of flow of individual bursts and the rate of the annual burst frequency.

Many water distribution networks are managed without using DMAs. However those that have successfully achieved low leakage levels without DMAs tend to have a combination of high quality infrastructure in good condition, an efficient repair operation and low, stable pressures.

### 3.3 Theory of DMA management

The key principle behind DMA management is the use of flow to determine the level of leakage within a defined area of the water network. The establishment of DMAs will enable the current levels of leakage to be determined and to consequently prioritise the leakage location activities. By monitoring flows in the DMAs it will be possible to identify the presence of new bursts so that leakage can be maintained at the optimum level. Leakage is dynamic and whilst initially, significant reductions can be made, levels over a period of time will tend to rise unless on-going leakage control is carried out. DMA management should therefore be considered as a method to reduce and subsequently maintain a low leakage level in a water distribution network.

The key to DMA management is the correct analysis of the flow to determine whether there is excess leakage and identify the presence of new leaks.

Real Losses are the difference between the system input and the total customer consumption (corrected for measurement inaccuracies) in a defined area. This is made up of Leakage (from mains, services up to the point of consumption and storage tanks) and Overflows (mainly from storage tanks).

Traditionally real losses were quantified as a volume and were calculated on an annual basis. However, this approach does not allow the necessary fine control of leakage to be achieved as it can take several months for a major change to be identified and the precision of leakage measurement is poor.

The extent of leakage can be gauged by assessing the 24-hour flow pattern of a network. A limited variation between the minimum and peak flow, particularly in a network with little industrial night use, is indicative of a leaky network. However this approach does not allow the leakage level to be directly quantified.

Leakage is most accurately determined when the customer consumption is a minimum, which normally occurs at night. This is the principle of minimum night flow originally recommended in the UK document Report 26 (1980).

The size of the DMA will influence the level of burst leakage that can be identified. A large DMA will tend to have more leakage and customer night use, which will mean that a burst represents a smaller percentage of the minimum night flow, thus reducing its definition.

Figure 1 shows the typical variation of minimum night flow in a DMA in which there is little seasonal variation in night consumption. The presence of reported and unreported bursts can be identified.

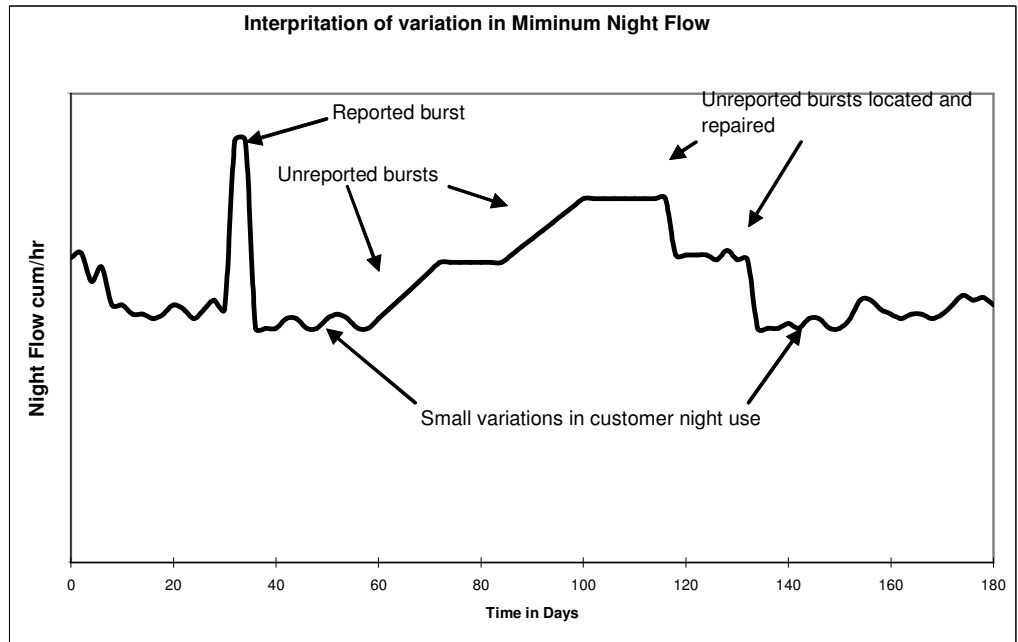


Figure 1 Variation in minimum night flow over time

If all detectable leaks and bursts are promptly repaired, then the lowest minimum measured night flows will consist only of customer night use and background (undetectable) leaks, as shown in Figure 2.

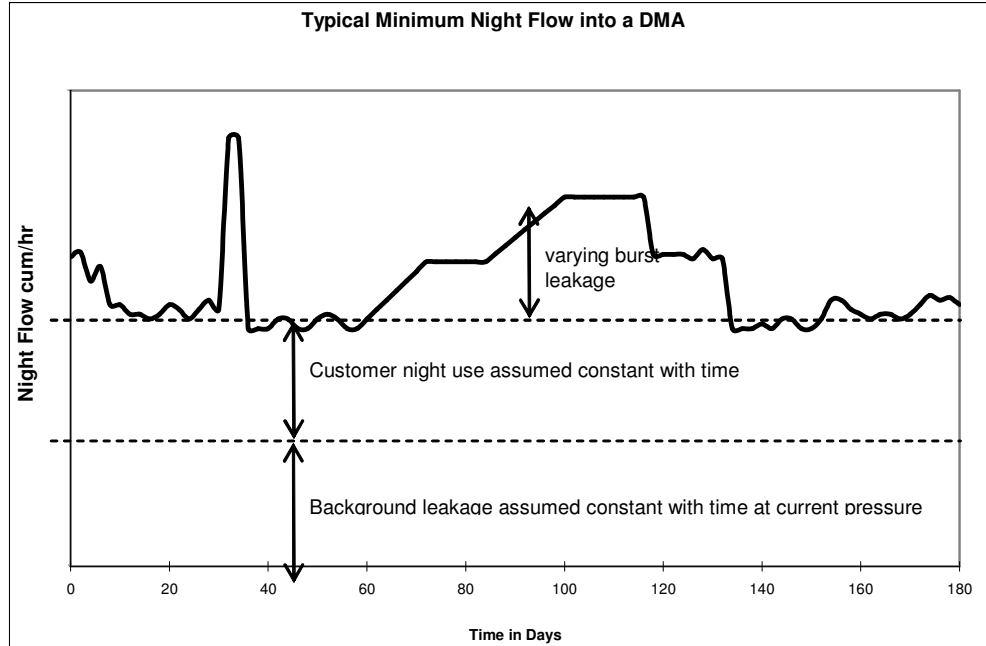


Figure 2 Variation in time of leakage

Customer night use varies on a weekly and seasonal basis in most DMAs, so it is usually necessary to make some appropriate local judgement when interpreting components of night flows.

In countries where the consumption is metered, it is possible to accurately estimate the real night use of the customers by applying a typical night factor to the average measured consumption. This is then subtracted from the minimum night flow in the DMA to yield the effective leakage value. Where there is little or no customer metering, it is necessary to apply an estimated value for the legitimate night use.

The simplest approach to assess the data is to express the night flow (say in m<sup>3</sup>/hour) as a % of the average daily flow. If this value is higher than the pre-determined guideline value, it indicates the need for a leakage location intervention. However, 'guideline' values can vary significantly between countries. For example in Germany a 5% value is applied whilst in the USA the corresponding value is equivalent to 35%. An alternative qualitative parameter is used in Japan to express the measured minimum night flow in terms of the length of main (m<sup>3</sup>/km/hour) whilst in the UK the connection density of is often used (m<sup>3</sup>/connection/hour). As the management of DMAs involves comparing existing value with the target value, the choice of parameter should reflect the local requirements and characteristics of the water network.

As part of a major initiative by the UK industry to gain further understanding of leakage, a more advanced and detailed component based analysis of the night flow was developed.

## 3.4 Theory of component leakage

Leakage can be considered to be composed of two main components.

- **Background Leakage** is the aggregation of sources of leakage from all fittings on the distribution network that are individually too small to be detected by visual or acoustic inspection for leakage. Pressure management has a major influence on this component of leakage. (Background leakage are individual leaks with flow rates less than 0.25 m<sup>3</sup>/hr at 50 m pressure which typically represents the minimum leak that can realistically be detected with modern detection technology)
- **Burst Leakage** is the loss of water resulting from bursts on the distribution network, which can be further classified as reported and unreported. The total amount of leakage from these bursts is affected by the speed with which the location of the burst is identified and subsequently repaired; it is therefore the control of this duration or runtime of the burst that minimises leakage.

**Burst leakage volume = (the rate of flow of burst) x (runtime of burst)**

Reported bursts are defined as those bursts that are reported to the water utility, typically by customers who have supply problems or by the public observing water escaping from the ground.

Unreported bursts are defined as those bursts that would remain undetected unless detection measures are undertaken.

Reported bursts are usually visible and often have a high flow rate. However, the greatest annual volume of losses is often generated by the unreported bursts, as their runtime is usually longer.

The runtime of a burst (the total time period a burst runs for), can be split into three distinct periods, which are termed **awareness, location and repair**.

- Awareness is the time from when a burst first occurs until the water utility is aware that it has occurred.
- Location is the typical time it takes to pin point the burst.
- Repair is the typical time it takes to carry out the repair once the burst has been pin pointed including planning and statutory notices to highway agencies.

For the reported bursts, awareness and location times are usually short, as the leakage is either immediately visible or needs to be located to resolve customer complaints. It can be therefore independent of any active leakage control management systems.

For the unreported burst, the awareness time is affected by the leakage management practices: without leakage management, the utility will remain unaware of its occurrence. If the network is surveyed for unreported leaks once a year then on average unreported burst runtime would be six months plus the time to carry out the repair.

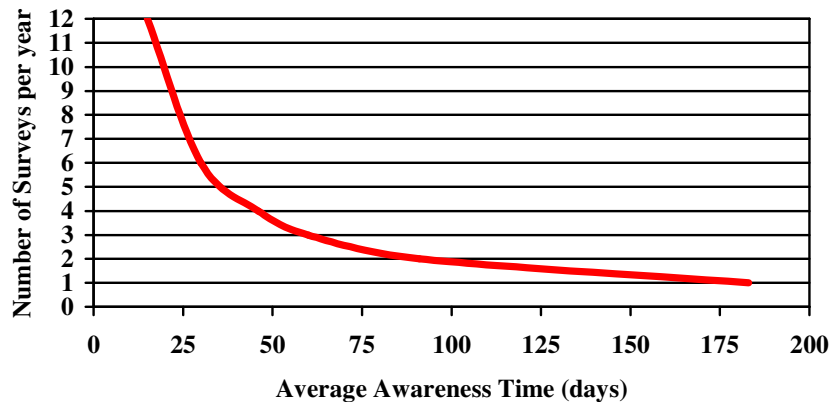


Figure 3: Effect of number of surveys per year on awareness time

The regular analysis of the DMA flow will potentially reduce the runtime by reducing the awareness time. So if DMA flow is analysed every month, then on average the awareness of an unreported burst runtime would be 15 days. For the monthly example the total runtime of a typical unreported burst would be: -

- Awareness      15 days

- Location typically 5 days
- Repair typically 10 days
- Total runtime 30 days

It should be noted that location time and repair times will be dependent on local practice, manpower availability and local legislation regarding utility activity in highways.

Figure 4 shows the importance of dealing with bursts other than those reported by the public. The total runtime of larger (reported) burst tends to be much less than that of the smaller bursts. The much longer awareness and location time of these smaller bursts can lead to higher overall losses.

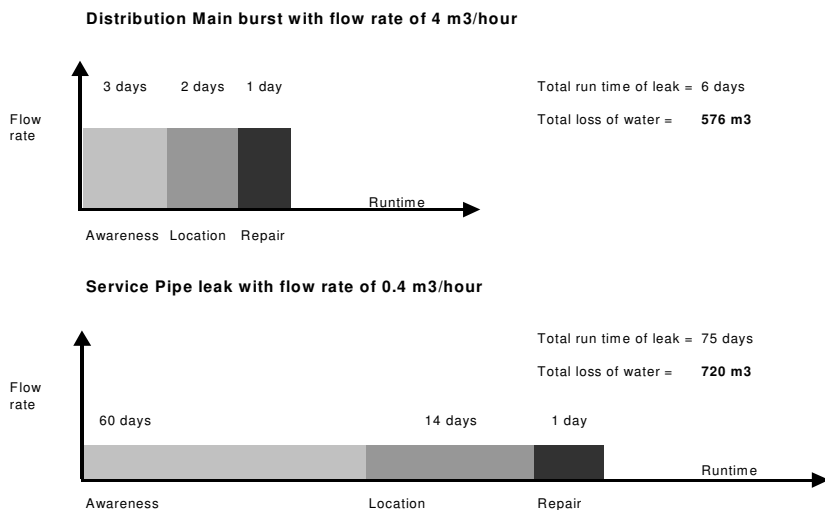


Figure 4 Effect of burst duration on total leakage

It is therefore the analysis of the flow in the DMA that an unreported burst has occurred that is the key factor to controlling leakage.

The principal objectives of analysing night flows in a DMA are therefore:

- To identify the presence of unreported leaks and bursts so as to limit their average run-time.
- To identify which parts of the network require active leakage location thus enabling resources to be deployed most effectively.

### 3.5 Intermittent supply

DMA management can be utilised in networks which are subject to intermittent supply. The major difficulty relates to quantifying the leakage level, as most customers tend to store water when it is available to cover the hours of interrupted supply. However, the principles of quantifying the leakage level remain the same. If customer metering is available and is

reliable, then it is necessary just to adjust the average consumption to compensate for the reduced hours of service. If reliable consumption data is not available, then it will be necessary to undertake monitoring on a representative sample of customers to obtain typical values.

In some cases it might be possible to supply the DMAs on a 24-hour rotational basis so that a minimum night flow can be measured. Care is needed however that increased wastage (over flowing tanks, unauthorised consumption) does not affect the data.

It has been shown that intermittent supply is often a consequence of high leakage. Consequently the estimate of customer consumption is unlikely to have a significant effect on the total leakage level. When the largest leaks have been repaired, the period of intermittent service can be significantly reduced and possibly even eliminated, thus simplifying significantly the DMA management.

## 3.6 Effect of pressure

The effect of pressure, though well understood in theory, has only recently been appreciated in the management of leakage, both in terms of reducing and maintaining a low level of leakage in a water network.

Considerable work has been undertaken to understand the relationship between pressure and leakage, which is outside the scope of these Guidance Notes.

In essence, the simplest and most reliable expression for the relationship between pressure and leak flow rates is:

$$L_1 = L_o (P_1 / P_o)^{N1}$$

Where  $P_o$  and  $L_o$  are the initial pressure and leak flow rate in the network,  $P_1$  &  $L_1$  are the values at a revised pressure, and the exponent  $N1$  typically varies from 0.5 to 1.5, for individual DMAs, depending upon the predominant type of leaks, and whether pipe materials are rigid or flexible.

The average  $N1$  value for large systems with mixed pipe materials is often assumed (for simplicity) to be 1, implying a linear relationship between leak flow rates and pressure.

The pressure in a network varies according to the flow. So as the flow increases (e.g. at times of peak demand) the pressure will reduce, thus reducing leakage as shown in Figure 5.

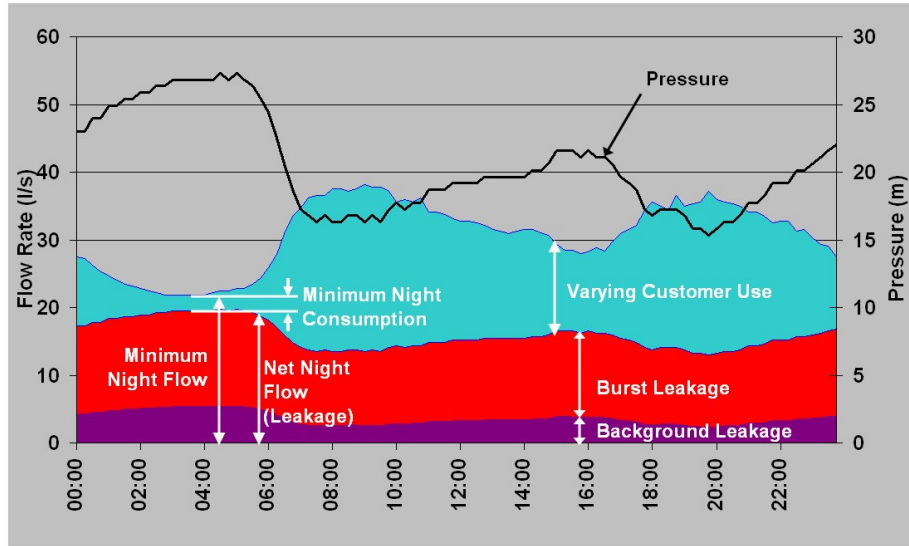


Figure 5: Variation of flow, pressure and leakage in a water network

Accordingly, the leakage rate is not constant over a 24-hour period. The parameter used to relate the night leakage rate to the daily leakage rate is known as the 'Night-Day Factor' (NDF), (hour to day factor in UK) and is determined as follows:

$$\text{Daily leakage volume} = \text{NDF} \times \text{night leakage rate per hour}$$

Where NDF is expressed in hours per day.

Therefore the daily savings will be

$$(L_1 - L_0 (P_1 / P_0)) * \text{NDF}$$

For DMAs with gravity supply, the NDF is usually less than or equal to 24 hours per day, and for low pressure gravity systems with large frictional head losses, the NDF can be as low as 12 hours per day. However, for DMAs supplied by direct pressure, or those with pressure modulation devices (based on time, or flow), the NDF is usually greater than 24 hours per day, and can be as high as 36 hours per day.

The NDF is clearly a major factor which must be considered when using night flows to estimate daily and annual leakage. For this reason, it is always preferable to express leakage rates based on measured night flows on a 'per hour' basis, and leakage rates based on water balances on a 'per day' basis.

The approach for calculating the NDF is included in Appendix A.



4.1 Introduction

The division of a large water network can be a delicate operation which if not undertaken with care can cause supply and quality problems. However, if approached and undertaken correctly, even the largest and most complex networks can be successfully divided as the numerous examples from all over the world testify. The key is to have a detailed and in-depth knowledge of the hydraulic operation of the existing network.

Ideally the first stage of designing a DMA management scheme should include a review of the infrastructure supplying the network. The design of DMA schemes is very specific to individual networks' hydraulic and water quality conditions and regulations. Typically the design would commence from the trunk mains and extend towards the distribution network. The objective is to separate as much as possible the DMAs from the trunk system, thus improving the control of the former without affecting the flexibility of the latter. Consequently a key element of this initial review will be to determine local practice or legal requirements regarding flexibility of supply such as satisfying fire fighting capacity etc.

A typical layout is shown in Figure 6

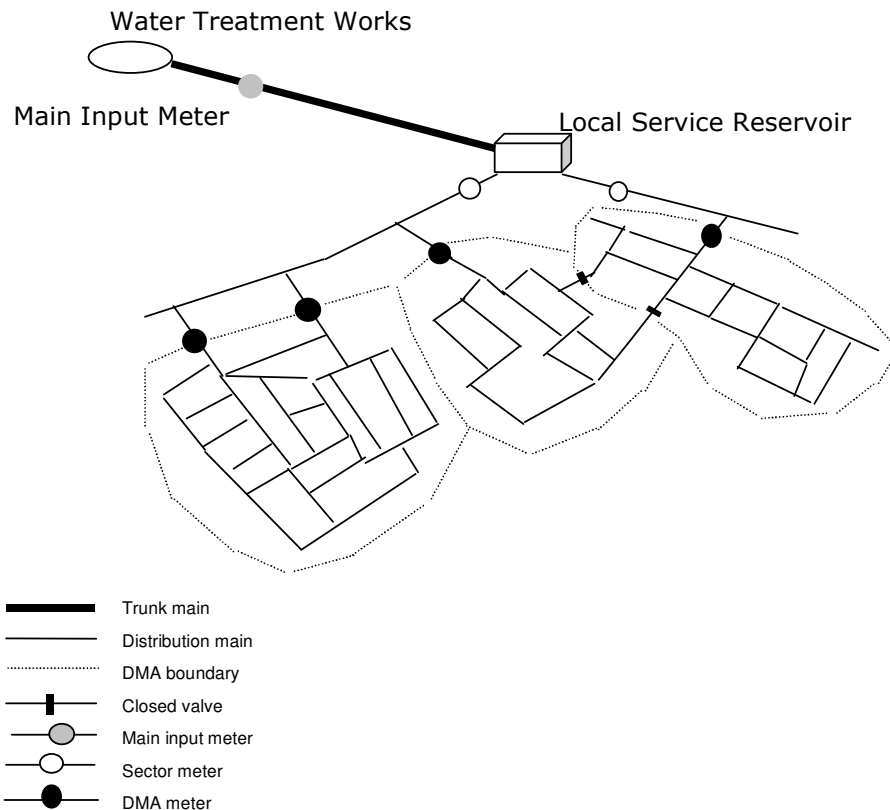


Figure 6: Typical DMA configuration

In large and complex networks, DMA management should be introduced as part of an overall plan to monitor the flow from the main sources. In such situations, it might be preferable to divide the network first into larger sectors to identify the leakiest parts of the network. These sectors can then be prioritised for the creation of DMAs. This initial plan needs careful consideration to determine the boundary, as this initial design will be crucial to the overall success of the project and its long-term efficiency. In fact, where possible, natural boundaries should be used (rivers, streams and railway lines etc.) to limit the number of valves to be closed. However in a complex network, particularly where the existing pressures are low, it is advisable to use a calibrated hydraulic network model to identify the hydraulic balance points. Small urban and rural networks tend to lend themselves more easily into DMAs, thus eliminating the need for sectors.

Pressure control is now recognised as a key feature of leakage management and where possible should be incorporated into the reconfiguration of the system during the design of the DMA scheme for three main reasons:

- Reduce the existing leakage level;
- Reduce the risk of new leaks occurring when the existing leaks have been repaired.
- Prolong the useful life of the network

Pressure control has been successfully implemented in networks having very low pressures (less than 15m). The design requires very detailed hydraulic analysis, often with mathematical simulation models, and high quality pressure reducing valves which have low head losses at peak flows and excellent control at low flows.

## 4.2 Design of Sectors

For large distribution networks, the initial planning stage should divide the distribution system into suitably sized sectors, using a large-scale distribution mains map, which includes ground contours to draw provisional boundaries. This step utilises local knowledge of the network, available hydraulic data (pressure and flow), existing boundaries, natural features such as railways rivers major roads and the topography of the city, so that as part of the process the area is split into potential large pressure zones where appropriate. In the more complex networks it is advisable to use a mathematical hydraulic network model to allow the hydraulic balance points to be identified. In this way, it will be possible to close line valves to create a permanent boundary without affecting the operation of the existing network.

**Note:** it is not important that the area is split into equal sectors as existing infrastructure and topography will determine the most beneficial approach.

If possible these sectors should not include the trunk mains so that the flexibility of the supply system is maintained. Ideally the sectors should be established with the closure of valves at the boundaries or physical

disconnections of pipes across the boundary. Where it is not possible to create such a boundary, meters can be installed, to measure imports and exports. The design of the sectors can be optimised by using a mathematical simulation model. In this way it will also be possible to identify parts of the network that are oversized or redundant which will require evaluation to ensure they do not cause water quality problems. In many instances, these mains were effectively oversized or redundant also in the existing system, but were not previously identified. Over sizing of mains often results from a change in development plans, previous lack of hydraulic analysis or as a result of the reconfiguration of the network.

The process of designing the sectors is key to the overall success of the DMA management scheme. The subsequent division of the sectors into DMAs is much easier when the configuration of the sector has been optimised. It cannot be over emphasised how important this first stage is and it should be subject to review by experienced engineers to ensure the best configuration is achieved within the financial constraints.

An additional advantage of establishing sectors is that work can progress on establishing DMAs within individual sectors at varying timescales and design teams can be allocated to different sectors. The early establishment of these sectors will also enable an initial estimate of leakage, which could significantly affect the program of design of the DMAs so that activity can be focused in the leakiest sectors. In some instances the establishment of the sectors will be beneficial for retargeting leakage location activities and this could be part of an overall program of introducing additional leakage activities.

Ideally, water storage (service reservoirs and towers etc) should be outside the sectors. Alternatively if this cannot be achieved, inlets and outlets of storage reservoirs can be metered and included in any flow analysis but again at the detriment to the overall accuracy of the measurement.

### 5.1 Introduction

The technique of leakage monitoring requires the installation of flow meters at strategic points throughout the distribution system, each meter recording flows into a discrete area, which has 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:

- To divide the distribution network into a number of DMAs, so that the flows into each district can be regularly monitored, enabling the presence of unreported bursts to be identified and leakage to be calculated with confidence.
- To manage pressure in each or a group of DMAs so that the network is operated at the optimum level of pressure.

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

- Supplied via single main (preferable) or multiple feeds;
- A discrete area (i.e. no flow into adjacent DMAs);
- An area that cascades into an adjacent DMA (to be avoided if at all possible).

An effective permanent leakage control system will:

- Maximise the accuracy of measurement of leakage within DMAs;
- Facilitate the location of the leaks;
- Limit or if possible eliminate the number of closed valves;
- Minimise the changes to the hydraulic and qualitative operation of the existing network.

### 5.2 DMA design criteria

The factors that should be taken into account when designing a DMA are:

- The required economic level of leakage;
- Size (geographical area and number customer connections);
- Housing type i.e. blocks of flats or single family occupancy housing;
- Variation in ground level;
- Water quality considerations;

- Pressure requirements;
- Fire fighting capacity;
- Target final leakage level;
- Number of valves to be closed;
- Number of meters used to monitor flow ideally minimised;
- Large metered customers should have their meters measured as export meters from the DMA.
- Infrastructure condition

The over-riding factor is to successfully create the DMAs without significantly affecting the quality of service to the customers. This is particularly important in networks where the existing operating pressures are already low. It should also be remembered that the reduction in leakage that the creation of DMAs allows will also tend to increase the operational pressures within the network.

A DMA boundary should not necessarily be considered definitive. With the change in operating conditions, it might be necessary to modify the boundary. For this reason it is usually better to create a boundary by closing valves rather than cutting the pipes. However care must be taken to ensure that these valves are leak tight and that their accidental opening is avoided.

### 5.3 DMA sizing and Economics

The size of DMAs has an impact on the cost of creating them: the smaller the DMAs, the higher the cost. This is because more valves and flow meters will be required. The maintenance at a later date will also tend be more costly. However the benefits of smaller DMAs are:

- New leaks will be identified earlier reducing "awareness time";
- Smaller leaks can be identified against the "noise" of night use;
- The location times can be reduced because it is quicker to carry out detection in smaller DMAs to find a given leak than a large one;
- Detection costs will be reduced because less of the network needs to be searched to find a given number of leaks.
- This all allows a lower leakage level to be maintained.

In practice, there will always be a significant variation in size of DMA due to the layout of the existing infrastructure and the need to optimise pressure management. In the UK, DMAs are often sized by the number of properties, where typically a property is supplied by a single customer connection.

Consequently, DMAs in urban areas vary between 500 and 3000 properties.

It has been found that 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 burst location takes longer. However, large DMAs can be divided into smaller temporary DMAs by closing additional valves 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 networks with very poor infrastructure condition the high burst frequency (and the pressure increases after repairs that lead to further bursts) make it worthwhile having very small DMAs: less than 500 customer connections.

Alternatively DMAs can be sized by km of pipe work, particularly in systems that contain blocks of flats which tend to have a very low connection density. This has the additional advantage of being easily referenced to the leakage location activity which is normally quantified in terms of the length of mains.

In general, hydraulic, practical and economic factors will ultimately determine the size of the DMAs.

Water utilities often have their own criteria for determining the appropriate method of economic leakage control. Where this includes DMA management, the analysis will determine the type of active leakage control policy, size of DMAs, targets and staffing policy. For instance, the UK water industry has undertaken considerable work on the economics of leakage, which is explained in Managing Leakage Report C - Setting Economic Leakage Targets and

## 5.4 Water quality considerations

Creating a DMA involves permanently 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 depending on local water quality. The greater the number of closed valves in a DMA, the higher is the likelihood of this happening, particularly if the closed valve is not situated at the existing hydraulic balance point. The problem can be partly alleviated by a flushing programme, starting at the design stage and at regular intervals afterwards, although great care is needed to ensure that this does not aggravate the situation. Some water utilities have a boundary valve configuration which consists of two valves, either side of a fire hydrant to alleviate this problem. It should be remembered though, that the creation of DMAs only aggravates an existing water quality problem, which would eventually have become evident when the network configuration was modified for reasons not connected to leakage control.

## 5.5 DMA planning

The planning stage is the process of dividing each sector into suitably sized DMAs. This is most common in large inter-connected networks. In small distribution systems, it is unlikely that this stage will be necessary.

Outline planning is the first step, using small-scale distribution mains maps to draw provisional boundaries. The map should identify:

- any buildings that require water supplied at a pressure above the norm for the area;
- any large or special customer;
- ground level contours;

This step utilises local knowledge of the network and available hydraulic data (pressure and flow) to identify potential trouble spots, which could be made worse by closing the boundary valves. Where the DMA boundary crosses a main, a valve is closed (or a meter is installed). This allows the net night flow to be calculated.

In large inter-connected networks, especially ones suffering existing low pressure or water quality problems, it is preferable to use a calibrated hydraulic network model. In this way it is possible to identify many of the anomalies in the network (unknown closed valves, connectivity errors on the mains records) which if not eliminated are likely to cause supply problems to the customers when the DMAs are created.

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 minimise the cost of installation, operation and maintenance. The model is particularly useful to identify existing hydraulic balance points where a DMA boundary valve can be closed without modifying the existing operation of the network, thus limiting pressure or water quality problems. The detailed hydraulic understanding that a hydraulic network model provides also allows selective reinforcements to be designed which in some cases are necessary to enable the optimum single DMA supply to be realised, particularly in cases where fire-fighting requirements are very restrictive. In fact, experience has shown that even in the most complex networks where the mains records are of poor quality, it is possible to successfully create a single feed DMA – provided that a hydraulic network model has been used. Where water quality is considered to be a problem, flushing points should be included in the design. Consideration should be given to the ease of operation of these flushing points by local staff, particularly with regard to traffic. DMA boundary valves should be readily identifiable.

Ideally trunk mains should be excluded from DMAs to avoid costly meter installations, to improve the accuracy of flow information and to maintain the flexibility of supply. Where a large proportion of the flow entering a DMA passes out again to other parts of the system, the accuracy of measurement is significantly reduced.

Clearly, the actual boundaries will have to be a compromise if the DMAs are to be constructed with a minimum of new infrastructure changes. For instance, an existing valve might not be available exactly at the hydraulic balance point and so the next nearest will have to be used. In some instances it may be economic to provide link mains, particular if these would allow pressure management to be achieved.

Exact total infrastructure information is not necessary at the design stage, although the location of important industrial consumers should be identified and allowed for. Initially, sufficient accuracy is needed to confirm whether the DMA fits within the broad design criteria. Where a network model is available, estimated flow data will have already been determined. If not, the best source of customer information is from GIS, billing records, post-code information, or a street-by-street survey.

The design of the meter location will require a large-scale map, so that details of the line of the main, and the position of valves, bends, connections, other utility information and obstructions are clearly visible. Valves and bends can cause inaccuracies to the flow readings in some meters. It is important to site such meters on a straight length of main, as free from obstructions (particularly bends) as possible. Manufacturers' recommendations on the number of pipe diameters between the meter and upstream/downstream obstructions should be followed.

Consideration should also be given to how the data will be obtained from the meter. In many instances small kiosks or pits can be located in convenient locations at the sides of the road where telemetry connections can be installed or portable hand held computers can download the data.

The key to good DMA design is

- Minimum variation in ground level across the DMA;
- Easily identified boundaries that are robust;
- Size appropriate to number of burst to be identified;
- Meters correctly sized and located;
- Involvement of all operational staff affected by network changes;
- Limit the number of closed boundary valves;
- Limit the number of flow meters;
- Optimise pressure to maintain customer standards of service and to reduce leakage

## 5.6 DMA testing

After the design of the DMA boundaries, trial closure of the valves should be undertaken to verify their efficiency and identify those valves which need



to be replaced. The importance of tight boundaries should not be underestimated, as one inefficient valve can compromise the leakage estimate of two DMAs. In fact, an important reason for locating a boundary valve as close as possible to the natural hydraulic balance point is to limit the pressure drop, and hence any flow, across the valve. Once the efficiency of the valves has been verified, they should be closed and the pressure inside each DMA monitored to ensure that the operational pressure is as designed. Ability to cope with peak or fire fighting flows can be simulated by opening hydrants to check hydraulic conditions. If the designed pressures are not maintained, then the DMA details will need to be checked in detail.

A common problem encountered in the field, is the existence of unknown closed or partially closed valves. If checks reveal none of the above problems then it is likely that there is an error in the design. The use of a hydraulic network model allows such problems to be identified and resolved at the design stage.

Once the DMA has been created, a zero pressure test should be carried out. This involves closing the supply to the DMA and checking that the pressure drops towards zero. All boundary and divisional valves should be sounded to check whether the valves are tight. If faulty valves are found, these should be rectified and the zero pressure test repeated.

A typical procedure for a pressure zero test is as follows:

- 1** Indicate boundary valves by marking valve covers (e.g. often by painting the valve cover red).
- 2** Arrange for the test to take place between 01.00 and 05.00. Inform customers with special needs (hospitals, dialysis patients etc.)
- 3** Ensure staff have plans indicating the DMA boundary, boundary valves, and the DMA inlet valve.
- 4** Set up pressure loggers or gauges at key locations throughout the DMA.
- 5** Close the DMA inlet to isolate the DMA.
- 6** Analyse the pressure data. If the pressure drops to zero then it is likely that the boundary is tight or at the very least, if there is an unknown connection, it is likely to be very small. However, if after 10 minutes, the pressure has not dropped, a second check should be made by simulating a consumption (e.g. opening a fire hydrant within the DMA) to induce some flow, which should zero the pressure. If there are no unknown connections, the pressure should remain at the low level when the hydrant is closed.
- 7** If the test fails, i.e. the pressure creeps up; it is likely that there is an unknown connection. An assessment of the heads (pressure + ground level) at each of the monitoring points will allow the area of a potential inlet to be identified. Further investigation is then necessary, possibly with additional zoning of the DMA, to identify the unknown inlet. It cannot be over stressed the importance of verifying the

tightness of the DMA boundary, as all subsequent leakage location activities is dependent on the accuracy of the leakage estimate.

On completion of the test, the supply valve is reopened. The pressure is monitored to ensure that supply has been restored to the DMA.

## 5.7 Meter selection

The flow meter should be capable of accurately measuring low flows whilst avoiding excessive head losses at peak flows.

State of the art flow meter 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 sub-divisions of a DMA;
- The very low flows associated with step testing.

The choice of meter size and type will depend upon:

- Size of main;
- Flow range;
- Head loss at peak flows;
- Reverse flow requirements;
- Accuracy and repeatability;
- Data communication requirements;
- Cost of the meter;
- Cost of ownership and maintenance requirements;
- Water utility preference.

The flow range and accuracy requirements of the meter will also depend on the mode of use. Traditionally, DMAs have been used for leakage monitoring which required good repeatability rather than absolute accuracy. This is particularly the case where the initial leakage level is very high. As the use of DMAs to quantify total leakage data, historic flow trends and establish customer use trends has increased, so has the accuracy required of individual meters.

Electro-magnetic full-bore meters are most suited to DMA application as they possess the required low flow accuracy without affecting significantly the head losses at peak flows. However they tend to be expensive and in most cases require external power supply. Ultrasonic meters tend to have the same disadvantages but have lower installation costs as there is no need to cut the pipe. In smaller inlet mains, a helix-type meter will be more than satisfactory provided that a high-resolution pulse unit is used for data

logging (preferably 1 pulse / 10 l). Insertion meters, though less accurate than full-bore meters, can be useful, particularly as a temporary solution when the initial leakage level is very high.

The easiest way to maximise accuracy is to reduce the number of inlets. Measurement based on multiple inlets and outlets should be avoided if possible as they can give rise to misleading leakage levels due to the compound errors of the meters.

Meter sizing should take account head loss, seasonal fluctuation and demand changes. Where reverse flow has been encountered or is considered likely, a meter with such a capability will need to be specified. Comparison of previous years' records will give an indication of seasonal differentials. Allowance should also be made for the lower flows likely after bursts have been found and repaired.

If a network model has been applied for the design of the DMA, this should be used to predict the flow range of the meter, taking into account seasonal demands and future maximum and minimum 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.

Alternatively, the flow range can be estimated from demand calculations, using:

- Customer metering details;
- Number of customers;
- Estimates of non-household use (industrial demand);
- Estimates of exceptional night use > 500 l/hour (for maximum flows);
- Estimates of night use (for minimum flows);
- Estimates of leakage (for minimum flows after leak repair);
- Fire fighting flows.

Formulas have been developed using the Burst and Background Estimates (BABE) leakage concept to determine long-term minimum leakage levels that can be anticipated in the DMA. (see Appendix E)

## 6 DMA Establishment

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### 6.1 Proving

Following the installation of all boundary meters and establishing the permanent boundary, it is necessary to "prove" the district to ensure that:

- All meters are working correctly;
- There are no operational problems;
- All internal valves are at the correct status;
- Determine the average DMA pressure.

The DMA meter(s) and internal pressures should be logged for a period a few days and the resulting data analysed to determine leakage levels.

### 6.2 Management

Once a DMA has been proved, all subsequent work relates to its management, which involves the initial setting up of the procedures and the subsequent routine operation.

Initial setting up work comprises "housekeeping" issues such as:

- Set up records and recording procedures;
- Set up a monitoring & data collection procedure;
- Inform appropriate staff of valving changes;
- Determine order of priority for leakage location activities;
- Monitor customer complaints, especially for discolouration, low pressure and no-water.

The routine operation on the other hand involves the following activities:

- That DMA boundary valves are clearly marked for identification by all staff;
- That the status of the closed valves is regularly checked;
- If the boundary has to be opened in exceptional circumstances, that the corresponding flow data is not considered for any leakage evaluation;
- That flows are monitored for consistency. The daily pattern of flows into each DMA should follow the daily pattern of consumption within the DMA. If not, it probably indicates problems with boundary valves or meters. This should be used to initiate investigation.
- When estimates of night use and daily customer consumption are available, a simple check can be made to ensure that the losses

measured from night flows are consistent with the losses calculated by subtracting the total daily consumption from the net daily flow into the DMA. If not, it probably indicates problems with meters or boundary valves and should be investigated.

### 6.3 Data Requirement for Establishing Background and Night Use

In its simplest form, leakage in a DMA is the difference between the inflow and the consumption. When the DMA has been established, the inflow is measured directly by the meter(s). Quantifying customer consumption on the other hand is not so direct. Even if all the customers are metered, the data is subject to many factors that are not easily quantifiable such as meter errors and illegal use.

In networks where there is continuous supply, many of these problems are overcome by quantifying the leakage at times of minimum consumption, which usually occurs at night. As night consumption is usually very small, it follows that in all but the leak-free networks, most of the night flow will be due to leakage allowing an almost direct measurement.

Continuous supply is not however a prerequisite of DMA management. Even in networks having intermittent flows where the supply is suspended at night, it is still possible to quantify and manage the leakage in the DMAs, just that the results will tend to be less accurate. However, the importance of accuracy tends to increase inversely with the leakage level. So as intermittent supply is usually a consequence of high leakage, accuracy is therefore less important. The key is to quantify as realistically as possible the real consumption during the period of supply. It is necessary therefore to undertake field monitoring to determine the average consumption. In this way, the leakiest DMAs can be targeted first to reduce the leakage level, which might be enough to even eliminate the need to suspend supply. At that point a more precise approach based on night flows can be adopted.

### 6.4 Measuring Minimum Night Flow

The minimum night flow is the lowest flow into a DMA on each night. In most cases this flow will mostly consist of leakage, with relatively small amounts of customer consumption. In simple DMAs, this night flow will be from a single meter. However, in some cases, the minimum night flow will be the minimum of the aggregation of several meters (**not** the aggregation of the minimum flow of each of the meters).

The night flow should be the average over a set time. A period of one hour is useful and is widely used.

Typically, data loggers are set to measure flows and the minimum 1 hour value should be the lowest rolling 1 hour average of these values. The

minimum 1-hour flow is only slightly dependent on the logging interval and this effect can usually be ignored.

## 6.5 Calculating daily leakage value from minimum night flow

The minimum night flow approach to quantifying leakage is usually the most accurate, as it is an almost direct measurement of leakage. However care is required when extrapolating the night leakage value into an average leakage value because of the effect of pressure.

At night the pressure is usually at its greatest and then varies throughout the day as network flow induces hydraulic losses through the network. Therefore extrapolating the night leakage value over 24 hours will tend to overestimate daily leakage. To take account of this fact, leakage estimates based on night flow measurements are multiplied by a Night-Day Factor (NDF). In gravity fed systems values of 18 to 24 are typical. A method of assessing the NDF is given in Appendix A.

## 6.6 Customer Night Use estimates

Where the customer consumption is metered, it is possible to apply a standard night factor to the historical consumption to estimate the legitimate night use. Where such factors are not available or they are not considered reliable, it is advisable to undertake the monitoring of a sample of properties by logging the consumption at 30 minute intervals with a high accuracy meter installed in series with the existing meter for a period of at least 7 days. Such a test will also allow the meter error to be assessed by comparing the real quantity consumed by the test meter with the apparent consumption measured by the customer meter to yield the effective meter error. The same approach can also be applied to networks having intermittent supplies or where customers have storage tanks. Alternatively, a sample of meters can be read manually at regular intervals throughout the day to derive typical consumption profiles.

Significant work has been done in the UK on night use, which has been published in Managing Leakage Reports E, & F and UKWIR Household Night Consumption and Estimating Legitimate Non-household Night Use reports. An outline is given in Appendix D while the latest work published by UKWIR is detailed on the web site for UK research [www.ukwir.co.uk](http://www.ukwir.co.uk). Accurate night use allowances are important within the UK because individual water companies are required to report leakage (using night flows) to their regulator. Much of this work derives however from the fact that few UK customers are metered and where apartments are not very common.

It is recommended that customer night use be divided into at least three demand categories, in relation to the type of consumption in the network. These are:

- Domestic properties;

- Non domestic such as commercial properties and schools which consume water mainly during the day-time;
- Special consumers which can range from industrial and agricultural consumers to hospitals and clinics.

The assignment of the properties to DMAs can be carried out in one of two ways. The most precise and appropriate method is to use the addresses in the billing records. If not available, and the leakage level is very high, then it is sufficient to estimate the percentage of properties in each DMA and assign a typical consumption. Every effort should be made to quantify accurately the customer consumption to increase the confidence in the derived leakage value.

When the leakage level has been brought under control, it becomes increasingly difficult to further reduce the leakage level. In such circumstances, it is necessary to then assess in more detail each component of leakage. With this aim, the burst and background estimates (BABE) component approach to leakage was developed in the UK and when correctly applied, it can be used to underpin the analysis of the minimum night flow with confidence. Historically many methods have been used to compare and target DMAs. Unfortunately few allow for the comparison of DMAs of varying size, pressure and mix of infrastructure. Not only does the BABE approach overcome these difficulties, but it also allows the quantity of unavoidable leakage to be quantified to yield the burst or excess losses which can realistically be recovered to be determined.

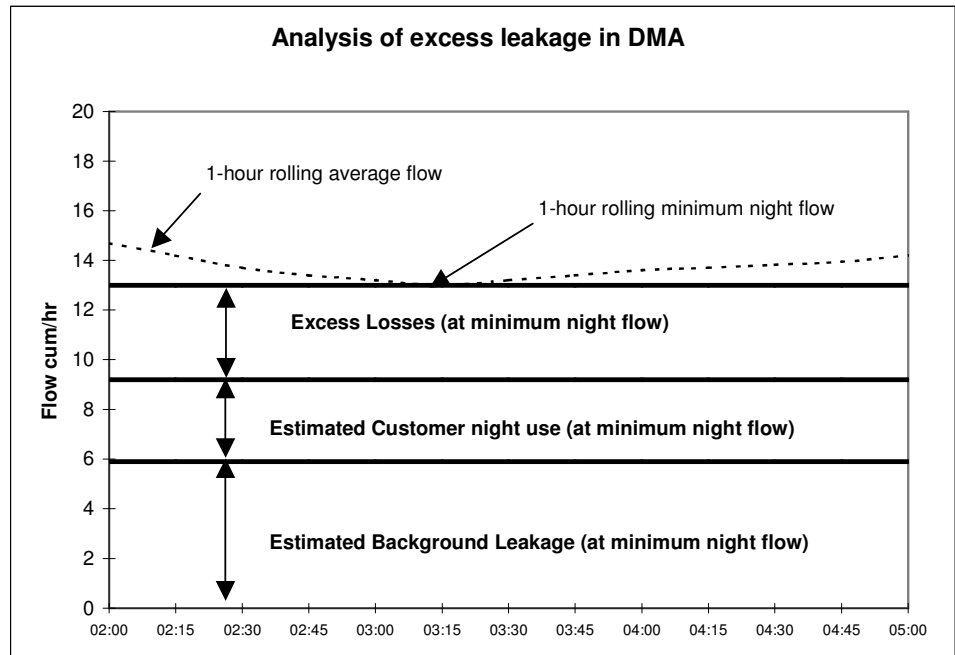


Figure 7 Quantifying excess losses

Excess losses in a DMA are caused by the presence of unreported bursts. To calculate the excess losses the other components of the minimum night flow must be measured or estimated.

Whilst the BABE approach can appear data hungry, the initial application can be simplified by using initial default values until more accurate data is gathered. A detailed description of the BABE approach is included in Appendix E

Data to establish customer night use comprises the following:

- Population
- Number of households (i.e. individual flats in buildings & houses)
- Number of non households (industrial) properties
- Details of internal plumbing practise
- Identification of non households estimated to have night flow > 0.5 m<sup>3</sup>/hr classed as Exceptional Night Users
- Further details of non households industrial properties such as type of user and average daily demand

Data to establish background leakage in DMA is the following.

- Length of mains
- Number of property connections
- Average length of private connection pipe
- Average zone night pressure AZNP
- How customers are connected to the distribution system

## 6.7 Night use where customers have significant storage

In networks subjected to intermittent supply, the customers often have their own tanks to store enough water to cover their daily use. This will significantly impact the accurate quantification of leakage unless a monitoring exercise is undertaken to quantify the consumption. Tanks are also used in networks having a 24 hour supply, which are subjected to low operating pressures. This can have an impact on the rate of filling, particularly at night. Again in such cases, the best solution is to undertake the monitoring of a representative sample, so that the correct demand profile can be applied to the leakage calculation.

It should be noted that the creation of DMAs, in addition to providing the ideal instrument to reduce leakage, is also useful as a demand management tool, to distribute the available water to all parts of the networks. This is achieved by installing a pressure reducing valve on the DMA inlet and regulating the outlet pressure with a timer.



Experience has shown, that in most cases, intermittent or low pressure problems are usually caused by very high leakage in the network. A permanent leakage and pressure control system is therefore the first step to resolving the problem.

## 6.8 Data Verification for minimum night flow

When flow data is received, which could lead to the DMA being targeted for leak detection, several checks should be undertaken before assigning leak detection crews to search for unreported bursts.

- Has the increase in flow occurred on successive days or just a single day? It is good practice to verify that the increase occurs over more than one day before acting on the change.
- Is it possible that the increase in consumption is due to a change in the consumption of a large consumer? For large consumers it is worthwhile having a loggable meter to verify consumption patterns.
- Is it possible that there has been a reduction in the night consumption? This could be relevant if the DMA has only just been set up.
- Is it possible that the change is due to maintenance works? Any such works should therefore be communicated to the leakage control team.
- Has the status of a boundary valve been changed? Sudden changes in flow are often caused by DMA boundary valves being opened or closed. Any changes should be communicated to the leakage control team.
- Are all the meters working correctly? The failure of one meter, particularly in inter-connected DMAs, could change the leakage value in more than one DMA.
- Is it possible that hydrants have been flushed? This should register as a sudden peak in the flow data and should not be included in the leakage evaluation.

## 7 Selecting DMAs for Leak Detection

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After several DMAs have been set up, leakage levels can be determined on a regular basis. An order of priority will then be defined to select the worst DMA for leak detection. This chapter sets out the methods available for doing this.

### 7.1 Setting Targets and Setting Resource Levels

The details of setting targets and resource levels for a whole distribution system are outside the scope of these Guidance Notes. However this needs to be discussed briefly to explain how target setting leads into the selection of DMAs for detection and repair.

#### 7.1.1 Deciding the Objectives

There are several different objectives for undertaking a leakage control programme in a distribution system. These could include:

- Improving the duration, reliability and quality of supply;
- Preventing depletion of a water resource;
- Saving expenditure on treatment and pumping;
- Meeting regulatory targets for raw-water abstraction and leakage.

The specific objectives will be defined in the strategic plan of the water company. These will then form the basis for setting up and subsequently selecting the DMAs for leak location. The approach adopted for meeting leakage targets is likely to be based on a combination of the following four actions:

- Active Leakage Control;
- Pressure Management;
- Infrastructure Management;
- Repair Management.

It is important to remember that, irrespective of the approach, the objective is not just to lower the existing leakage level, but also to maintain the lower leakage level in the future.

The assessment of the target leakage reduction from Active Leakage Control should go together with an assessment of staff resources required for leak detection and for leakage repair. Depending on the local situation the initial staffing requirement to set up the control system and for initial leak detection could be much higher than the requirement for maintenance of the leakage level once a target is achieved.

## 7.2 Methods for Selecting DMAs for Leak Detection

**The objective is to select those DMAs where the benefit attained outweighs the extra effort required to detect and repair the leaks.**

This implies a cost / benefit analysis (described in detail in Appendix C) where four key elements are required:

- Detection and additional repair costs;
- The reduction in leakage level as a result of the detection and repair?
- The value of the savings<sup>1</sup>
- Leakage return frequency<sup>2</sup>

There are practical problems associated with this approach:

- There is need for an analysis of historical data in order to make a reasonable estimate, which is not possible when the DMAs have just been set up for the first time;
- It can be difficult to calculate the value of the savings;
- The optimum application of this approach requires flexibility in the availability of the detection teams, which is not always possible.

If all the data is not available, it is necessary to resort to a more simplified approach, which is based on the actual data available, but which still takes into consideration the difference in size between DMAs.

### 7.2.1 The Simplest Approach

The simplest approach for networks with continuous supply is to represent the excess leakage (defined in Chapter 6 above) in terms of excess leakage per customer connection.

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<sup>1</sup> The value of savings depends on the circumstances in the DMA. Each of the four objectives in Section 7.1.1 should place a different marginal value on savings in DMAs. So, for example, the value of savings in a DMA with pumped supply from a source with high running costs where some customers get intermittent supply due to losses within the DMA would normally be higher than the value of savings in a DMA continuously fed by gravity from a source with low running costs. The value of improving duration, reliability and quality of supply will normally outweigh the other objectives.

<sup>2</sup> Initially active leakage control (ALC) will reduce the number of leaks in a DMA. When ALC stops in the DMA the number and size of leaks will slowly to rise, until, without further ALC, the leakage may return to its original level. If the number and flow rate of leaks rises quickly then the expenditure on ALC will have to be repeated. On the other hand if the leaks increase slowly, the expenditure may not have to be repeated for many years. So it is more cost-effective to carry out ALC on a high leakage DMA with low rate of rise than the same work on a high leakage DMA with a high rate of rise.

The DMAs should be ranked from highest excess leakage per customer connection to lowest excess leakage per customer connection. The DMAs with the highest excess leakage per customer connection should be selected for leak detection. This reflects the fact that most of the cost of detection is associated with customer connections in urban areas

However if the connection density is low (less than one connection per 100 metres of main)(in for example very rural areas or where a few connections serve a large number of individual apartments), then it may be more suitable to rank by excess leakage per km of main. This reflects the fact that at low connection densities the cost of detection is more closely associated with the length of main.

### 7.2.2 Intermittent supply

Continuous supply should be a priority for any water company as the effects of closing and reopening pressurised systems are serious both from a structural and qualitative point of view. Therefore, if parts of the network suffer from intermittent supply, leak detection work should concentrate on those DMAs where a reduction in leakage would make supply more continuous. However care is required in linking the cause of the intermittent supply just to the leakage in the DMAs where supply problems are encountered. In fact, experience has shown that intermittent supply is invariably caused by excessive leakage in the network upstream of the problem area. In such cases the priority should be given to the DMAs in these areas.

Often the leakage levels in areas suffering intermittent supply are very low. This should not necessarily be interpreted as signifying an almost leak-free network, because it is likely that the operating pressures are also low. It is possible therefore that once a continuous supply is obtained, then the leakage level will rise. For this reason pressure control should be considered also in DMAs where the operating pressures are already low. In some cases, the use of intelligent pressure control has been extended to managing intermittent supply problems, where the pressure to some DMAs is reduced to allow the problematic DMAs to be supplied. The use of a hydraulic network model will greatly assist the analysis of the cause and the definition of the solution to intermittent supply problems.

### 7.2.3 Approximation by the product of marginal savings and excess leakage per customer connection

If the network has the following characteristics:

- The marginal savings can be expressed in monetary terms<sup>3</sup>
- The marginal savings differ significantly between DMAs;

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<sup>3</sup> The marginal savings means the value of saving a single cubic meter of leakage. The monetary value of this is very dependent on particular circumstances.

- The rate of rise of leakage<sup>4</sup> in each DMA is either similar or unknown.

Then the DMAs can be prioritised by the ratio (R) of (the product of marginal savings (i.e. value saved per cubic metre saved) and the excess leakage) to customer connections.

$$R = \left( \frac{\text{Marginal value of savings(per m}^3\text{)} \times \text{excess losses(m}^3\text{ / day)}}{\text{(No of customer connections)}} \right)$$

The DMAs with the highest ratio should be selected first.

## 7.2.4 Indirect approach

A number of other methods are used for prioritising detection or providing supporting information. These methods quantifying the excess leakage and convert this leakage into a points system or an estimate of the number of bursts that can potentially be located.

Where the excess leakage is expressed as a number of bursts this potentially has the added advantage that an estimate of the number of excavations required to repair the bursts is also available, to provide an estimate of the resources required to carry out the repairs once the bursts are located.

Typically the number of bursts is expressed as the number of equivalent service pipe bursts, where an equivalent service pipe burst (ESPB) is estimated @ 1.6 m<sup>3</sup>/hr at 50 metres head with this volume being pressure corrected for the average pressure in the particular DMA. If initially the level of leakage or the network build is resulting in an average bursts of a higher volume being located then a system based on equivalent mains pipe burst could be adopted (EMPB). A value of 5.75 m<sup>3</sup>/hr at 50 metres head has been used as an initial value for mains diameter 80 to 150 mm until local information is available.

With experience the leakage inspector can analyse the latest minimum night flow, estimate the ESPBs to be located and review the previous night flows to establish broadly how the night flow has increased and make an initial judgement that in the particular DMA he is looking for say 3 ESPBs as the night flow has approximately risen in three steps or is looking for a mains burst as the night flow has risen in one step. Software can be utilised to provide part of the analysis.

The flow rate for mains bursts was based on information collected in the early 1990s in the UK. More recent experience has indicated that 0.6 m<sup>3</sup>/hr is a more typical service pipe burst flow rate.

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<sup>4</sup> Rate of Rise of Leakage is the rate at which leakage increases with time between periods of active leakage control. This can be measured by analysis of long-term flow and repair records. It is usually expressed in litres per connection per day per year.

## 7.2.5 Changing your DMA Selection Method

Many water undertakings have successfully applied simple approximations for many years without the need to introduce the cost / benefit approach.

However, for networks with intermittent supply, when the continuity of supply has been achieved, then it is necessary to consider the adoption of a more sophisticated approach.

Customer night use assessment; background losses assessments; ALC cost and effect assessment will all improve with time. If so, these assessments should be incorporated into the prioritisation method.

## 7.3 Intervention levels

The points (leakage levels) at which an intervention (i.e. leak detection work) should commence, are called intervention levels.

Typically, the intervention level will allow a number of bursts to occur and the exit level will be the point at which no more bursts can be located and only background leakage remains. Initially, where leakage is excessive in the whole network, the exit level could include a number of potentially locatable bursts until the overall level of leakage has been reduced.

The intervention levels will be based on the approach adopted for ranking the DMAs. If the intervention levels are set as a flow, then the size of the DMA would influence the lowest level of intervention that can practically be set. Where a detailed economic appraisal of the economic level of leakage has been undertaken, this can be translated into an intervention and exit level in DMAs.

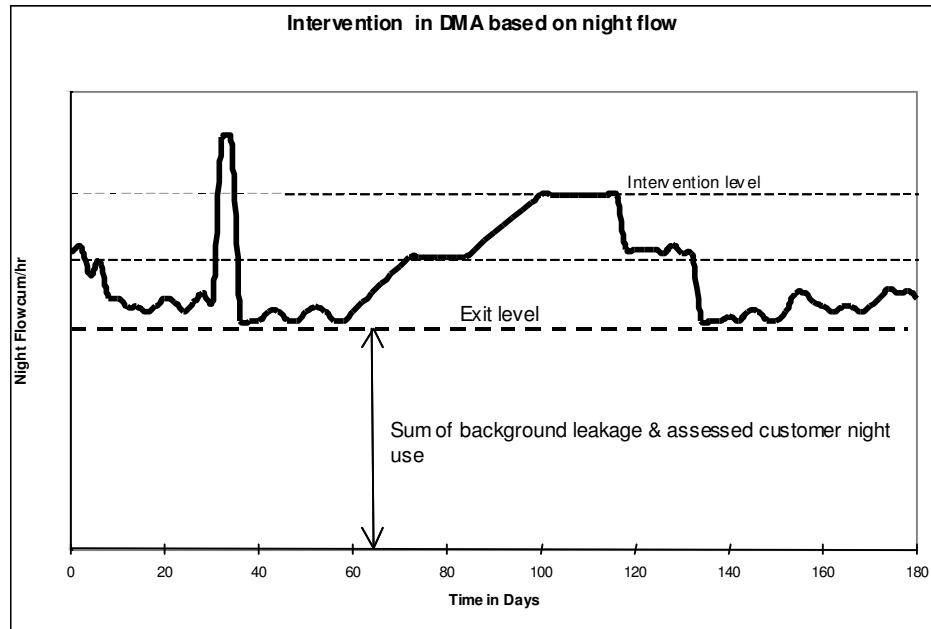


Figure 8 Typical intervention levels

## 7.4 Prioritisation as part of the DMA Management Process

After detection and repair resource requirements have been set, and a method for deciding on which DMA to work on has been decided, prioritisation should be carried out on a cycle with a duration of around one week.

Regular reviews of the prioritisation methods should also be carried out, along with assessments of which DMAs are responding to the detection and repair cycle and which ones are “problem DMAs” which need further investigation.

DMA targeting methods will develop as the staff become more knowledgeable. In time, as actual ALC costs are established, it will be possible to review the methodology by comparing the actual costs against the savings achieved. As a result targets and resourcing levels should be revised periodically

The whole process is summarised in the flow chart below.

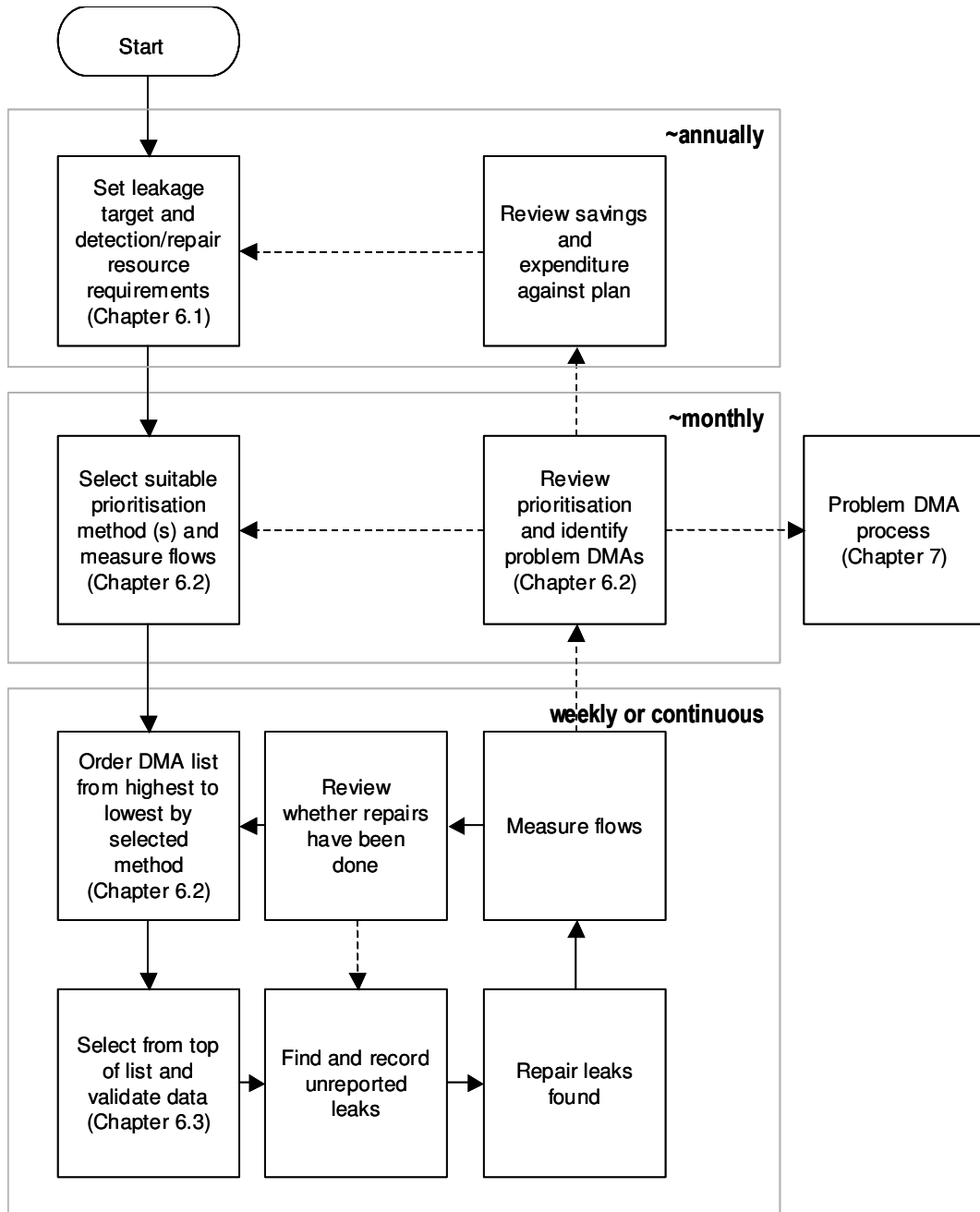


Figure 9 Flow chart for prioritising intervention

## 7.5 Summary

A good prioritising system will provide the leakage practitioner with the data required to optimise the leakage location activity. The priority system should be capable of evolving as more detailed information is captured and



leakage levels are reduced, while providing the practitioner with an easily understood ranking system.

## 8 Problematic DMAs

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Once a DMA has been prioritised for action and the leaks have been located and repaired, it is essential to assess the results. In some cases the recovery of the leakage might be much less than anticipated or that the results are short-lasting. Such DMAs are termed problematic DMAs and require a slightly different approach which is covered in the following sections.

### 8.1 High leakage, few leaks

There are many possible causes of apparently high leakage levels where only a limited number of small leaks can be located. If the DMA has been properly verified and the boundary has been shown to be tight, then in essence there are two main components that could cause the problem:

- Error in the quantification of the leakage level;
- Error in the leakage location activity.

The first task is verify the leakage level. Have the DMA boundaries been properly checked for tightness? Is it possible for instance that there is unknown or illegal consumption? Does the excessive leakage level really warrant further investigation? Some of the recommended actions are listed in Table 1 below.

Table 1: Actions to ensure that apparent leakage is real

Action	Comments
1. Check internal consistency of metering results	<p>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 at two times, say, 24 hours apart. The cumulative flow through the meter should then be compared to the total flow over the same period using the system by which DMA leakage is calculated (e.g. data logger). If these values disagree, the system by which data gets from the meter to the leakage calculation should be checked for an incorrect pulse unit multiplier etc.</p> <p>The method by which meter readings are added to give a total flow into the DMA should also be checked.</p>
2. Check basic DMA data	<p>The basic values used to calculate the leakage level should be checked. This includes all of the customer meter readings and 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.</p>
3. Check leakage calculation	<p>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.</p>
4. Check on metering errors	<p>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 <math>\pm 5\%</math> error, would account for the excess leakage, then consideration should be given to either: redesign of the DMA to reduce the number of meters or; replacement of those meters where fairly small percent errors would give large errors in reported leakage.</p>
5. Check boundary valves	<p>Boundary valves should be checked in the same way as they would be checked when setting up a new DMA.</p>
6. Perform pressure zero test	<p>A pressure zero test should be performed to ensure that no unknown connections exist that breach the DMA boundary.</p>
7. Short interval flow logging	<p>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</p>

Action	Comments
8. Verify meter accuracy	<p>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.</p> <p>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.</p> <p>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.</p> <p>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.</p>
9. Illegal use	<p>If the DMA contains metered non-households, which could potentially use large volumes of water, a survey of these may find some illegal use.</p>
10.Repairs	<p>Check that repairs to reported leaks and bursts have been carried out.</p>
11.Reconsider night use allowances	<p>A list of un-metered non-households in the DMA should be examined to find large users, which might 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.</p> <p>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.</p>

If the leakage level is shown to be correct, than it is necessary to asses the accuracy of the leakage location activity and to question specifically if it is possible that a leak was not identified.

The application of leakage location equipment is outside the scope of these Guidance Notes. However, as most location instruments are based on the acoustic method for detecting the presence of a leak, it is possible that the noise was not even picked up by the instrument. Non-metallic pipes and high background noise coupled to low operating pressures can seriously affect the efficiency of the instruments as can inaccurate maps or insufficient access points.

It is necessary therefore to undertake hydraulic testing with the aim of identifying more precisely the part of the network containing the largest consumption. This can be done by performing a night step test, during which the network is progressively isolated towards the DMA inlet by closing selective line valves. The reduction in flow immediately following the isolation of a step, corresponds to the consumption of the isolated part of the network. It is good practice to monitor pressure in every step during the test, to verify that the closure has effectively isolated the network. Alternatively, if isolating the network is not feasible, it is possible to undertake sub-metering which has the same aim. The disadvantage relates to the cost of creating the flow monitoring points and the fact that it is not possible in this way to verify the isolation of the network.

The detail procedure for undertaking step tests is outside the scope of these Guidance Notes. Listed below is a summary of the key points:

- The consumption of any significant customer night use should be quantified during the test;
- The steps should be as small as practical;
- All valves to be closed should be checked for tightness before undertaking the test, and replaced if found to be inefficient.

As a result of step testing or sub-metering, several lengths of main may be identified as having high night-flow losses. It is necessary to repeat the leakage detection activity in these areas and in some cases, create new access points to reduce the correlation lengths.

There are several other indirect methods which could be applied to find leaks in the DMA. They include pressure logging within the DMA to identify mains where large total head changes occur over short lengths of main and the application of hydraulic network models to simulate the effect on pressures of a leak.

## 8.2 Very low leakage

If DMAs have very low leakage (much lower than would be expected for a DMA with its characteristics: see Appendix E for the assessment of expected background leakage) then it may be useful to investigate the DMA to ensure it is functioning correctly. The points in Table 7.1 above could be used as a check list for ensuring the low leakage is real, with adjustments for low, rather than high apparent leakage.

## 8.3 High leak return frequency (high rate of rise)

Even if all the significant leaks have been successfully located and repaired, it is possible that the reduction in leakage is short lasting. This is an indication of a network in poor condition and is often caused by the increase in pressure resulting from the repair of the leaks. There are two possible solutions:

- Mains replacement;
- Pressure control.

Mains replacement is by far the most costly solution and can usually be justified economically only when the value of the water is very high. However it does mean that the bursts will be completely eliminated. Care should be taken however when a partial substitution of the worst mains is undertaken, that the leakage in the original network does not increase.

Pressure control on the other hand is a very effective and economical solution to the same problem. It involves installing a pressure reducing valve (PRV) on the DMA inlet which not only maintains the optimum pressure in the network at all times, but automatically compensates for the reduced flow following the repair of the leaks whilst maintaining the original operating pressures in the DMA. Experience has shown that in this way, it is possible to drastically reduce the frequency of bursts, even in networks which have very low operating pressures. However it does ideally require a single supply main and very careful designing and it won't eliminate the need to replace certain main in a critical condition.

## 8.4 Summary

All detected leaks 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..

There are several possible outcomes to a leakage location and repair programme. These are shown in Table 2

**Table 2: Outcomes from leak repair**

<b>Outcome</b>	<b>Further actions</b>
1. leaks detected and repaired: night-flow drops after repair by same amount as step	no further action necessary
2. leaks detected and repaired: night flow drops but by 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	further investigation of night use in step

length of main with high night-flow losses	investigate pressure reduction consider service and/or mains replacement
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In all cases where the leakage does not drop substantially, pressure control should be considered, because of its effects on both burst frequency and losses from existing bursts and leaks. Mains and/or service replacement is probably the most reliable method to eliminate a leakage problem, but this is seldom cost-effective..

## 9 Glossary

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**Active Leakage Control (ALC).** The process by which unreported leaks are detected and repaired. This contrasts to Passive Leakage Control.

**Average Zone Night Pressure (AZNP).** The property-weighted average pressure in a zone during the minimum night flow period.

**Awareness Time.** The time between the occurrence of an unreported leak and the water undertaking becoming aware of its existence.

**Background leakage.** The component of leakage that is not effected by ALC. This usually consists of very small leaks.

**Bottom-up.** This term refers to assessments of leakage made from night flows measured in DMAs and added together to produce an area leakage level.

**Burst.** A failure of a pipe or service leading to leakage. In this publication this term is interchangeable with Leak.

**Cascade.** A method of supplying DMAs where water flows through one DMA into another one. This necessitates more than one meter on some DMAs; a situation that is best avoided.

**Customer night use.** The water used by customers during the minimum night flow period.

**DMA.** A small metered area within the distribution network. The acronym stands for District Metered Area, but the term Distribution Monitoring Area is also used to describe the same thing.

**Economic Level of Leakage.** The level of leakage at which the net present cost of operation of the network is a minimum.

**Flats.** Apartments

**Flushing.** The induction of high flows in pipes by opening hydrants or washouts.

**Hydraulic Balance Point:** In a complicated network fed by several trunk mains, there will be points within the distribution mains network where the net flow is close to zero at a given time, as flows from different routes feed the customers on either side. These hydraulic balance points are often suitable for sector or DMA boundaries as the closure of a valve here will cause little disruption.

**Infrastructure.** The physical components of the distribution network. This normally excludes electrical components.

**Leak.** See Burst



**Leakage.** The water lost through holes in the pipes and tanks forming the network.

**Location Time.** The time taken from the point where the Water Undertaking is aware of the existence of a leak to the point when the undertaking is aware of the exact location of the leak.

**Losses.** Losses can be divided into apparent losses (meter errors and unauthorised consumption) and real losses. Real losses are equivalent to leakage from mains and service connections and overflows from service reservoirs and treatment plants **Minimum night flow.** The net flow into a metered area during the period of minimum flow: this period is usually one hour.

**Night Day Factor (NDF).** The factor by which night flow losses, (calculated from the Minimum Night Flow over a one hour period), should be multiplied to obtain the daily leakage. The NDF is usually less than 24, due to lower pressures during the day.

**Night Line.** See Minimum Night Flow

**Passive Leakage Control.** Leakage control carried out by repairing only those leaks that become visible and are reported to the Water Undertaking.

**PRV.** Pressure Reducing Valve. A control valve within the network which reduces the downstream pressure using various types of control method.

**Pressure Correction Factor (PCF).** If leakage ( $L_0$ ) is either measured, or estimated, at one pressure ( $P_0$ ), then in order to estimate the leakage ( $L_1$ ) at another pressure ( $P_1$ ), a relationship of the form:

$$L_1 = L_0.PCF$$

can be used. The PCF is a function of the two pressures  $P_1$  and  $P_0$ . This method is frequently used to translate leakage estimated at 50m head into leakage at the actual pressure experienced in a zone.

**Pressure zero test (PZT)** See zero pressure test.

**Rate of Rise of Leakage.** The rate at which leakage increases with time between periods of active leakage control. This can be measured by analysis of long-term flow and repair records. It is usually expressed in litres per connection per day per year

**Repair Time.** The time taken from the point when the undertaking is aware of the exact location of the leak to the point when the repair is completed.

**Reported burst.** A leak that the water undertaking becomes aware of without any detection activity. The reasons for this are typically that the water becomes visible on the surface or the burst leads to loss of supply to customers.

**Rota cuts.** Rationing of supply by providing supply to parts of the distribution network for restricted periods, often according to a timed rota. .

**Run time of burst.** The total time from the occurrence of a burst to its repair.

**Sector.** A section of the distribution network, usually much larger than a DMA and often defined by clear natural or manmade boundaries, such as rivers or railways.

**Step test.** A test to find the location of a leak. Parts of an area fed through a meter are progressively isolated while the flow is monitored. The drop in flow after each isolation is used to identify the amount of leakage in that isolated section.

**Top-down.** Refers to assessment of leakage levels through a water balance.

**Unreported burst.** A burst which can be found by active leakage control but not by passive leakage control.

**Water Undertaking.** A general term for the organisation responsible for operation of the water supply and distribution system.

**Zero pressure test.** A test to identify whether the boundary to a zone is watertight. An area of the distribution system is isolated by closing boundary valves. The pressure is monitored and if it drops to zero this indicates that the boundary is watertight.

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## Appendix A - Estimating Night-Day-Factors (NDFs)

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The NDF for any DMA can be calculated by recording the hourly pressures at the AZP (average zone point) over 24-hour periods. Then if :

- The AZP pressure over the hour of minimum night flow is  $P_{\min}$
- The AZP pressures corresponding to the hourly series of night flows  $Q_0$  (00 to 01 hrs),  $Q_2$  (01 to 02 hrs) etc, are  $P_0$ ,  $P_1$ , etc

then the NDF can be calculated as

$$\text{NDF} = (P_0/P_{\min})^{N1} + (P_1/P_{\min})^{N1} + (P_2/P_{\min})^{N1} + \dots + (P_{23}/P_{\min})^{N1}$$

Where  $N1$  is the exponent in the FAVAD equation which relates leakage rate to pressure, i.e.

Leakage is proportional to Pressure <sup>$N1$</sup>

It will be noted from the above formula that the NDF can be calculated without measuring the DMA inflows. If the relationship between average pressure and leakage rate is linear ( $N1 = 1.0$ ), as can be generally assumed in the absence of specific estimates of  $N1$  (see below), then the NDF equation simplifies to

$$\text{NDF} = 24 \cdot \left( \frac{\text{Average daily pressure}}{P_{\min}} \right)$$

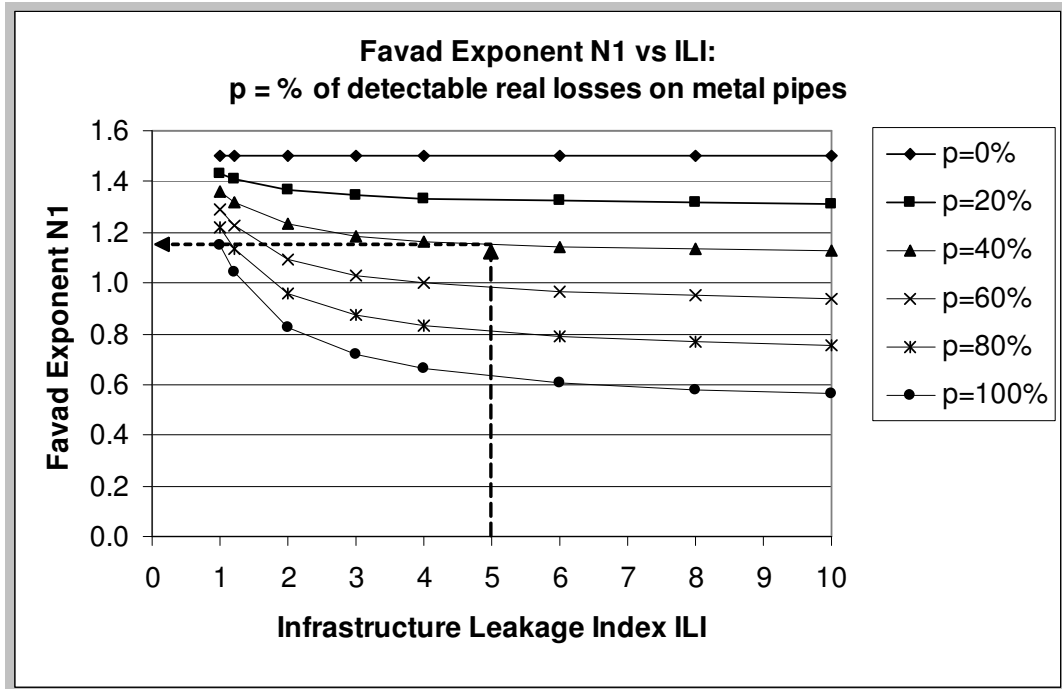
As 24-hour pressure profiles at the AZP can vary on different days of the week, and seasonally, the NDF also varies accordingly.

### Estimating $N1$ values

The value of the FAVAD exponent  $N1$  for pressure-leakage relationships in individual DMAs, based on extensive laboratory and field tests, is usually between 0.5 and 1.5. This is because background leakage, and detectable leaks (reported and unreported) from non-metal pipes, have  $N1$  values close to 1.5, and are quite sensitive to changes in pressure. In contrast, detectable leaks (reported and unreported) from metal pipes have  $N1$  values close to 0.5, which are less sensitive to pressure.

When doing detailed analysis of night flow components, it is necessary to take account of the different  $N1$  values of different types of leakage.

However, for calculating NDFs, from AZP pressure data, a simpler practical approach can be used, based on the following figure.:



First, estimate the scale of the leakage in the DMA, on a scale of 1 (lowest possible) to 10 (very high); this will give you a crude approximation for the Infrastructure Leakage Index (ILI), which is normally calculated more objectively. Suppose you estimate that the ILI is around 5.

Next, estimate what % of detectable leakage arises from metal pipes. The crudest estimate will be based only on the % of system pipe length (mains and service connections) that is metal. Suppose this is around 60%.

Then, simply read up from '5' on the X-axis, until you reach the '60%' curve, then read across to the Y-axis to estimate the N1 value, which is around 1.1.

## Appendix B - Estimating Average Zone Night Pressure

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Depending on local topography the ground level within a DMA may vary considerably, particularly in rural areas and in situations where the network is on the side of a valley. For calculations using the effect of pressure the average pressure within the DMA should be estimated. The average zone night pressure (AZNP) for a DMA should be the best estimate of the average pressure in the DMA at night, (when the minimum nightline is calculated). There are several ways to identify a surrogate point for this measurement:

- Place a pressure logger close to the mid point of the DMA and record pressure over several weeks to determine typical pressure at night.
- Obtain the ground level of all customer connections in the DMA. Calculate an average ground level of the connections. Determine the total head from pressure measured or estimated at the inlet to the DMA. Subtract average connection ground level to estimate AZNP.
- Use a calibrated hydraulic model of the network, calculate the pressure at each node in the DMA during the minimum night-flow period and calculate a connection-weighted average

An approach used by one utility to determine AZNP in some 3000 DMAs was to initially obtain best estimates from local staff and then to gradually improve this estimate using its geographic information system to determine the average ground level of the connections in a particular DMA and to then determine the typical pressure AOD at night in the DMA from pressure loggers at critical points, pressure reducing valve outlet pressures, pump outlet pressures and top water levels of service reservoirs.

Where a DMA contains multiple pressure zones, then AZNP should be calculated for each pressure zone and the AZNP for the DMA would be the connection weighted average.

Example of multi pressure DMA

Pressure zone 1-----500 connections at AZNP of 30 metres

Pressure zone 2-----200 connections at AZNP of 70 metres

Pressure zone 3-----700 connections at AZNP of 45 metres

$$\begin{aligned} \text{DMA AZNP} &= (500*30)+(200*70)+(700*45)/(500+200+700) \\ &= 43.2 \text{ m} \end{aligned}$$

It should be noted that depending on local conditions AZNP can usually be estimated robustly by local staff after guidance has been given that suits local information. As the pressure usually at night is the maximum that can be recorded in the zone, i.e. input pressure from PRV, service reservoir, etc, as the reduction in pressure during the day due to head loss is not required at this stage.

To calculate the average AZNP for a group of DMAs, value for each DMA should be calculated and then a connection weighted average should be calculated as per example of multi pressure DMA calculation.

In situations where seasonal variations in pressure are experienced and considered to be significant it may be necessary to undertake pressure logging over a longer period of time to estimate the effect of seasonal variations.

Where pressure systems are more complex or are subject to imposed reductions in flows to conserve or ration supplies consideration should be given to the impact on estimated AZNP

## Appendix C – Selecting DMAs for ALC where key data is available

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If large amounts of data on detection and repair costs are available, it is possible to develop a method to select DMAs for detection which will produce a near-optimal result. There are several variations on the method in use which use different levels of sophistication and different models of the leakage process. The description given here is a fairly simple approach, which can readily be improved.

The data required for each DMA is as follows:

- The cost of carrying out leak detection in the DMA to get down to a background level of leakage after repair
- The value of the saving that can be achieved as a result
- The rate of increase of leakage between rounds of ALC

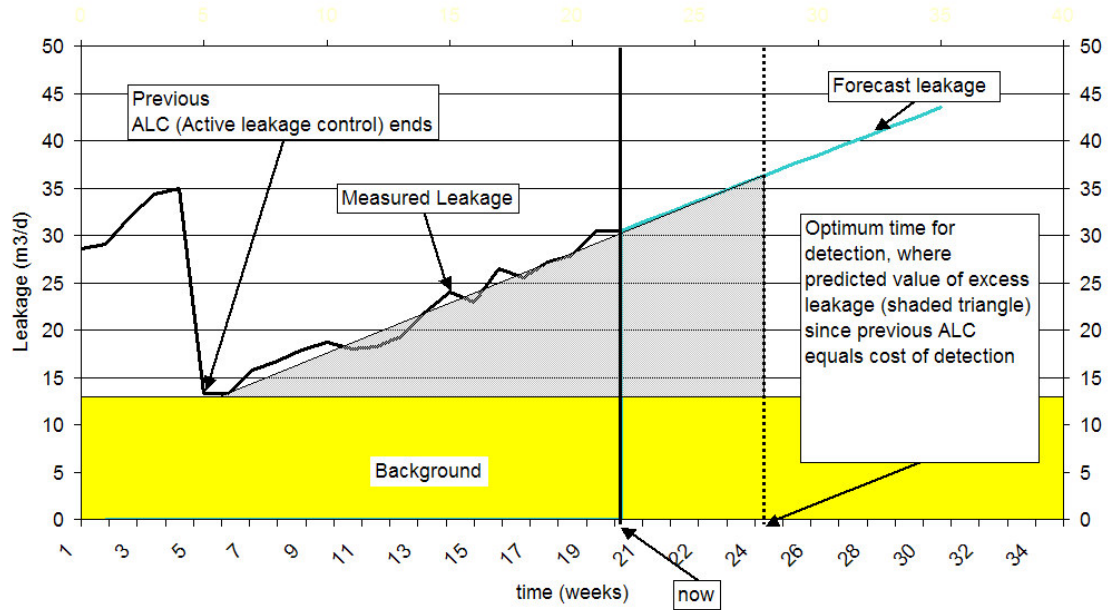
The main assumptions are:

- The rate of rise of leakage between ALC rounds is linear
- The leakage level achieved immediately after ALC is not dependent on the starting level
- All data can be predicted accurately
- That repair costs are unimportant because all leaks would eventually become reported.

In this case, as leakage rises, the detection and repair should be carried out at the point where the value of the excess losses equals the cost of the detection. This is illustrated in the figure below.



Figure C-1: Illustration of alternative method for selecting DMAs for ALC



## Appendix D: Night Consumption Estimation: UK Experience

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Much effort has been put into estimating night consumption in the UK. This has been driven partly by regulatory pressure. The methods set out below were developed during the UK National Leakage Initiative, in 1994. (Described in the Managing Leakage reports: “Managing Leakage, UK Water Industry Engineering and Operations Committee, published by WRc(1994)”). These relatively simple methods are likely to be suitable for application elsewhere as a first step. These methods have been further developed since 1994 and these developments are described in “Leakage Estimation from Night Flow Analysis, UK Water Industry Research Ltd (1999)”, “Estimating Legitimate Non-Household Night Use Allowances, UK Water Industry Research Ltd (1999)” and “Household Night Consumption, UK Water Industry Research Ltd (2002)”.

### Household night use

Irrespective of whether customers are metered or not, it is likely that household night use in a particular system will be affected by the internal plumbing system and the occupancy of a household. Work in the UK has identified that occupancy of the household is a key factor to estimating customer night use. This is not surprising as with the increased numbers in a household, the likelihood of using more water at night is greater. To date, the majority of household night use has been based on:

*Household night use = Number of households x rate of night use*

Where average utility occupancy rate has been utilised to determine average night use.

Summary Key results from UKWIR Household Night Consumption

“The appropriate night consumption allowance will be different for each company and should be determined from local data. Indicative results are presented in this report derived from IHM data. The results are derived after eliminating any leakage but do not make allowance for meter under-registration or any bias in the sample data sets compared to the composition of company populations.

Annual average household night consumption values between 1.8 and 2.5 1/prop/h have been derived from the individual household monitors (IHM) reviewed for this project using all available data. These figures, which exclude under-registration allowances, are higher than the 1.7 1/prop/h (including under-registration) quoted in Managing Leakage.

### 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.

The Managing Leakage Report E has a basic method for calculating non-household night use. This gives the result:

$$\text{Non-household night use} = \text{number of non-households} \times 8 \text{ litres/hour}$$

The value of 8 has recently been updated by one UK Company to 10 litres/hour as a result of more detailed work excluding exceptional night users.

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

The Managing Leakage Report E also has a more complex method, where there are five categories of night user and:

$$\text{Non-household night use} = \text{sum of (non-households in category} \times \text{allowance for category) for categories A to E.}$$

The categories, and their allowances are shown in the following table:

**Table D-1: 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, work sites.	20.7
E	Old peoples homes, mines, quarries.	60.6

## Special consumers

Typically, these are the larger Non household industrial customers whose night use is more than 500 l/hr and are likely to have a significant variation in night use from night to night. 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 a one-hour interval 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 understood 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.

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

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

## Appendix E - The BABE Concept

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### Calculating AZNP

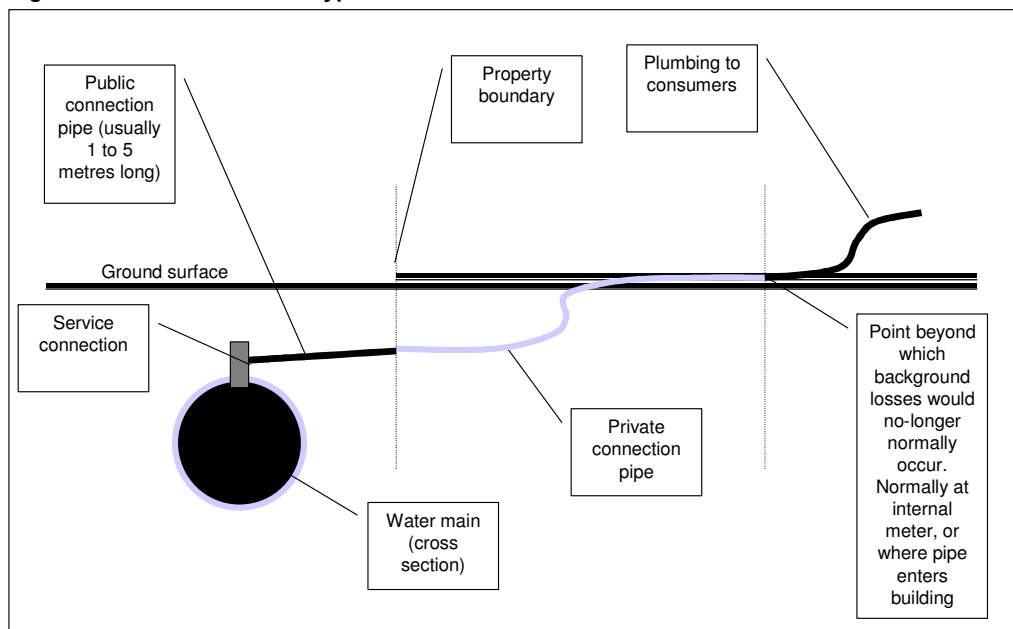
The average zone night pressure AZNP for a DMA should be the best estimate of the average pressure in the DMA at night, (when the minimum nightline is calculated). This is explored in Appendix B above.

### Calculating background leakage

Using burst and background principles, background leakage in a DMA can be estimated based on:

- Length of main
- AZNP average DMA night pressure
- Number of property connections
- Length of private connection pipe (UK service pipe, USA property line from curb stop to customer meter).

**Figure E-1: Cross section of typical customer connection**



The recommend formula by IWA in 2004 is as follows.

The background loss estimate with infrastructure in good condition at 50 metres in litres/hr

= 0.02 x metres of main + 1.25 x no of connections + 0.033 l/metre of private pipe + 0.25 litres per household or non household (industrial)

A more flexible approach is the following equation:

= ICF x (0.02 x metres of main + 1.25 x no of connections) + (ICF <sup>see note 1</sup> x 0.033 l/metre of private pipe) + 0.25 litres per household or non household   
 see note 2

ICF is the Infrastructure Condition Factor the value normally lies between 1 and 4.0, depending on the condition of the mains: (a value of 1 if the mains are considered to be in good condition, or 4.0 if they are considered to be in poor condition from a water tightness point of view). An initial estimate of 2 was used extensively in the UK whilst more detailed information was gathered.

The equation can be further developed to take into account pressure by using a pressure correction factor based on the average zone night pressure. A power law of 1.5 has been developed specifically for background losses from international data.

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

= (ICF x (0.02 x metres of main + 1.25 x no of connections) + (ICF <sup>see note 1</sup> x 0.033 l/metre of private pipe)) x (AZNP/50)<sup>1.5</sup> + (0.25 litres per household or non household x (AZNP/50)<sup>1.5</sup> <sup>see note 2 & 3</sup>)

#### Note

1. Where the customer meters are located at junction of property connection and private pipe it is unlikely that ICF affects the private pipe, as it would be in the interest of customers to minimise any leakage.
2. Plumbing losses are unlikely to be affected by the condition of the underground infrastructure
3. Pressure will only affect customer plumbing where supplies are direct. Therefore customers plumbing supplied via ground tanks or roof top storage will not be affected by pressure and an initial value of plumbing losses of 0.25 l/household/non household (industrial customer is recommend)

## Example of calculation of DMA background losses

DMA infrastructure details	
Length of main metres	22500
AZNP metres	60
Number of connections	1500
Number of private pipes	1500
Average length of individual private pipe metres	12
ICF	1.5

Calculation where customers are not metered and supplies are direct

$$= \{1.5 \times [(22500 \times .02) + (1500 \times 1.25) + (1500 \times 12 \times .033)] \times (60/50)^{1.5}\} + \{(1500 \times .25) \times (60/50)^{1.5}\}$$

$$= 6250 \text{ l/hr or } 6.3 \text{ m}^3/\text{hr}$$

Calculation where customers are metered at boundary of private pipe and supplies are direct

$$= \{1.5 \times [(22500 \times .02) + (1500 \times 1.25) + (1500 \times 12 \times .033)] \times (60/50)^{1.5}\}$$

$$= 5860 \text{ l/hr or } 5.9 \text{ m}^3/\text{hr}$$

**Variation of background losses with AZNP and ICF customer meters at boundary of private pipe and supplies direct**

AZNP	Background losses (l/connection/hr) for infrastructure in:		
	Good Condition	Average Condition	Poor Condition
	ICF=1	ICF=2	ICF=4
20	0.5	0.9	1.6
30	1.0	1.6	3.0
40	1.5	2.5	4.6
50	2.1	3.5	6.4
60	2.8	4.7	8.5
70	3.5	5.9	10.7
80	4.2	7.2	13.0
90	5.1	8.6	15.6

[Note: assumes 10m of mains/connection & 12 metres average private pipe length]






## Appendix F - Examples of successful DMA implementation

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The examples set out here summarise a few projects that have successfully implemented DMAs in several different countries. These examples show some of the particular problems and solutions which have been encountered in countries with widely differing types of infrastructure, customer requirements and regulatory regimes. *It is important to note that the methods used here are not necessarily those recommended by the Guidance Notes authors or IWA Water Loss Task Force as best practice.*

## El Dorado Irrigation District , California, USA

<b>Description of the project</b>	
1	<i>A brief description of the location</i>
	<p>The DMA was created in El Dorado Irrigation District (EID), California, United States of America as part of a research project partially funded by the American Water Works Association Research Foundation (AwwaRF) with the goal to assess the transferability of international leakage management technologies to North America.</p> <p>The topography of EID`s supply area is not homogeneous, which is why the distribution network is already subdivided in pressure control zones. Therefore, it was decided to convert an existing pressure zone into a permanent DMA. The selected area is “North Shingle”, which is fed through a single inflow point. The DMA serves a population of approximately 1,200 people with an average zone pressure of 78 meters. It took about 3 month from start of DMA design until the DMA was operational.</p>
2	<i>The level of real losses before and after installing DMAs</i>
	The level of real losses in the North Shingle DMA was 1,545 l/con/day or 18.62 l/con/day/m with a corresponding ILI of 9.23.
3	<i>Supply arrangements for typical households.</i>
	Every service connection in the DMA is equipped with meter, no storage tanks are found in the households. The typical supply pressure at the point of delivery ranges from 50 meters to 140 meters in the DMA. Due to the hilly terrain there are parts of the DMA with excessive pressure and therefore the majority of service connections are equipped with a PRV.
<b>Design</b>	
4	<i>What influenced the design of individual DMAs?.</i>
	The design of the DMA was influenced by the need to make use of an existing pressure control area with a single feed, and the need to be able to meet fire flow, minimum pressure, and insurance requirements.
5	<i>Was pressure management considered at the design stage?</i>
	Pressure management was considered at the design stage due to excessive system pressures. The DMA is fed through one inflow point which is equipped with 2 PRVs (one lead PRV and one lag PRV) which are managing the pressure for the entire DMA.
6	<i>The methods used for design.</i>
	No design work for the boundaries of the DMA or the size of the DMA was required as an existing pressure control zone was converted into a permanent DMA. Consumption data from the billing system and known ratios between summer and winter peak demand have been assessed. Fire flow demands and requirements have also been assessed. Historic pressure data from critical points within the DMA have been analyzed and in addition new pressure measurements throughout the DMA have been conducted. Based on the initial assessments, calculations and measurements, it was decided that the existing 200mm inflow main would have flow velocities during the period of minimum night consumption that are too low for accurate flow measurements. Therefore the project team came to the decision to convert the lead 150mm PRV into a metering PRV (this technology is available from most PRV manufacturers). The lag 200mm PRV feed was designed to be used for fire flow and emergency purposes. No network model was used for the DMA design.

8	<i>How was the integrity of the boundary tested?</i>
	The results of the minimum night flow (MNF) test and the calculated daily consumption per service connection was cross checked with the billing data from the DMA accounts. The billing data consumption and daily consumption based on the MNF test matched very closely verifying that integrity of the DMA.
9	<i>How were the boundaries of DMAs defined and managed?</i>
	The DMA boundaries were existing, with significant physical separations due to topography, different pressure zones, and dead-end lines.
10	<i>Do the new boundaries include flushing facilities?</i>
	No new boundaries were established, and the existing boundaries included blow-offs for manual flushing as needed.
11	<i>Are any systems in place to ensure boundary valve operation is recorded?</i>
	N/A
12	<i>How were meters selected.</i>
	As an existing pressure control zone was converted it was decided to make use of the existing pressure regulation station. Through research it was found that PRV manufacturers offer retrofit kits for PRVs to convert existing PRVs into metering PRVs. The manufacturer for the metering PRV kit was selected based on the manufacturer of the existing PRV.
13	<i>Describe a typical meter installation</i>
	



**Permission to publish details: El Dorado Irrigation District has granted permission to publish the information provided above within the IWA – DMA Guidance Notes.**

## Water Board of Lemesos, Cyprus

	<b><i>Description of the project</i></b>
1	<i>A brief description of the location</i>
	<p>The town of Lemesos is situated on the south coast of the island of Cyprus in the north-eastern Mediterranean Sea, has a current population of 150.000 and is the second largest town on the island of Cyprus. The Water Board of Lemesos is a non-profit, semi-government organisation charged with the responsibility of supplying potable water to the town and environs of Lemesos.</p> <p>In 1985, the Water Board embarked on an ambitious expansion programme involving a major extension to the distribution system, which included division of the distribution network into pressure zones, each with adequate storage reservoir capacity. A series of pumping stations to lift water to higher zones was constructed. A comprehensive Supervisory Control and Data Acquisition system (SCADA) with remote terminal units installed at all sources of water, reservoir and pumping station sites with its central control room at the main offices of the Water Board was commissioned in 1988.</p> <p>The topographical location of Lemesos is such that the elevation of the supply area varies from zero at the coast to 315 meters above sea level at the foothills. To ensure acceptable pressure limits to consumers, the entire supply area was divided into seven pressure zones, each with its own dedicated storage reservoir. Each pressure zone is divided into District Metered Areas (DMA's) which are fed by gravity from their respective reservoir via ductile iron trunk mains varying in diameter from 800mm down to 300mm. Until 2003 the total number of DMAs was 27 but it was considered important to carefully examine the size of these DMAs particularly in the larger pressure zones in an effort to further reduce the real losses from the system and at the same time to provide better and more effective active leakage control. The restructuring of the DMAs commenced in 2004 and will be completed in 2007 resulting in 52 DMAs. The average pressures in the DMAs before restructuring varied from 4-6 bar. After restructuring pressure control is applied to all DMAs with pressures varying from 2-4bar.</p> <p>Today the Water Board covers an area of about 100km<sup>2</sup> with approximately 800km of underground mains, with approximately 70.000 registered consumers and annual water production of 13MCM.</p>
2	<i>What was the level of real losses before and after installing DMAs?</i>
	<b>See attached Graph 1 and Graph2</b>
3	<i>Briefly describe the supply arrangements for typical households:</i>
	<p>All house connections are metered and the water meter is placed very close to the property line. Up to the water meter is the responsibility of the Water to install and maintain the connection. After the water meter it is the responsibility of the property owner to install the plumbing. It is required that a direct potable supply point is taken from the water meter to the kitchen. A second supply point is to the cold water roof tank from which the water is distributed into the house for use in the bathrooms, toilets, kitchen, etc. The level of pressure provided by the Board is 2 bar at the highest point of the DMA at maximum demand. The AZNP in DMAs is of the</p>

	order of 2.5-3.5 bar. Under normal conditions the water supply is continuous. However, in periods of extreme water shortage the supply has been intermittent.
	<b><i>Design</i></b>
4	<i>What influenced the design of individual DMAs?</i>
	<p>The following key factors formed the basis of the DMA design:</p> <ul style="list-style-type: none"> <li>• size of the DMA</li> <li>• minimum variation in ground level across the DMA,</li> <li>• easily identified boundaries that are robust,</li> <li>• area meters correctly sized and located,</li> <li>• single entry point into the DMA,</li> <li>• discrete DMA boundaries,</li> <li>• pressure optimised to maintain standard of service to customers,</li> <li>• degree of difficulty in working in urban area.</li> </ul> <p>It was aimed to have small to medium size DMAs (up to 3000 properties) with minimum ground level variation so that effective pressure reduction and control could be applied. Physical discontinuity of pipelines was applied at boundary conditions between DMAs avoiding where possible dead-ends. In cases of dead ends flushing facilities were installed. Main highways and physical feature such as streams were chosen to form discrete boundaries between DMAs.</p>
5	<i>Was pressure management considered at the design stage?</i>
	<p>The variation in ground levels across the study area was examined and particular attention was given to the influence of the pressure within the DMA. Management of pressure is a key factor in an effective leakage management policy. This has long been recognised by the Water Board and the ultimate goal is for all DMAs to be equipped with PRVs to reduce pressure where possible and to control and stabilise pressure in DMAs where pressure reduction is not practicable.</p> <p>Measurements of pressures within the DMAs were carried out to establish operating pressures at the low, medium and high points of the DMA as well as the Average Zone Night Pressure (AZNP) for each DMA. Furthermore, the pressure measurements were critically examined with the aim to reduce pressure as much as possible whilst maintaining the minimum standard of service to the consumers. As a rule a minimum standard of service of 2 bar at the highest point in the DMA at maximum demand was considered. This of course had to be reconsidered in some cases where there were high-rise buildings which used the system's pressure to get the water to their roof tanks. In these cases the Water Board will subsidise the installation of ground tanks and pumping systems in order to pump the water to the roof tanks of the high rise buildings thus enabling further pressure reduction to be</p>

	<b>effected.</b>
6	<i>The methods used for design.</i>
	<b>The important factor considered was the hydraulic performance of the network. This was designed to provide optimum performance within the limitation imposed by the network layout.</b>
7	<i>Was a hierarchy of metered zones used?</i>
	<b>All DMAs were designed to function independently with a single point of entry which is metered.</b>
8	<i>How was the integrity of the boundary tested?</i>
	<b>In order to verify that all interconnecting pipes between DMAs were located and isolated a zero pressure test was carried out which involved closing the valve at the inlet to the DMA thus isolating the DMA and observing that the pressure within the DMA dropped immediately indicating that all interconnecting pipes were isolated. This test was usually carried out between 02:00 and 04:00 in the morning in order not to inconvenience consumers.</b>
9	<i>How were the boundaries of DMAs defined and managed?</i>
	<b>The design process yielded DMAs of smaller, more manageable size with physical pipe work discontinuity between DMAs. With closed valve boundaries there is always the danger of the valves accidentally being opened and remain open.</b>
10	<i>Do the new boundaries include flushing facilities?</i>
	<b>Where possible dead ends are avoided for water quality reasons. If this is not possible flushing facilities are provided at these points.</b>
11	<i>Are any systems in place to ensure boundary valve operation is recorded?</i>
	<b>There are no boundary valves. The policy of the Water Board is to have pipe work discontinuity.</b>
12	<i>How were meters selected. This includes both the type of meter and the size selected.</i>
	<b>The selection of the flow meters was based on the historical data available of minimum, average and peak flows taking into consideration seasonal variations. The meters chosen were low cost mechanical "Waltman" type of metrological class B with pulse output having a flow range up to 200 m<sup>3</sup>/hr. Most DMAs required a 100mm nominal diameter meter with the larger size DMAs needing a 150mm nominal diameter.</b>
13	<i>Describe a typical meter installation.</i>
	<b>PLEASE SEE ATTACHED PHOTOGRAPH</b>
14	<i>How were night use allowances calculated for use in assessing leakage levels (if any)</i>
	<b>Data required to establish legitimate customer night use and background leakage in each DMA were collected. Having available this information the Burst and Background Estimates (BABE) component approach to leakage was used to analyse the Minimum Night Flow (MNF).</b>



	<b><i>DMAs in use</i></b>
15	<i>How is flow data collected from typical DMA?</i>
	<p>It is essential, for the effective operation of DMAs, to establish a reliable on-line monitoring system in order to apply best practice DMA management which involves the analysis of DMA night flow referred to as the Minimum Night Flow (MNF) in order to assess leakage. For this purpose each district meter is equipped with a programmable controller which is powered in most cases by solar energy panels providing a cheap and effective solution. The programmable controller is performing the following tasks:</p> <ul style="list-style-type: none"> <li>• Data logging of flow and pressure</li> <li>• Control (open-close) of PRV</li> <li>• Communication with the control room at Water Board's offices via a PSTN line, GSM, radio or landline.</li> </ul> <p>The on-line monitoring of the district meters combines information technology and telecommunication networks to transfer the data via the World Wide Web. The historical data gathered in the programmable controller of each DMA are sent by the controller to an email account. Dedicated software operating from a computer at the Water Board's control room connects to this email account every hour and downloads the data, which are first sorted according to the DMA and then are used to update existing reports. Direct access to the programmable controllers from the control room enables modification to the programming of the controllers, downloading of historical data on request and closing or opening of the PRVs. A typical template of the district meter on-line monitoring is shown in Figure 1.</p>
16	<i>How is flow data checked to ensure that it is valid?</i>
	<p><b>Continuous flow monitoring began immediately upon completion of each DMA. This enabled the establishment of the flow pattern for the DMA providing essential information such as maximum and average daily flows as well as minimum night flows. A typical flow and pressure pattern in a DMA is shown in Figure 2.</b></p>
17	<i>Describe how the flow data is interpreted to assess the level of losses. Does this include both a night-flow measurement and a water balance? How are these reconciled? Is the IWA water balance used? If a water balance is used at DMA level, what period is it carried out over and does it include measurement of customer consumption over the same period?</i>
	<p><b>Data is collected and BABE calculations are carried out in order to determine background and locatable losses for each DMA. In order to determine the locatable losses in a DMA the Minimum Night Flow is used which is taken from the on-line monitoring system. The DMAs are then ranked according to level of locatable losses and active leakage control is performed in the DMA with the highest ranking. This "bottom-up" approach is performed for all DMAs. A water balance is performed on an annual basis as a "top-down" approach arriving at the level of real losses. This level is compared with the "bottom-up" result and necessary adjustment are made</b></p>

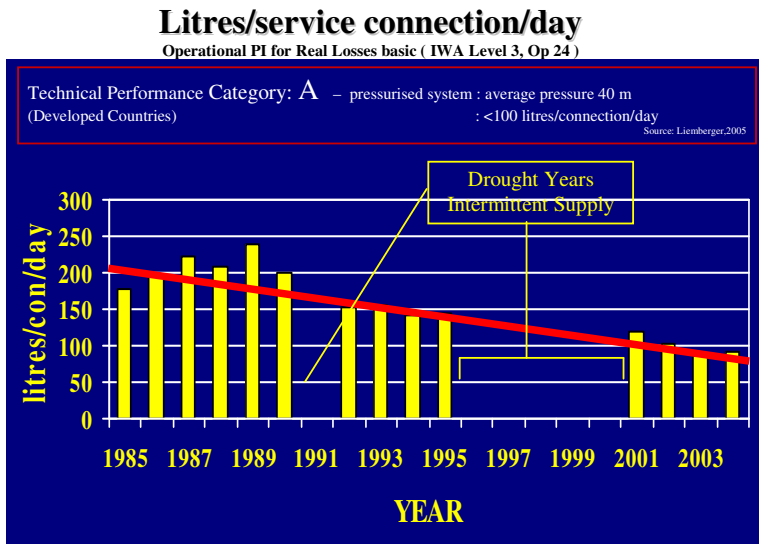
	<b>to the assumptions made in both approaches until the level of real losses is the same using both methods.</b>
18	<i>Describe the process by which decisions are made on which DMAs are investigated by leakage control teams.</i>
	<b>The prioritisation is based on the level of locatable losses. In the example below the priority for locating and repairing leaks is been given first to DMA 230 followed by DMA 225 and DMA227. For the rest of the DMA it is considered uneconomical to investigate for locatable losses as the level of these is below one equivalent pipe burst(Table 1).</b>
19	<i>What happens when DMAs are investigated by leakage control teams but the leakage is not reduced?</i>
	<b>At the Water Board of Lemesos we use the four basic constraint activities, i.e. Pressure Management, Pipeline and Asset Management, Active Leakage Control and Speed and Quality of Repairs to reduce leakage. This methodology is very effective and there is no reason if applied correctly not to have reduction in leakage.</b>
20	<i>Describe maintenance processes.</i>
	<b>Data collection is continuous for both flows and pressures through the on-line monitoring.</b> <b>The following activities are carried out at regular intervals:</b> <ul style="list-style-type: none"> <li>• <b>Checking and cleaning of area water meter strainers every six months.</b></li> <li>• <b>Checking and adjusting if required PRV settings every six months.</b></li> </ul>
21	<i>Describe the other uses that you put DMAs to.</i>
	<b>Of course DMAs are extremely useful for assessing real losses. In addition useful information and data on customer demand, seasonal demand variation, pressure fluctuation, and frequency of pipe bursts are obtained.</b>
	<b>Other aspects</b>
22	<i>Is there any other aspect of the design, installation and use of DMAs that has been important, but has not been covered in the questions above? This could include particular problems and how they have been overcome</i>
	<b>It is important to understand that the application of DMA philosophy must be a part of a strategic plan for effective and efficient Leakage Management.</b>

**Name of contributor: Bambos Charalambous**

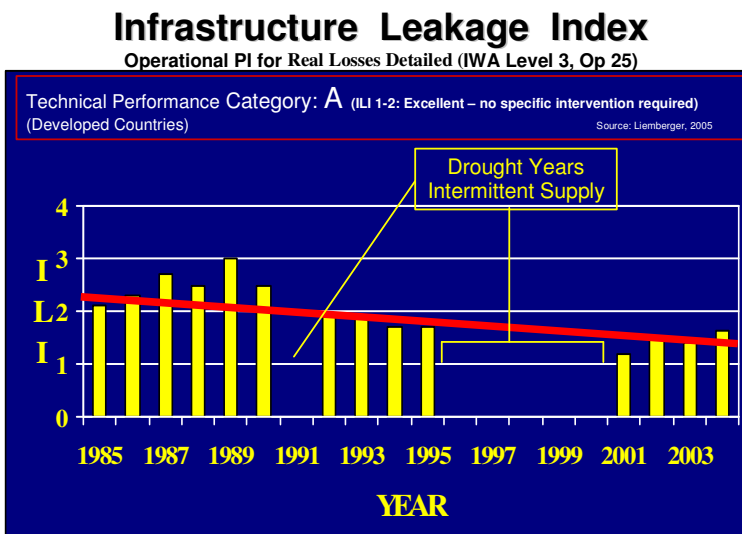
**Organisation: Water Board of Lemesos, Cyprus**

Operational Performance over the last 20 years in litres/connection/day and ILI.

Graph 1:



Graph 2:



## DMA Inlet Chamber

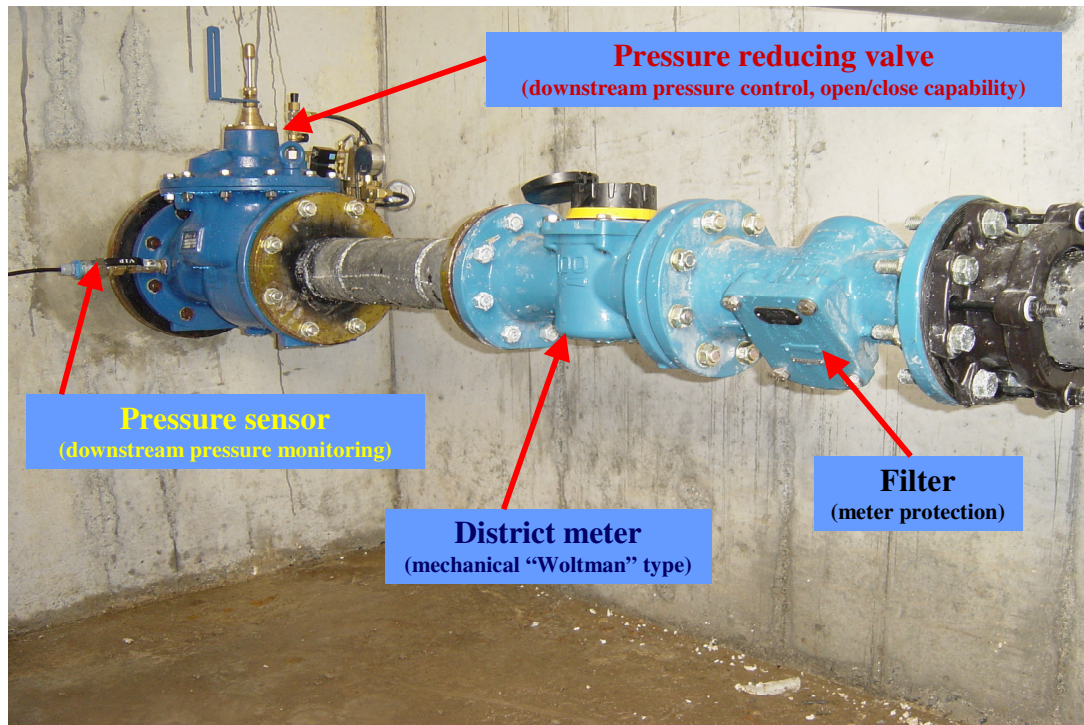


Figure 1. Typical template of the on-line district meters monitoring system

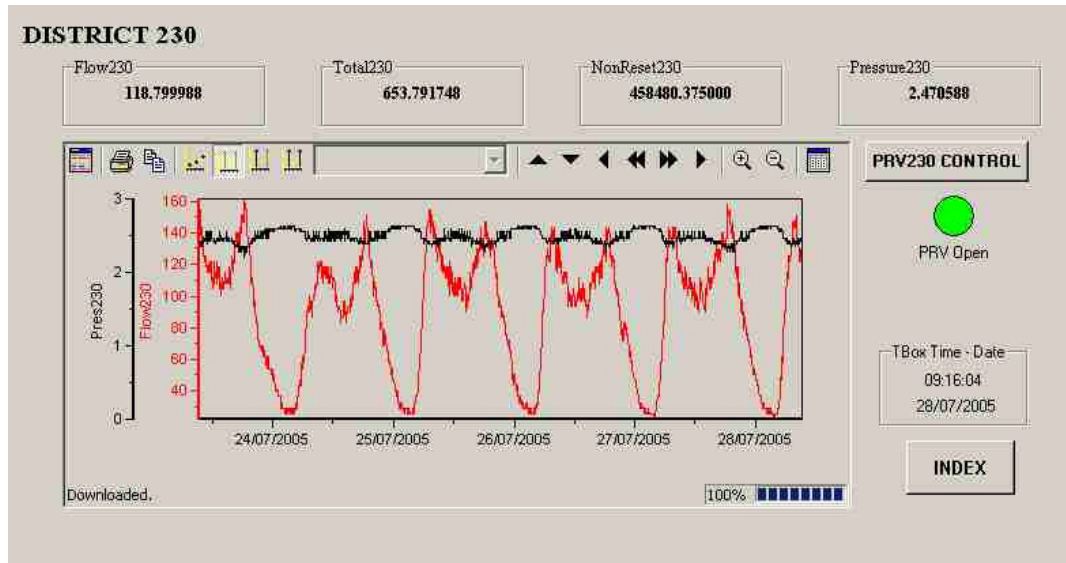
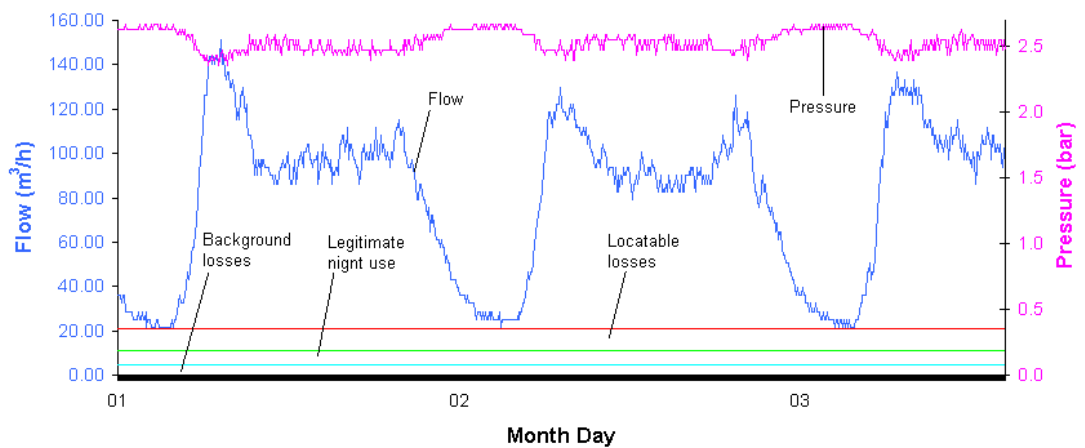


Figure 2. Typical flow and pressure pattern in a DMA



**Table 1.** Typical prioritisation for Pressure Zone 2

<b>DMA</b>	<b>Actual MNF (m<sup>3</sup>/hr)</b>	<b>Background Losses (m<sup>3</sup>/hr)</b>	<b>Legitimate Night Use (m<sup>3</sup>/hr)</b>	<b>Locatable Losses (m<sup>3</sup>/hr)</b>
220	2,16	0,24	1,41	0,51
221	3,85	1,65	2,13	0,07
222	2,24	0,71	1,49	0,03
223	2,56	0,82	1,54	0,20
224	2,52	0,82	1,59	0,11
225	9,78	2,41	3,38	<b>3,99</b>
226	6,84	2,55	4,05	0,24
227	10,44	3,38	5,50	<b>2,56</b>
228	7,20	3,03	3,67	0,50
229	3,73	0,96	0,92	1,85
230	18,00	4,60	6,86	<b>6,54</b>
231	7,92	3,54	4,21	0,18
232	4,32	1,05	1,64	1,63
233	3,96	1,10	1,49	1,37
234	2,44	0,23	0,97	1,24

## City of Bangor, Dwr-Cymru Welsh Water, Wales, UK.

	<b>Description of the project</b>
1	<p><i>A brief description of the location (e.g., country/state; the population served, typical supply pressures; a brief description of the supply arrangements), the reasons for considering installing DMAs and the actual duration of the project from start of design to completion of functioning DMAs..</i></p>
	<p><b>The city of Bangor is located in Wales, UK. The city is a small university town comprising mainly of residential buildings, offices, university buildings, shops and light industry on industrial estates. The residential buildings are a mix of terraced and detached houses typical of the UK.</b></p> <p><b>The supply to the city was from two remote water treatment works via local service reservoirs with an additional direct supply from the trunk mains into the distribution network. No effective active leakage control was being practised.</b></p> <p><b>Active leakage control was necessary, as at peak demand or when bursts occurred the same high-level properties went without water. The city lies in a valley with the service reservoirs on one side and the bulk of the properties on the valley floor or on the opposite side. The properties are situated at sea level to around 80 m AOD with the service reservoirs at 94 &amp; 114 m AOD.</b></p> <p><b>Active leakage control using DMAs was chosen for implementation, based on the predictions of reduction in leakage indicated in Report 26 Leakage Control Policy and Practice and the need to move to a method of leakage control where the actual leakage levels could be measured.</b></p> <p><b>The overall duration of the project to completion of the final DMA and PRV regime was over many years as the initial phase was to improve mapping followed by initial sectorisation, DMA, PRV design and implementation followed by relining of existing cast iron mains followed by additional fine tuning of PRV management.</b></p>
2	<p><i>What was the level of real losses before and after installing DMAs in any or all of the following units: m<sup>3</sup>/yr, l/connection/day, litres/connection/day/m of pressure, l/l.</i></p>
	<p><b>Initial estimate of leakage was based on sample measurement was of the order of 440 l/connection/day rough estimate of 6-8 l/connection/day/m</b></p>
3	<p><i>Briefly describe the supply arrangements for typical households: whether there is storage in the household, and if so whether ground-level tanks and/or elevated tanks; whether typical connections are metered; the typical (or required) supply pressure at the point of delivery; whether supply is continuous everywhere in the area served.</i></p>
	<p><b>Typical houses are supplied by separate 12mm diameter service pipes, which are not metered, with either one or all of the cold water taps supplied direct from the mains and all the hot water taps and remaining cold taps supplied from small household storage tanks typically in the roof space. Supply continuous to 99% of connections.</b></p>
	<p><b>Design</b></p>
4	<p><i>What influenced the design of individual DMAs? This could include: keeping similar pipe materials together; the target DMA size; water quality; number of boundary valves, fire fighting; insurance; reliability of supply; maintaining similar pressure (available head) across the whole DMA to facilitate pressure management etc.</i></p>

	<b>The design of the DMAs was governed by the topography, water quality and the existing network configuration</b>
5	<i>Was pressure management considered at the design stage? If so was it designed to cover all DMAs? If not how were decisions made on where to install pressure management?</i>
	<b>Due to the topography, pressure management short term and long term was integrated into the design of the DMAs. The initial opportunities to pressure manage were not available as excessive leakage was causing too much head loss across the system. Once an initial sweep of the city for bursts had been completed and the network sectorised by future pressure requirements, the pressure was then maintain at the lower pressures the customers had previously experienced at peak demand. Additional fine-tuning of the pressure management system was implemented on completion of mains scraping and lining of cast iron pipes, which increased the network hydraulic capacity. This work was undertaken due to water quality problems</b>
6	<i>The methods used for design. This could include what initial investigations and trials were made, and whether (and to what extent) network models were used.</i>
	<b>The initial mapping of the area was incomplete and part of the design process to determine DMA configuration was the complete relocation of existing mains and subsequent mapping. The topography and main link mains into the network readily determined the DMA layout. Outline network analysis was undertaken to determine the broad sectorisation of the area into pressure areas and confirm redundant links that could be abandoned.</b>
7	<i>Was a hierarchy of metered zones used: i.e. did the DMAs fit into larger metered zones, and were these larger zones installed as part of the same process, or did they already exist, and if so were they already metered?</i>
	<b>There is a hierarchy of metering with initial input meters into the two service reservoirs (SRs) followed by outlet meters to the SRs and where the outlet to the SR meters do not directly input into the DMA, further meters downstream supplying into the DMA. The network configuration allows for one input meter and no export meters into all DMAs. There are additional meters upstream of the SRs on the trunk main links back to the water treatment works.</b>
8	<i>How was the integrity of the boundary tested? Was it by listening to valves, carrying out a pressure zero test on the whole DMA (where an area is isolated from the rest of the distribution system and the pressure monitored to ensure it drops to close to zero), carrying out a pressure-zero test on individual section of main next to the boundary, or some other testing method.</i>
	<b>The integrity of the boundaries was tested by variety of methods initially by listening on valves; comparisons of adjacent pressures and finally by pressure zero testing.</b>
9	<i>How were the boundaries of DMAs defined and managed? For example: are boundary valves closed and marked or are sections of pipe removed and the ends capped to produce permanent boundaries?</i>
	<b>The boundaries of the DMAs were formed with closed valves, where the lids of the closed valves are painted red and the valves are indicated as closed on the electronic mapping system. In the event of the valves having to be opened status reports are generated.</b>
10	<i>Do the new boundaries include flushing facilities?</i>
	<b>Where necessary flushing facilities were located by closed valves</b>
11	<i>Are any systems in place to ensure boundary valve operation is recorded?</i>
	<b>Initial management of the closed valves in the initial period required considerable effort but once the DMA configuration had been established closed valves were</b>



	<b>recorded on mapping system and requirement to complete status reports if the valves were operated.</b>
12	<i>How were meters were selected. This includes both the type of meter and the size selected.</i>
	<b>Meters selected were of the Waltman type with ability to generate pulse outputs. Majority of DMA meters rang 80 to 100 mm with some 150 mm</b>
13	<i>Describe a typical meter installation (i.e. is the meter on a bypass, what materials and jointing are used, where are the gate valves and hydrants, is the installation underground?) This may be most easily described with a diagram or photographs.</i>
	<b>Meters are located in underground chambers, except where they are fitted in service reservoir control chambers. Where possible the meters are either on a by pass or have by pass round them for ease of replacement.</b>
14	<i>How were night use allowances calculated for use in assessing leakage levels (if any)</i>
	<b>The calculation of night allowance has been gradually refined in line with best UK water industry practise and is now based on the BABE approach of determining customer night use and background leakage.</b>
	<b><i>DMAs in use</i></b>
15	<i>How is flow data collected from typical DMA? This includes the frequency of data collection, the data storage intervals, whether the data is stored in a logger and retrieved manually or via telemetry. Is pressure is recorded?</i>
	<b>Data over the period the DMAs have been established has been collected in a variety of ways and has gradually moved to continuous logger data acquisition with modem links enabling daily retrieval of data and alarm sensing of excessive flows.</b>
16	<i>How is flow data checked to ensure that it is valid?</i>
	<b>Comparison against previous flow patterns and checks on adjacent DMA flows.</b>
17	<i>Describe how the flow data is interpreted to assess the level of losses. Does this include both a night-flow measurement and a water balance? How are these reconciled? Is the IWA water balance used? If a water balance is used at DMA level, what period is it carried out over and does it include measurement of customer consumption over the same period?</i>
	<b>DMA leakage levels are typically analysed weekly based on the MNF and the predicted BABE background leakage level plus assessed customer night use. The DMAs with the highest potential excess leakage are then targeted for active leakage control. Annually a bottom up assessment of annual leakage using the minimum night flows (MNFs) from the DMAs is undertaken and compared with the annual water balance or top down approach to leakage. The top down approach estimates customer use from customer meters and an estimate of unmeasured customer use based on a per capita consumption monitor for unmeasured customers. Note all industrial users are metered.</b>
18	<i>Describe the process by which decisions are made on which DMAs are investigated by leakage control teams. This may include a prioritisation process. Include examples of the use of a prioritisation process, showing which performance indicators are used and which DMAs were selected as a result.</i>
	<b>Inspectors are responsible for a group of DMAs and active leakage is based on weekly reports that assess the current level of excess leakage in each DMA. Prioritisation of the DMAs is either by total excess leakage or excess leakage per 100 connections.</b>
19	<i>What happens when DMAs are investigated by leakage control teams but the leakage is not reduced?</i>

	<b>If the predicted level of leakage cannot be achieved by a significant level, additional checks are undertaken to insure boundary integrity, exceptional night users and finally if appropriate a noise logging survey is undertaken.</b>
20	<i>Describe maintenance processes, such as DMA boundary checks, audits of DMA data, pressure logging, flushing. This should include whether at regular frequencies or in response to incidents.</i>
	<b>Data is retrieved daily and pressure-reducing valves are maintained annually.</b>
21	<i>Describe the other uses that you put DMAs to, such as: Assessing annual losses; Demand studies; Per capita consumption (PCC); Infrastructure condition factor (ICF); Planning; Performance monitoring; Monitoring costs; Natural rate of rise of leakage; Network analysis; Day to day running of network.</i>
	<b>DMAs are utilised to determine PCC and infrastructure condition ICF as part of the assessment of economic level of leakage. With increased sophistication of network modelling to include all mains models, the DMA flow patterns are utilised to determine nodal demands within a DMA.</b>
	<b>Other aspects</b>
22	<i>Is there any other aspect of the design, installation and use of DMAs that has been important, but has not been covered in the questions above? This could include particular problems and how they have been overcome</i>
	<b>A key element of the success of DMA active leakage control is management commitment and a realisation that success is only brought about with an ongoing commitment. In this example the DMA infrastructure has remain largely unchanged for 20 years, continuous supply even at peak demand is maintained and leakage has been reduced from 440 to 110 L/connection/day.</b>

Name of contributor: J A E Morrison

Organisation: on behalf of Dwr Cymru Welsh Water

# Johore, Malaysia

## Description of the project

Project situated in Johore, the southernmost state in Peninsular Malaysia.

800,000 metered consumers with a 100% coverage of population in the state.

Typical supply pressures are between 1 bar and 7 bar. To install Pressure Reducing Valve for pressure above 3bar.

The contract requires Ranhill Water Services to undertake a holistic approach to reduce the current NRW level of 36.6% down to 20.0% by the year 2010. Presently there were 650 DMAs which to be monitored and will be expanded to 800 within the next two years to cover 100% of customers in the state of Johore.

Non Revenue Water is an indicator of operational performance, calculated by taking total production volume minus total billed volume.

To implement active leakage control with a manageable control area, water supply areas were divided into sub areas as District Metering Area (DMA). DMAs were fed through one feeder and adjacent areas were separated with boundary valve which will be closed at all time. This is to ensure incoming flow can be recorded and monitored.

To establish a DMA, from mapping of pipeline, pressure survey, zero pressure testing, Legitimate Night Flow sampling, T factor calculation, installing and commissioning of flow meter right up to first flow measurement thus monitoring of DMA, it will take an average of 1 month to be completed.

Real losses in DMAs were monitored using Net Night Flow figures. During the earlier stage of the project, levels of real losses were ranged between 5lit/sec. to 50lit/sec. By implementing active control policy , DMA nightlines are to be reduced to average of 2.5lit/sec.

Most of households were supplied through their elevated storage tank with the minimum capacity of 0.5 m<sup>3</sup>. Only one direct tap was allowed. All consumers were metered and meter readings were made monthly. Minimum allowable residual head for each household was 7.6m head. Presently, all consumers were served with 24hrs. supply.

## Design

*Criteria to be looked into for designing of DMA :-*

- Connection from 500 to 2000
- Being fed through one feeder
- Maintaining minimum residual head in the system

- Continuous supply of water
- Boundary valve can be located and closed
- Available valve for step testing or to install new

Pressure survey for the area including adjacent area to the DMA was to be carried out to have a better understanding of the pressure contour. Points of highest, lowest, nearest and furthest from feeder within DMA and adjacent to it, pressure loggers were installed before any isolation being made.

To complete establishing a DMA, activities below are to be carried out :-

- Established schematic drawing to the proposed DMA including site investigation and verification.
- Pressure Survey
- Zero Pressure Testing
- Legitimate Night Flow Sampling
- T Factor Calculation
- Initial Flow Measurement to record Peak Flow, Minimum Flow, Flow Trending and Background Leakage Level.

All boundary valves after being confirmed their location and closed will be marked by painting their chambers in red.

Electromagnetic flow meters were selected to be used for flow measurement for this project. Experience in using mechanical meter which gave high head loss during peak flow and choking up strainer with debris has put the usage of electromagnetic flow meter as a reliable and effective data capturing. Electromagnetic flow meter has been proved to be hassle free maintenance for the past decade since it was installed in Johore with the earlier version.

Sizing of this meter was based on design demand for the maximum flow and the ability to record minimum flow. Minimum head loss through the meter was adapted to choose the suitable meter. Future demand was considered during the design process.

As electromagnetic meter was maintenance free, it was buried underground with their communication cable installed inside a cabinet which was constructed above ground. Meter was installed online with the pipeline with both side connected using flange adaptor. No strainer was used as this meter on full bore.

### **DMA's in use**

Meters were read monthly and consumption was averaged daily. Where there is increment of average daily consumption, leakage levels were calculated. For background leakage above 20%, manual logger was installed to record minimum night flow.

Nightline above 2.5lit/sec, leakage teams were deployed for leakage detection activities. For DMAs which have been installed permanent loggers, nightline were monitored daily. Flow and pressure data were conveyed daily through telemetry to the control room to be analyzed.

Recorded flow data was transformed into Net Night Flow after deducting Legitimate Night Flow. This nightline was used to interpret background leakage which occurs in the DMA. Other components of Non Revenue Water were only being measured during Flow Balance activities. Flow Balance was one activity being carried out as a holistic approach to ensure volume of water produce from water treatment plant was accounted and this volume balanced throughout the system.

DMA meters were read monthly and a table was produced to show their leakage level. Leakage level was prioritized based on their net night flow. Those DMAs which have NNF above 5lit/sec, leakage detection team will be deployed to carry out Visual Inspection Sounding. To pinpoint leaks, noise loggers and correlators were used either for the whole area or sub divided into smaller section. For areas, which after deploying teams for leakage detection seem no reduction of leakage, step test will be carried out to reduce leakage at the targeted area. A comprehensive study should be made for this smaller areas to precisely determine the leakage level and their causes whether from the pressure, pipe material, age of pipe, soil condition, communication pipe, workmanship during installation and all related matters. A recommendation such as pipe replacement or reducing the incoming pressure should be made to overcome the leakage level for this particular sub area.

DMA boundaries were check before doing step test. For monthly reading which gave anomalies reading, boundary valve were checked to make sure DMAs was getting supply from one feeder. Legitimate Night Flow should be carried out every 5 years or if there is any different in trending usage of water.

Other than leakage control programme, in establishing a DMA, it also can provide water supply management such as :-

- Assessing annual or monthly loss
- Demand studies
- Per capita consumption
- Pressure Management
- Trending Usage of Water
- Customer Tagging
- Pipeline rehabilitation programme
- Daily monitoring pressure and flow

# Halifax Regional Water Commission

	<b>Description of the project</b>
1	<i>A brief description of the location (e.g., country/state; the population served, typical supply pressures; a brief description of the supply arrangements), the reasons for considering installing DMAs and the actual duration of the project from start of design to completion of functioning DMAs..</i>
	<b>The Halifax Regional Water Commission is located in Halifax Nova Scotia, Canada and currently serves a population of 320,000 with an average supply pressure of 50 meters. Halifax is supplied by two large surface water treatment plants, a 180MLD plant serving the West Region and a 90 MLD plant serving the East Region. Halifax has a high natural rate of rise of water main breaks and with the construction of the new treatment plant serving the east region, and the corresponding increase in the marginal cost of water, it became a corporate priority to reduce real losses. Elevations in Halifax range from 170m ASL to sea level requiring many discrete pressures zones and pumping stations. These pressure zones and pumping stations formed the earliest DMAs by simply installing flow meters at the control facilities. In 1999, with the knowledge that DMAs provide early indication of leakage, the HRWC implemented a program to create DMAs throughout the Utility. After six years, the program is nearing completion</b>
2	<i>What was the level of real losses before and after installing DMAs in any or all of the following units: m3/yr, l/connection/day, litres/connection/day/m of pressure, ILI.</i>
	<b>Annual real losses prior to full DMA implementation (1999) 18,055,000 m3. As of March 31, 2005, the annual real losses were 8,101,000 m3. The first ILI was calculated at 6.4 in 1999/2000, as of March 31, 2005 it was at 3.8. We expect a further reduction for 05/06 possibly 3.4</b>
3	<i>Briefly describe the supply arrangements for typical households: whether there is storage in the household, and if so whether ground-level tanks and/or elevated tanks; whether typical connections are metered; the typical (or required) supply pressure at the point of delivery; whether supply is continuous everywhere in the area served.</i>
	<b>The typical household has its own supply line with an average supply pressure of 50 meters. There is no residential storage and the system is pressurised constantly. All service connections are metered with the water meter inside the household.</b>
	<b>Design</b>
4	<i>What influenced the design of individual DMAs? This could include: keeping similar pipe materials together; the target DMA size; water quality; number of boundary valves, fire fighting; insurance; reliability of supply; maintaining similar pressure (available head) across the whole DMA to facilitate pressure management etc.</i>
	<b>Target size such that it can be sounded in one day. Fire flow requirements. Commercial industrial flow requirements. Multiple or redundant feeds. Water quality, and possible meter locations. Location of large users.</b>
5	<i>Was pressure management considered at the design stage? If so was it designed to cover all DMAs? If not how were decisions made on where to install pressure management?</i>
	<b>We have just begun implementing flow modulated pressure management and will continue to apply it on a DMA by DMA basis considering Infrastructure Condition</b>

	<b>Factor, re-break history, average pressure within the DMA, and cost to implement.</b>
6	<i>The methods used for design. This could include what initial investigations and trials were made, and whether (and to what extent) network models were used.</i>
	<b>The DMAs are designed on paper taking advantage of existing boundaries wherever possible. Using the criteria identified in question 4; the DMAs are marked on the base mapping and submitted to engineering (in house) for review. Whenever significant changes are required, the DMA is modelled to ensure adequate supply. The DMA is then set up as a temporary DMA and actual flow testing takes place and night flows are recorded using a temporary meter.</b>
7	<i>Was a hierarchy of metered zones used: i.e. did the DMAs fit into larger metered zones, and were these larger zones installed as part of the same process, or did they already exist, and if so were they already metered?</i>
	<b>There are situations where there is a hierarchy of metered zones and cascading zones, where the water from one DMA first passes through another. In most cases, the larger zones existed as a result of required hydraulics and necessary boundaries.</b>
8	<i>How was the integrity of the boundary tested? Was it by listening to valves, carrying out a pressure zero test on the whole DMA (where an area is isolated from the rest of the distribution system and the pressure monitored to ensure it drops to close to zero), carrying out a pressure-zero test on individual section of main next to the boundary, or some other testing method.</i>
	<b>The DMA boundary is confirmed by closing all identified valves, leaving only a single valve open to supply the DMA. With pressure loggers installed along the boundary, outside of the DMA, the pressure within the DMA is reduced to minimums. Flow and pressure in adjacent DMA are recorded through the SCADA systems and reviewed for any changes. The pressure loggers are reviewed to ensure there was no influence across boundaries. With the pressure at minimums, all boundary valves are sounded.</b>
9	<i>How were the boundaries of DMAs defined and managed? For example: are boundary valves closed and marked or are sections of pipe removed and the ends capped to produce permanent boundaries?</i>
	<b>Once established, the boundary valves are entered into the GIS as closed valves and given a unique symbol identifying them on base mapping as such. Markers are placed inside the valve box to ensure they are not accidentally operated.</b>
10	<i>Do the new boundaries include flushing facilities?</i>
	<b>Where water quality issues occur, fixed rate jumpers are installed across the boundary valve where the problem exists. There are few of these. There are also a few “blow offs” that are operated when necessary. This water is discharged to the storm water collection system.</b>
11	<i>Are any systems in place to ensure boundary valve operation is recorded?</i>
	<b>All systems valves are checked and operated as part of a valve maintenance program; however, boundary valves are checked but not operated.</b>
12	<i>How were meters were selected. This includes both the type of meter and the size selected.</i>
	<b>At the HRWC, meter size and type are determined on a site by site basis, matching the performance characteristics and features of the meter, with the specific requirements of the site. In-line magnetic flow meters are the preferred choice, however, strap on ultrasonic meters are considered on pipe larger than 200 mm, and in-line turbines are considered on bypass lines 100 mm and smaller. In any case,</b>

	<p><b>meters must be capable of interfacing with the HRWC SCADA system using either a pulse output or a digital protocol.</b></p> <p><b>Accuracy is a concern with all meters and when required, the meters are field calibrated.</b></p>
13	<p><i>Describe a typical meter installation (i.e. is the meter on a bypass, what materials and jointing are used, where are the gate valves and hydrants, is the installation underground?) This may be most easily described with a diagram or photographs.</i></p>
	<p><b>The HRWC has standardised DMA meter installation. Where pressure control is required, the meter is installed on the smaller bypass in line with a small PRV. A larger PRV is in parallel and supplies fire flows and any other exceptional demands... A limit switch on the larger PRV provides indication that it has opened. Where pressure control is not required, direct bury mag meters are installed in manholes with RTU panels mounted on nearby utility poles. Pipe material is usually ductile iron within manholes and either ductile iron or stainless steel within PRV vaults. Meters are flanged with the exception of strap on ultrasonic meters. Valves on each side of the meter provide isolation. With the exception of Pumping Stations, all meters are underground. See accompanying photos.</b></p>



14	How were night use allowances calculated for use in assessing leakage levels (if any)																																																				
	<table border="1"> <thead> <tr> <th></th> <th>Data Entry</th> <th>Defaults</th> <th>Calculated values</th> </tr> </thead> <tbody> <tr> <td colspan="4" style="text-align: center;"><b>Standard Parameters for Assessed Night Consumption</b></td> </tr> <tr> <td>Household occupancy</td> <td>3.00</td> <td>persons per household</td> <td></td> </tr> <tr> <td>Night toilet use</td> <td>6.0%</td> <td>of persons, 03 to 04 hrs</td> <td></td> </tr> <tr> <td>Average toilet cistern size</td> <td>14.0</td> <td>litres</td> <td></td> </tr> <tr> <td>Average night toilet use</td> <td>2.52</td> <td>Litres/household/hr</td> <td></td> </tr> <tr> <td>Assume</td> <td>1.0%</td> <td>of Household toilet cisterns leak</td> <td></td> </tr> <tr> <td>Assume</td> <td>2.5</td> <td>Toilet cisterns per household</td> <td></td> </tr> <tr> <td>Assume a leaking cistern runs at</td> <td>10.0</td> <td>litres/hour average</td> <td></td> </tr> <tr> <td>Average toilet leakage</td> <td>0.25</td> <td>Litres/household/hr</td> <td></td> </tr> <tr> <td>Other household leakage after meter</td> <td>0.25</td> <td>Litres/household/hr</td> <td></td> </tr> <tr> <td>Ave. Household night consumption</td> <td>3.02</td> <td>Litres/household/hr</td> <td></td> </tr> <tr> <td>Ave. non-household night consumption</td> <td>10.0</td> <td>Litres/non-Household/hr</td> <td></td> </tr> </tbody> </table>		Data Entry	Defaults	Calculated values	<b>Standard Parameters for Assessed Night Consumption</b>				Household occupancy	3.00	persons per household		Night toilet use	6.0%	of persons, 03 to 04 hrs		Average toilet cistern size	14.0	litres		Average night toilet use	2.52	Litres/household/hr		Assume	1.0%	of Household toilet cisterns leak		Assume	2.5	Toilet cisterns per household		Assume a leaking cistern runs at	10.0	litres/hour average		Average toilet leakage	0.25	Litres/household/hr		Other household leakage after meter	0.25	Litres/household/hr		Ave. Household night consumption	3.02	Litres/household/hr		Ave. non-household night consumption	10.0	Litres/non-Household/hr	
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	<b>Meters are calibrated on site by flowing water through a calibrated test meter and ensuring the two meters record the same flow. This requires isolating the meter.</b>																																																				
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	<b>HRWC applications automatically average the night flows between 03 and 04 hrs and compare this to the calculated minimum night flow (bottom up calculation) for each DMA. ILI calculations for each DMA have not happened as yet, however, it is the intent as we align meter-reading routes with DMAs.</b>																																																				
18	Describe the process by which decisions are made on which DMAs are investigated by leakage control teams. This may include a prioritisation process. Include examples of the use of a prioritisation process, showing which performance indicators are used and which DMAs																																																				

	<i>were selected as a result.</i>
	<b>Using the flow data in the data historian, an HRWC application posts to an intranet site, the five most recent actual averaged night flows (averaged between 03 and 04) and compares these values to the calculated minimum night flow for the particular DMAs. Leak detection crews are sent to the DMAs with the highest levels of active leakage. Pumped systems are given a further priority.</b>
19	<i>What happens when DMAs are investigated by leakage control teams but the leakage is not reduced?</i>
	<b>Leak crews are usually very successful in finding the leaks however when they do not find it after the first pass, a more aggressive and detailed approach is taken that includes listening on all valves and surface sounding gaps. If this fails to yield results, the metering is confirmed and exceptional night use is investigated. If leakage cannot be reduced with these methods, advanced pressure management is planned.</b>
20	<i>Describe maintenance processes, such as DMA boundary checks, audits of DMA data, pressure logging, flushing. This should include whether at regular frequencies or in response to incidents.</i>
	<b>System wide flushing occurs annually in the spring. Pressure logging is a standard within each DMA. Boundary valves are checked as part of a system wide valve program however they are not operated. If a DMA is not functioning properly and leakage across valves is suspected, boundary valves will be sounded.</b>
21	<i>Describe the other uses that you put DMAs to, such as: Assessing annual losses; Demand studies; Per capita consumption (PCC); Infrastructure condition factor (ICF); Planning; Performance monitoring; Monitoring costs; Natural rate of rise of leakage; Network analysis; Day to day running of network.</i>
	<b>DMAs are used to determine the ICF, for demand studies and to calibrate or confirm the Hydraulic model. Unauthorised withdrawal from fire hydrants is often identified (apparent loss). Water used for capital work, system flushing and maintenance can be measured for accounting purposes. System performance is monitored and necessary improvements identified.</b>
	<b>Other aspects</b>
22	<i>Is there any other aspect of the design, installation and use of DMAs that has been important, but has not been covered in the questions above? This could include particular problems and how they have been overcome</i>
	<b>Positioning large customers at or near the extremities of the DMA can help with keeping the water fresh. In North America, the requirement to meet fire flows and the need for multiple feeds mean very low velocities in large mains, which make metering a challenge and therefore meter selection and location very important.</b>

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Organisation: **Halifax Regional Water Commission, Halifax Nova Scotia, Canada**

# Reducing leakage in Jakarta, Indonesia

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**D Rogers**

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**Key words:** Leakage control, mathematical models, pressure control

## Abstract

Jakarta, the capital city of Indonesia, loses around half of its water production from leaks in the pipes. The low operating pressures, non-metallic pipes and the high background noise make the application of acoustic instruments impossible. A step-by-step approach, based on quantifying directly the leakage, was developed which proved very successful.

The importance of pressure control to maintain a low leakage level in the network was highlighted. The application of a mathematical model was essential to design the permanent pressure and leakage control systems.

## Introduction

Water is one of the world's most valuable resources. Without it, life would not exist. It is predicted that within 20 years, almost a third of the world's population will have insufficient supply of water. Yet in the light of such a drastic situation, it is surprising that many of the world's water networks still lose around a half of the available resource through leakage from the pipes. Already the signs for the future are ominous. The closure at night of the network to fill the reservoir has become a routine operation in many parts of the world, from south and Central America, through Europe to Asia. In extreme cases, communities even go to war. Around two thirds of the world faces a potential crises. The challenge is to find an effective solution.

With a rapidly increasing population, the situation is bound to get worse. The experience in Jakarta, the capital city of Indonesia, shows that the starting point to improving the situation is to use more efficiently the existing resource by drastically reducing the leakage in the water network. However there are many difficulties to overcome, not least to define the most appropriate approach when there is limited knowledge of the network and its characteristics are not compatible with the technology traditionally applied in more developed parts of the world.

## Situation in Jakarta

Jakarta is a sprawling city of around 12 million inhabitants. The management of the network was privatised in two separate concessions towards the end of 1990's. The project outlined in this paper relates to the part managed by Palyja, which is owned by the Suez Group.



**Figure E-1** Typical conditions in Jakarta

The water network extends for well over 3000 km. It is composed primarily of non-metallic pipes varying in diameter from 1200 mm to 25 mm. The operating pressures rarely exceed 15 metres and usually are less than 10 metres. Some parts of the network, particularly at the extremity, have zero pressure for most of the day. Much of the network was constructed by contractors. As a result, many of the streets have four different pipes and the availability of accurate as-built plans is very limited. Furthermore, old networks have not always been abandoned when a newer network was constructed. Like in so many Asian cities, the traffic is noisy and seems to be perpetually grid-locked. Non Revenue Water (NRW) is equivalent to 46% of which over 75% is Real or Technical losses. Due to the ground conditions and the fact that many of the roads have a concrete foundation, leaks seldom become visible. Almost all excavations are dug by hand.



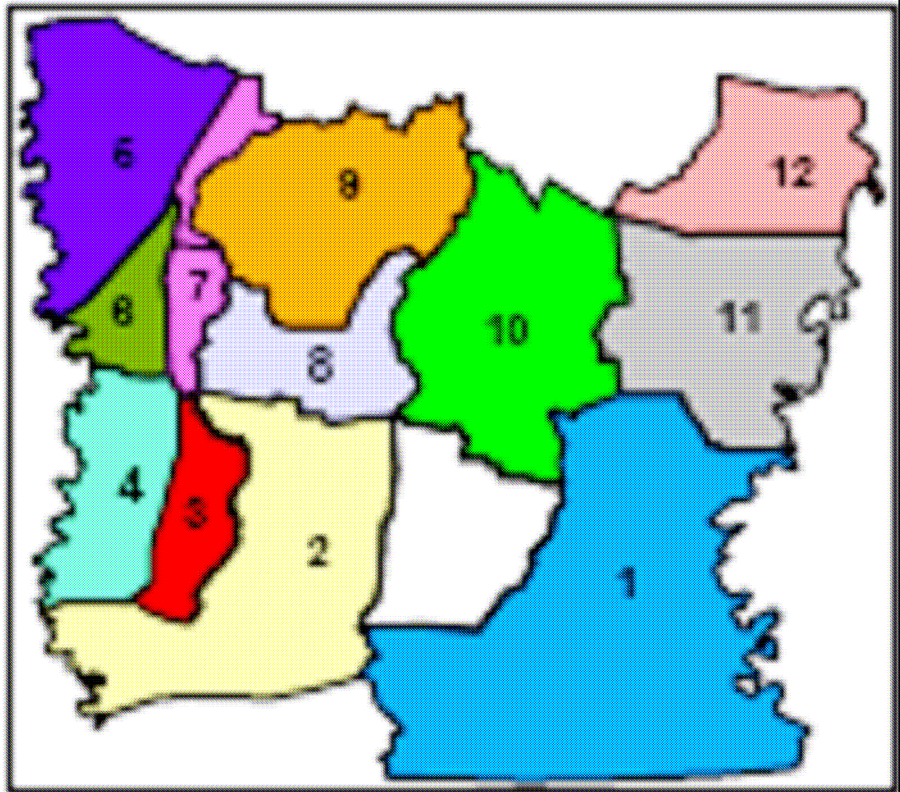
**Figure E-2** Excavation by hand

The traditional approach for locating leaks is to use acoustic instruments such as correlators, noise loggers and ground microphones. However to be successful they require adequate pressure to generate a leak noise, good transmission of the noise along preferably metallic pipes, accurate mains records and low background noise. In Jakarta, all these characteristics are absent. As a result it was necessary to develop a totally different approach, which in some cases modifies the traditional way leakage is controlled and located.

### **Technical approach**

The possibility of successfully locating a lost personal item is significantly increased if the search is directed to one particular room of a house, rather than a random search of the whole town. The same is true with leakage. By permanently dividing the network into a number of sectors, supplied by a few key mains, it is possible not only to immediately identify the presence of a leak, but also to locate it more easily. Consequently, the leakage teams are able to maintain the leakage at its minimum level by always working in the highest priority sectors.





**Figure E-3** Permanent Areas in UPPS

Such an approach is not new. The District Meter Area concept has been applied with much success in the UK and elsewhere. However, the same approach is not feasible in a situation like Jakarta because of the size, complexity and the lack of knowledge of the network.

The main objective of a permanent control system is to continuously quantify the current leakage level and identify immediately the presence of a new leak. It is vital therefore that the boundaries of the sectors are tight. One way to ensure this is to use natural boundaries. It is also necessary to understand the existing hydraulic operation of the network.

The closure of pipes to create the sector boundaries will tend to reduce the capacity of the network. In Jakarta such an approach, if not undertaken with care, could further reduce the already low operating pressures. However there are many pipes in the water network which have little or no hydraulic function as they represent hydraulic balance points. It follows therefore that their closure will have little or no effect on the operation of the network. The aim therefore when dividing any network is to identify such points. In Jakarta it was essential to do so. The answer is to use a hydraulic mathematical model.

The mathematical model developed for Jakarta needed to be accurate enough to identify errors in the historical knowledge of the network and to understand its hydraulic operation. It contained all the pipes of 125 mm diameter or more, had an accurate allocation of the consumption. It was fully calibrated by comparing the calculated pressures and flows with those measured in the field during a field test. In fact, a number of anomalies were identified during the calibration of the model which were

later verified on site. The model was then used to optimise the division of the network into sectors termed Permanent Areas. Each was supplied by a maximum of 3 key pipes on which was installed a permanent flow meter. Valves were closed on the other connections to create the permanent boundary. Thanks to the application of the model, the number of closed valves was reduced to a minimum.

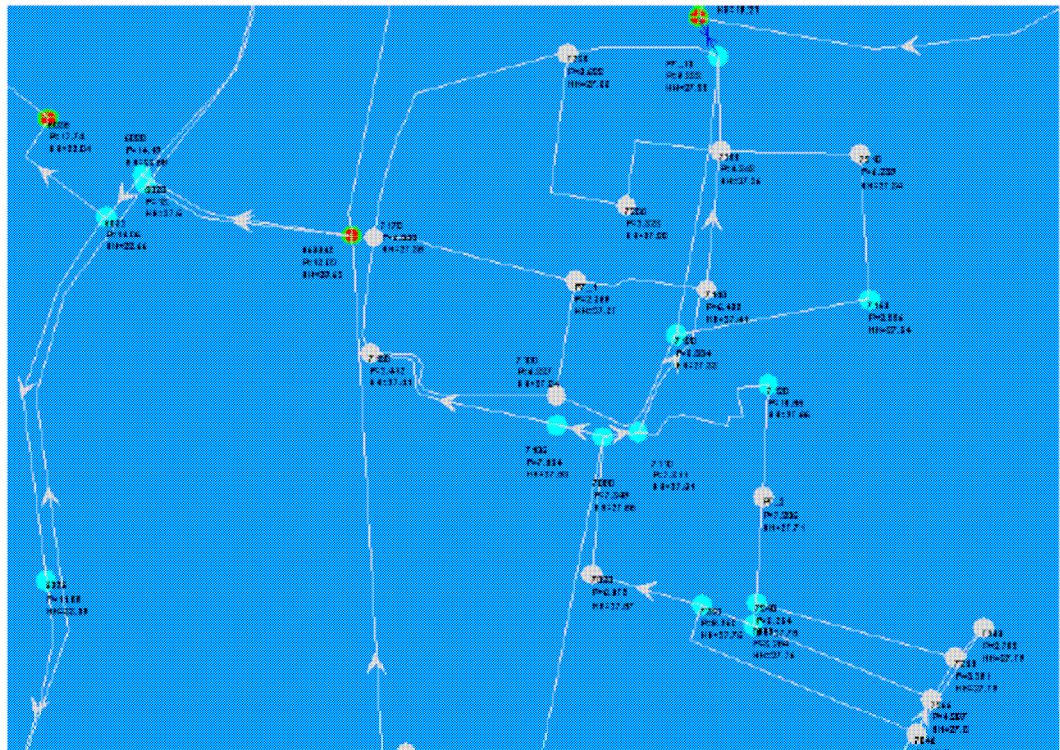


Figure E-4. Mathematical model of Jakarta

A total of 12 Permanent Areas were created in the pilot area comprising of around 1200 km. The only difficulty experienced to create the boundaries was in the Blok M part of the network, which is very densely populated. The reason can be attributed to an inaccurate representation of the real network on the maps, and the exceptionally low operating pressures. Having created and quantified the leakage level in each Permanent Area it was possible to define an order of priority, where the activity of leakage location was directed.

The most representative parameter to do this was found to be the leakage per unit length of main as it was simple to determine and gives a direct indication of the effort required to reduce the leakage level.

Once the leakage level in a Permanent Area warrants intervention, the network is divided into what are termed Temporary District. They cover typically around 20 km of network and are supplied by a single pipe on which is installed an insertion flow meter. Even though their design was optimised with the mathematical model, it was still impractical with the existing pressures to permanently close the boundaries without creating supply problems. As a result, they were created for a week to allow the mentoring to be completed, hence the name Temporary Districts. In this way it is possible to narrow down further the part of the network with most leakage. In the future, once the leaks have been repaired these districts can become permanent,

The creation of the Temporary District requires a much more detailed knowledge of the network than with the Permanent Areas. A thorough investigation was necessary to verify the configuration of the network, which involved hydraulic testing and excavations.

This is quite a time-consuming activity as many significant differences were identified between the maps and the reality. The advantage is that the work is undertaken only where strictly necessary.

In those Temporary Districts with most leaks, which is typically around 40% of the Permanent Area, night step tests were performed during which the network was progressively isolated. The reduction in the flow following each closure corresponds to the leakage in the isolated network. In this way it is possible to define accurately the leaking pipes.

A trial was performed using the acoustic instruments, which confirmed that the combination of low noise generation and poor propagation capacity renders these instruments practically useless. The best solution was therefore to abandon the leaky pipes and move the customer connections, which in Jakarta is possible in view of the large number of pipes in each street in Jakarta. Where this is not feasible, a cost / benefit analysis is undertaken to determine the economic effectiveness of replacing the pipe.

The advantage of such a step by step approach is that the effort is directed only to those areas where the returns are maximised. This applies not just to locating the leaks but also to undertake hydraulic tests to understand the real layout of the network.

## Pressure control

The objective of a permanent leakage control system is not just to reduce the leakage but also to enable a low leakage level to be maintained in the future. The approach developed for Jakarta proved highly successful in locating the leaks. However it soon became apparent that no sooner had a big leak been eliminated that another broke out. Figure E-5 shows the variation of the leakage level in one Permanent Area over an 18-month period. The reason is pressure.

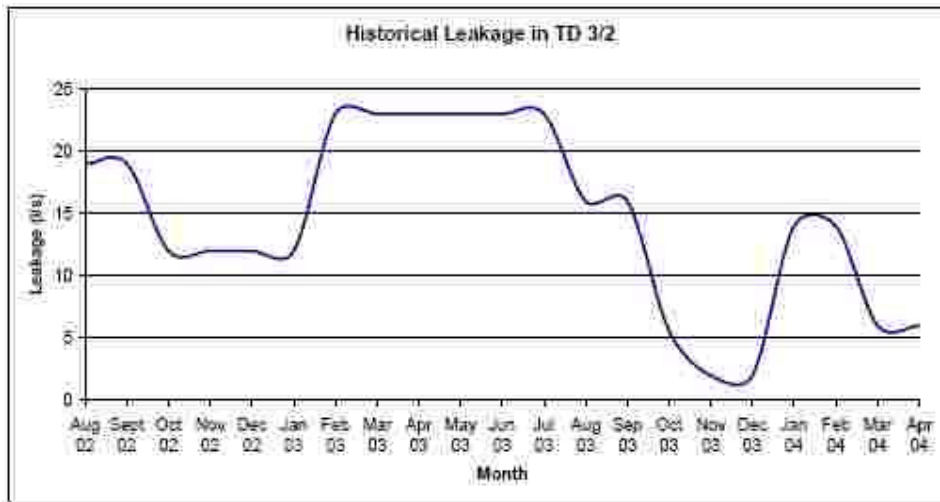


Figure E-5. Variation in leakage level over time



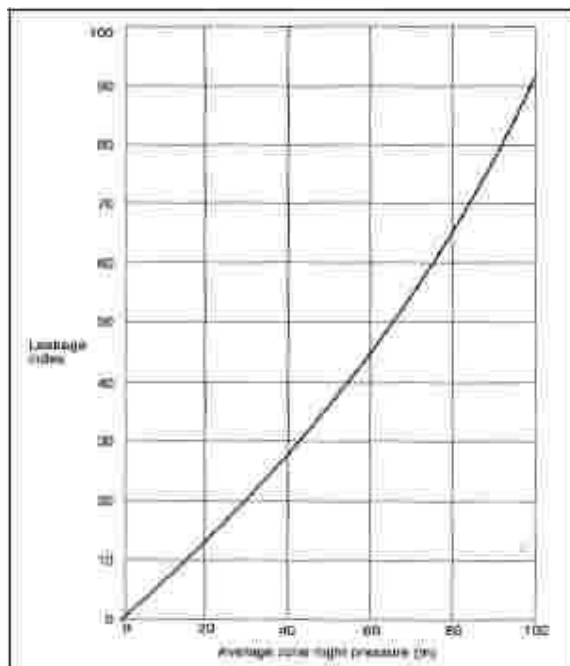
In hydraulic theory, the discharge through an orifice in a pressure system follows the square root relationship:

$$V = Cd\sqrt{2gP}$$

Where:

- V is the velocity of the water through the orifice,
- Cd is the discharge coefficient,
- g is gravity
- P is the discharge pressure.

Studies undertaken in Japan, Brazil and most notably in the UK has shown that the effective relationship is in fact more linear. Figure E-6 shows one of the relationships derived in the UK [This relationship has been superseded in the UK].



**Figure E-6.** Typical Pressure – Leakage relationship

Although the benefits of lowering the pressure have been exploited in many parts of the world, it has tended to be applied at the top end of the curve where the pressures were excessively high. Less well appreciated is the positive impact that controlling pressure has on leakage even when the pressures are as low as they are in Jakarta.

High leakage creates high flow, which increases the headloss and reduces the pressure. But when the leaks are repaired, the converse is true. The higher pressure causes a corresponding increase not just in the water lost from other smaller leaks but also in the risk of new leaks breaking out. This fact was verified in Jakarta and probably explains why the quantity recovered in the past following the replacement of pipes was much less than anticipated. With the creation of a pressure control system, the reduced headloss is automatically compensated for by the Pressure Reducing Valve (PRV).

Although it was clear that the solution to the problem of recurring leakage in Jakarta was the pressure control, it was far from clear whether such a system would work when



Furthermore, the installation of a pressure reducing valve enables the recovery to be maintained in future. In fact, with the application of an electronic controller, it was possible to lower the night leakage by a further 50%.

These results are significant for the following reasons:

- That it is possible to reduce leakage even in networks where the traditional acoustic technology cannot be applied;
- That large leaks are possible also in low pressure networks;
- That the low pressure is a consequence of the high leakage level;
- That pressure control is essential to ensure that new leaks don't break out following the repair of the existing leaks;
- That significant gains can be achieved by reducing the night pressure even when the existing operating pressures are very low;
- That typically only around 40% of the network has a serious leakage problem;
- That just in the pilot area which covers a sixth of the network of Jakarta it is feasible to recover well over 300 l/s;
- That the leakage recovered will enable the extremities of the network to receive a constant supply of water.

In view of the success achieved with the application of the approach, it has been decided to extend the work to cover all of the 3000 km of network it manages.

## Conclusion

Like many parts of the world, the network of Jakarta is very large, complex and loses around half of its water production through leaking pipes. It is constructed primarily of non-metallic pipes in densely populated streets and has extremely low operating pressures. As a result, it is not realistic to use the traditional acoustic instruments to locate the leaks.

A step-by-step approach based on the direct measurement of the leak was developed which involves dividing the network into a number of Permanent Areas supplied by a few key mains on which are installed flow meters. These Areas are much larger than the more traditional District Meter Areas (DMA) as they cover around 100 km of network. But in the same way as a DMA, they serve to quantify regularly the leakage level and to identify the presence of new leaks.

In those Permanent Areas where the specific leakage is high, the network is divided into Temporary Districts, each supplied by a single pipe in which is installed a temporary insertion flow meter. The districts are temporary as the creation of the boundary can cause localised pressure problems. In this way it is possible to pinpoint more accurately the part of the Permanent Area with most leakage where a night step test can be undertaken to identify the leaky pipes. These can then be replaced or abandoned depending on the local conditions.

One of the difficulties in the Jakarta network is the inaccuracy of the mains records. When coupled to the very low operating pressures of 10 metres or less, this makes creating a permanent control system very difficult indeed. In Jakarta this was overcome by building calibrated mathematical models to identify the anomalies, which were then investigated fully in the field by undertaking hydraulic tests and selective excavations. This approach has proved very successful as over a third of the network managed by Palyja has already being divided into Permanent Areas with only minor difficulties. The

advantage of such an approach is that the long, difficult and tedious work of updating the mains records is undertaken only where it is strictly necessary. The Jakarta project has also showed that importance of controlling pressure even in networks where there is very little pressure in the first place. The importance of lowering pressure to reduce the amount of water lost in a burst has been understood for a long time. What is less well understood is that high leakage will cause low pressures. So when the leaks are repaired, the pressure will rise, increasing the risk of new leaks forming. The solution is the installation of a Pressure Reducing Valve, which will compensate automatically for the increase in pressure, thus ensuring that the lower leakage level can be maintained in the future. With the application of a PRV controller, it is possible to lower further the night pressure, with consequential lowering of the leakage.

So successful has the Jakarta pilot project been, that it is currently being extended to cover all of the 3000 km of network managed by Palyja. Not only will this yield a significant reduction in the leakage level, but more importantly perhaps, enable the extremities of the network to receive a continuous supply of water.