WATER LOSS
SPECIALIST GROUP

District Metered Areas

Guidance Notes for DMA Management

March 2024

Version 2

DMA Management Guidance Notes: These guidance notes were originally written by the DMA Team of the Water Loss Specialist Group. The Water Loss Specialist Group 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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The Water Loss Specialist Group, decided that an update to the guidance notes was needed, to include changes in technology and procedures over the 20 years since the original guidance notes were written. In addition, the update is intended to give a more international view, rather than a UK based document. For the version 2 update the main authors were:

- John Morrison
- Stephen Tooms
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Acknowledgement

The DMA Team would like to acknowledge the help and support of other members of the IWA Water Loss Specialist Group, who have made many constructive comments on the content and layout of the Guidance Notes, provided content in the form of pictures and text on specific subjects, provided the case studies included here as appendices and acted as proof readers.

Version history

Version 1 - 2002

Contents

1 Foreword

The Water Loss Specialist Group (WLSG) is one of the International Water Association's Specialist Groups. The vision of the WLSG is to *"provide leadership in the field of Water Loss Management through effective and sustainable international best practices".*

The mission of the WLSG 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 WLSG 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 WLSG are well documented in articles, conference proceedings, software, manuals and textbooks. The WLSG will continue expanding Water Loss Management strategies and developing new research initiatives which can be universally applied.

Within the above context the WLSG 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 are 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 WLSG. 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 Water Loss Specialist Group page on IWA Connect Plus:

https://www.iwaconnectplus.org/group/feeds?CommunityKey=a0M4K0000027gqLUAQ

Or from the Global NRW website:

https://globalnrw.com

Stuart Hamilton
Chair,
Water Loss Specialist Group,
June 2022

2 Introduction

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 Specialist Group 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 Engaging stakeholders

Installing DMAs is a significant investment. It changes the way that the water distribution system operates and changes the way that it is managed. Everyone connected to operation, management and use of the distribution system will be affected by DMAs and they can all influence the success of the project.

For such change to happen it requires:

- Alignment of different stakeholders around a business and economic vision to reduce leakage.
- The ability to transfer such vision to the organization's strategy, objectives, and operating procedures.

From the above it's not difficult to foresee some of the obstacles that may prevent a successful implementation, and these are just a few of the challenges:

- Build a common vision and get the commitment at all levels of management and staff to the project. Consider including customers in that common vision.
- Build and train a dedicated project team of staff and consultants.

- Develop a financial and economic model of the costs and benefits of the project.
- Trial DMAs in a small area to demonstrate benefits and fine tune the solution to local circumstances.
- Train operations and maintenance staff in using DMAs.
- Identify resources required to implement infrastructure changes, such as install meters and pressure control valves.
- Plan whether in-house or contractors or a mix of staff will locate leaks once the DMAs are established.
- Plan how to repair of the backlog of repairs that is likely to be identified within the DMAs

2.5 Management of DMAs

Leakage control by ALC has proven to be very successful as part of an overall plan to reduce and subsequently maintain leakage. Over the last 40 years, 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.

2.6 Items covered by the Guidance Notes

The items covered by these Guidance Notes include the following:

- Theory of DMAs
- Design of DMAs.
- Analysis of flow measurement.
- Management of DMAs.

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

3 Philosophy of Leakage Control by DMA Management

3.1 Introduction

As water networks deteriorate, they become prone to leakage. In addition, new networks frequently start to leak 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 series of sectors called DMAs, 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.

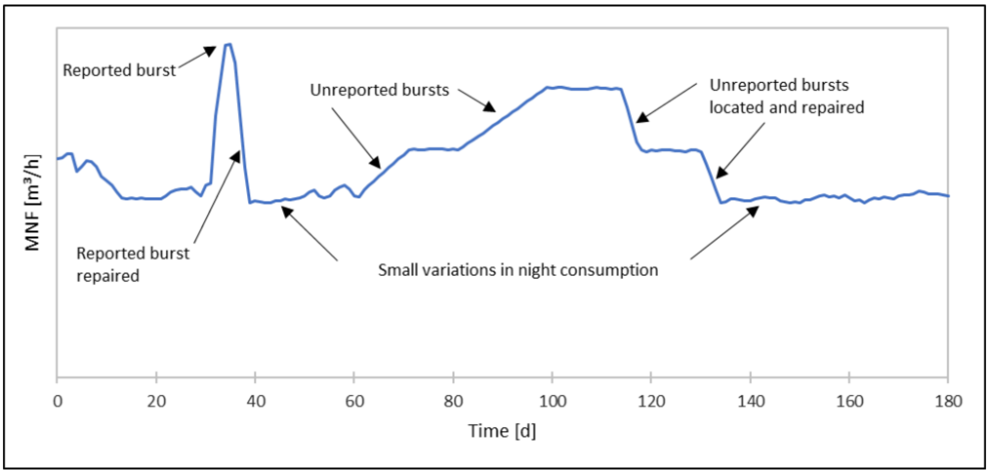

Figure 1 Variation in Minimum Night Flow (MNF) over time.

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

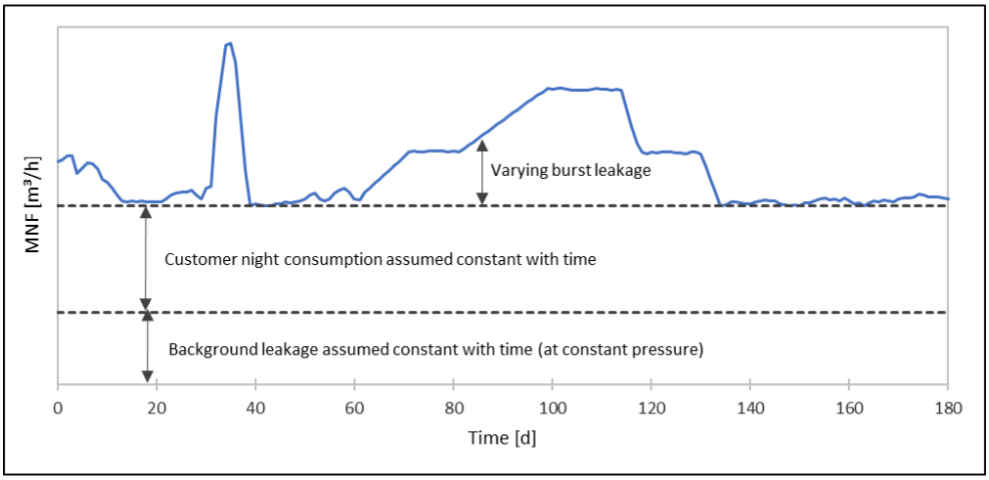

Figure 2 Basic components of minimum night flow, and their variation with time.

Customer night consumption 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^3/h) as a percentage 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. 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:

- **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.
- **Background Leakage** is the aggregation of leaks from joints and fittings that are individually too small to be detected by visual or acoustic inspection with available technology. Average zone pressure and pressure management, and location of meters on private supply pipes also have a major influence on this component of leakage.

3.4.1 Calculating burst leakage

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 (ALR)**.

- **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 relevant authorities.

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 therefore be independent of any active leakage control systems.

Burst leakage volume is calculated as the flow rate of the leak multiplied by the runtime of the leak.

$$V_{L,burst} = Q_L \cdot T_{ALR} \qquad \textit{Equation 1}$$

For the unreported burst, the awareness time is affected by the leakage management practices, as 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 illustrates how the average awareness time is affected be the number of annual surveys.

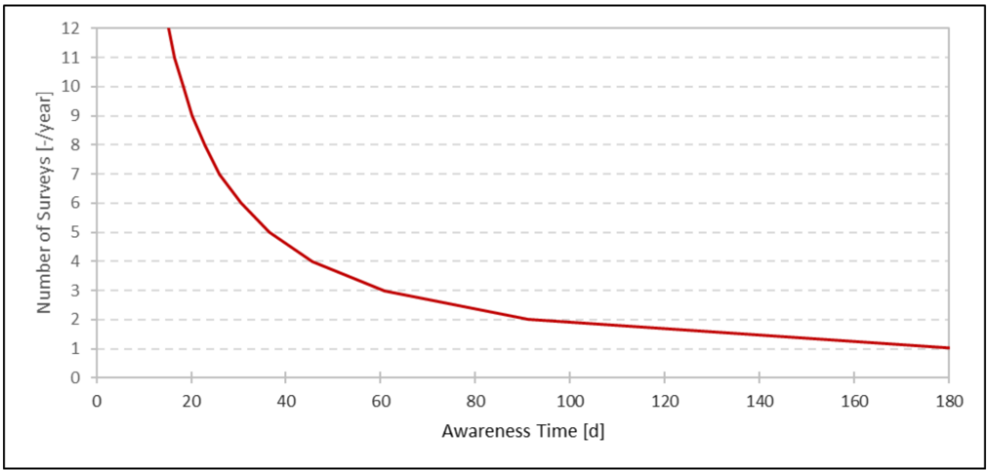

*Figure 3 Average **Awareness** time as a function of the number of annual surveys.*

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.

<u>*Example: ALR calculation for monthly DMA flow analysis*</u>

Estimation of total ALR time (leak run time)		
Awareness	*= 365/12/2 days*	*15 days*
Location	*≈ 5 days*	*5 days*
Repair	*≈ 10 days*	*10 days*
Total Runtime		***30 days***

It should be noted that location time and repair time will be dependent on local practice, manpower availability and local legislation regarding gaining approval from necessary authorities.

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.

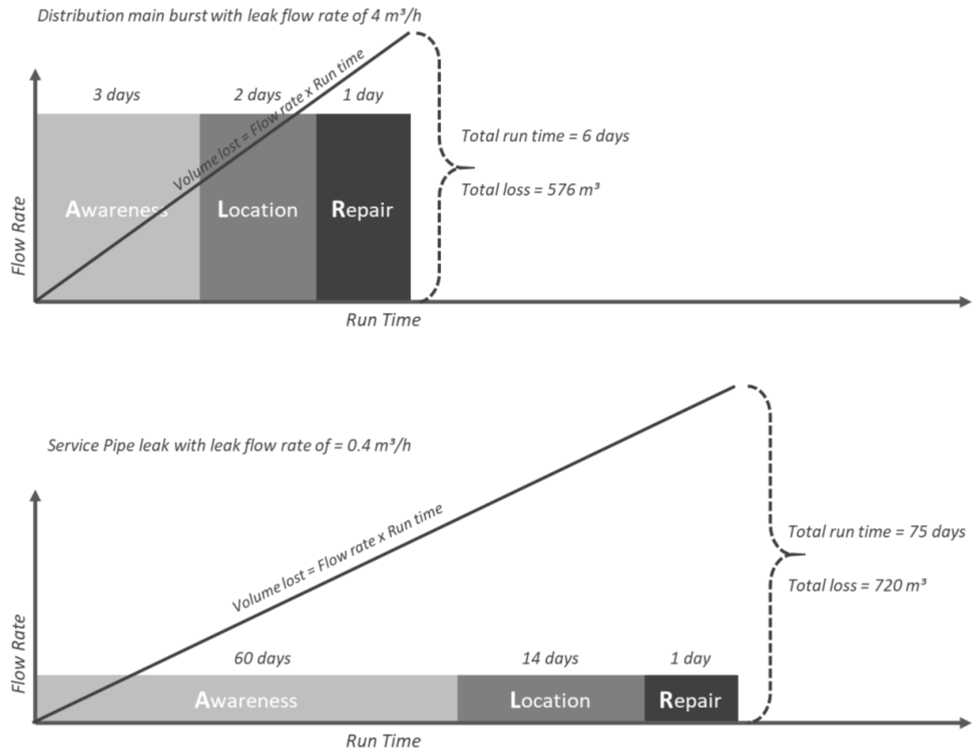

Figure 4 ALR duration effect on total water loss from bursts and leaks.

It is therefore the analysis of the flow into a DMA, enabling rapid identification of unreported burst or bursts as they occur, 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, to limit their average run-time.
- To identify which parts of the network require active leakage location activities, thus enabling resources to be deployed most effectively.

3.4.2 Calculating background leakage – Component Analysis

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

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

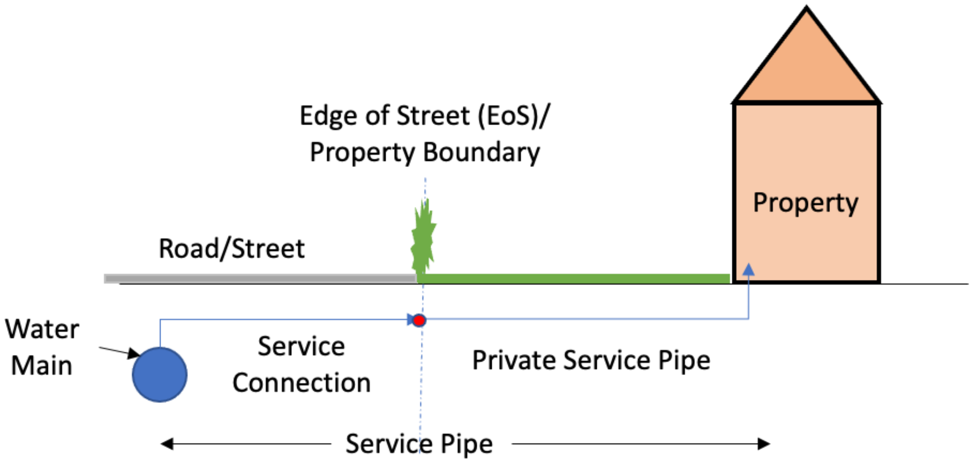

Figure 5 Cross section of a typical customer connection.

The recommended formula by IWA for estimating the Unavoidable Background Leakage (UBL) with infrastructure in good condition, including a pressure correction based on a reference average zone pressure of 50 mwc is given as:

$$UBL = (0.02 \cdot L_m + 1.25 \cdot N_C + 0.033 \cdot L_p) \cdot \left(\frac{AZPN}{50}\right)^{1.5}$$

Equation 2

Where:

UBL:	Unavoidable Background Leakage [l/h]
L_m:	Length of main pipes [m]
N_C:	Number of service connections [-]
L_p:	Total length of private pipes [m]
AZNP:	Average Zone Night Pressure [mwc]

The power law of 1.5 derived specifically for background leakage using international data shows why pressure management is very effective in managing and reducing background leakage.

UBL can be used as part of a flexible approach to assess actual background leakage (BL) as scaling of UBL by the Infrastructure Condition Factor (ICF):

$$BL = ICF \cdot (0.02 \cdot L_m + 1.25 \cdot N_C + 0.033 \cdot L_p) \cdot \left(\frac{AZNP}{50}\right)^{1.5} \qquad \textit{Equation 3}$$

Where:

BL: Background Leakage [l/h]

ICF: Infrastructure Condition Factor

The Infrastructure Condition Factor (ICF) normally lies between 1.0 and 4.0, depending on the condition of the joints and fittings on the mains and service connections. A value of 1.0 is achieved if the mains and service connections are considered to be in good condition, or up to 4.0 if they are considered to be in poor condition from a water tightness point of view.

Here it is to be noted that:

- Where the customer meters are located at the junction between property connection and private pipe, the ICF on the private pipe background leakage is likely to be close to 1.0, as it would be in the interest of customers to minimise any leakage.
- Higher initial ICFs are often associated with a backlog of unrepaired known and unknown leaks, particularly on private unmetered service connections.
- Plumbing losses are included in the night consumption within the property. Distribution systems pressure will only affect leakage on customer plumbing where supplies are direct. Therefore, customers' plumbing supplied via ground tanks or roof top storage will not be affected by pressure in the distribution system.

Example: Calculation of DMA background losses

DMA Characteristics	
Total length of mains	*22,500 m*
Number of connections	*1,500*
Average length of private pipes	*12 m*
Number of private pipes	*1,500*
Infrastructure Condition Factor	*1.0*
Average Zone Night Pressure	*60 mwc*

Calculation where customers are not metered, and supplies are direct:

$$UBL = [1.0 \cdot (0.02 \cdot 22{,}500 + 1.25 \cdot 1{,}500 + 0.033 \cdot 1{,}500 \cdot 12) + 0.25 \cdot 1{,}500] \cdot \left(\frac{60}{50}\right)^{1.5} \; l/h$$
$$= 4{,}330 \; l/h = \mathbf{4.3 \; m^3/h}$$

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

$$UBL = [1.0 \cdot (0.02 \cdot 22{,}500 + 1.25 \cdot 1{,}500 + 0.033 \cdot 1{,}500 \cdot 12)] \cdot \left(\frac{60}{50}\right)^{1.5} \; l/h = 3{,}837 \; l/h$$
$$= \mathbf{3.8 \; m^3/h}$$

3.5 Effect of pressure on DMA leakage

Understanding of the beneficial effects of pressure management on leak flow rates and burst frequencies in water distribution systems has progressed significantly in recent years. Improved concepts to reduce and maintain low levels of leakage in DMAs and water networks are now available to assess benefits. This is illustrated in Figure 6.

Pressure Management: Reduction of Excess Average and Maximum Pressures								
Conservation Benefits			Water Utility Benefits				Customer Benefits	
Reduced Flow Rates			Reduced Frequency of Bursts and Leaks					
Reduced Excess or Unwanted Consumption	Reduced Flow Rates of Bursts and Leaks	Reduced and More Efficient Use of Energy	Reduced Repair and Reinstatement Costs, Mains and Services	Reduced Liability Costs and Reduced Bad Publicity	Deferred Renewals and Active Leakage Control	Reduced Cost of Active Leakage Control	Fewer Customer Complaints	Fewer Problems on Customer Plumbing and Appliances

Figure 6 High level conceptual benefits of pressure management[1].

This Guidance Note is limited to outlining the relationships between pressure and leak flow rates used in DMA analysis.

Figure 7 shows an example of how the average zone pressure (AZP) for a DMA varies inversely with inflow rate, as the frictional losses increase with demand due to the higher velocities of water in the pipes. In this example of a gravity supply DMA the average zone pressure and the leak flow rates are highest at the time of minimum night flow, and lowest at times of peak demand.

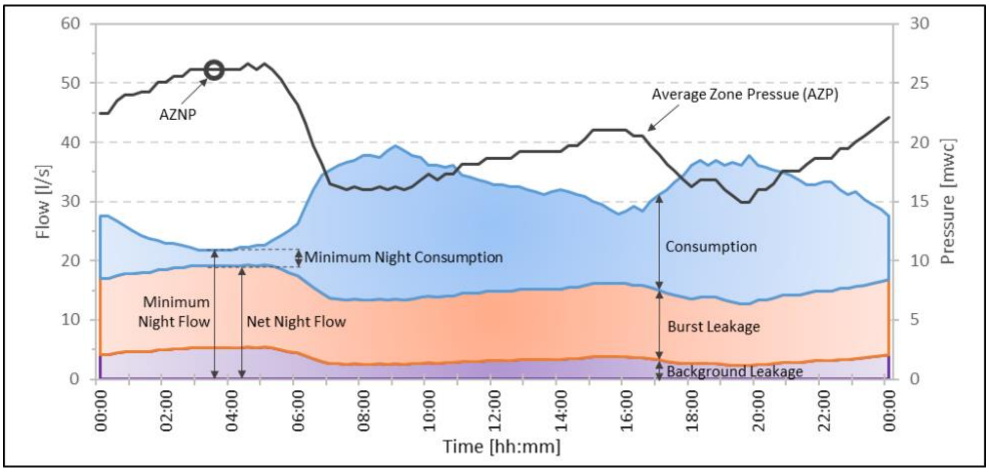

Figure 7 Example of variation of supply to a DMA divided into components, combined with average zone pressure.

If pressure management is applied, the reverse of the situation depicted in Figure 7 can occur, with lowest pressure at night and highest pressure during daytime. In pumped or flow modulated systems, either situation can occur.

A multiplication factor known as the Night-Day Factor (NDF), or Hour to Day Factor (HDF) in UK, is used to convert the 1-hour night leakage rate to the 24-hour daily leakage rate. In Figure 7 the daily leakage volume will be over-estimated if the hourly night leakage rate of approximately 20 l/s, 72 m³/h, is simply multiplied by 24 h/d, which is a common but generally unreliable practice. NDFs are zone-specific and depends upon variations in average zone pressure and the relationship between

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[1] *Australian WSAA PPS-3 Asset Management Project 2008-11, Framework for targeting Leakage and Pressure Management. Wide Bay Water Corporation and Water Loss Research & Analysis Ltd*

zone leak flow rate and average zone pressure. In practice NDF can vary from 10 to 80 h/d, refer to Appendix A for details on NDF calculations and usage.

The relationship between average zone pressure (AZP) and leak flow rate can be assessed from measurements of Minimum Night Flow (MNF) and Average Zone Night Pressure (AZNP) during night-time, when the leakage usually forms the largest proportion of the DMA supply, refer to Figure 7. Multiple sets of corresponding values of (AZNP, MNF) can be recorded over several days, preferably (if possible) combined with changes in supply pressure to achieve a significant variation in the data set. The variation in MNF with AZNP can then be assessed. The relationship between AZP and leak flow rate is usually expressed initially as a simple power law:

$$L = C \cdot AZP^{N1} \qquad \text{Equation 4}$$

C is assumed constant and N1 is expected in the range from 0.5 to 1.5. If test results lead to N1 being calculated outside this range they should be used with great care, and only if they meet strict quality measures. However, there are some situations where legitimate higher or lower values could occur, for example when the dominant leak(s) occur in a part of the network with average pressures significantly higher or lower than the AZP.

This also means that if the average zone pressure is changed from AZP_0 to AZP_1 then the change in leakage rate from L_0 to L_1 can be calculated as:

$$L_1 = L_0 \cdot \left(\frac{AZP_1}{AZP_0}\right)^{N1} \qquad \text{Equation 5}$$

However, as seen from Appendix A, N1 does vary with pressure (except at limiting values of 0.5 and 1.5) meaning that this relation is only valid for small changes in pressure.

The Fixed And Variable Area Discharge (FAVAD) concept[2] is more hydraulically appropriate for general analysis and predictions as it includes hydraulic theory for the pressure - leak jet velocity relationship, and two main classes of pressure dependent leaks.

Hydraulic theory clearly shows that leak jet velocity varies with the square root of pressure , which for the leak in a DMA is formulated as:

$$L = C_d \cdot A \cdot (2g \cdot AZP)^{0.5} \qquad \text{Equation 6}$$

Where:

- *L*: Leak flow [m^3/s]
- C_d: Hydraulic form factor (typically around 0.60) [-]
- A: Area of leak orifice [m^2]
- *g*: Acceleration due to gravity [m/s^2]

Which then can be reduced as:

$$L = 0.60 \cdot A \cdot (2 \cdot 9.81 \cdot AZP)^{0.5} = 2.66 \cdot A \cdot AZP^{0.5}\ [m^3/s] \qquad \text{Equation 7}$$

As leak flow rates equal leak area multiplied by leak velocity, and the velocity relationship with pressure is clear, progress towards a better understanding of pressure - leak flow relationships has

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[2] *John May. 1994. Pressure Dependent Leakage. World Water and Environmental Engineering, October 1994.*

been possible through a deeper analysis. Rather than considering A as being constant in Equation 4, it is now also being considered as a pressure dependent variable.

According to the FAVAD concept, some leaks have fixed areas (A_f) which do not vary with pressure, while other leaks have variable areas A_v which vary linearly with pressure:

$$A = A_f + A_v = A_f + m \cdot AZP \qquad \textit{Equation 8}$$

Where:

- A_f: Fixed leak area (pressure independent) [m²]
- A_v: Variable leak area (pressure dependent) [m²]
- m: rate of leak area increase with pressure [m²/mwc]

This then leads to the FAVAD equation:

$$L = 2.66 \cdot \left(A_f + m \cdot AZP\right) \cdot AZP^{0.5}\ [m^3/s] \qquad \textit{Equation 9}$$

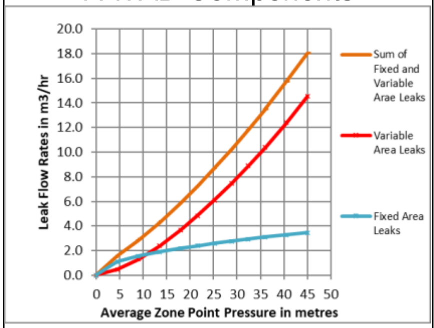
Corrosion holes, ring cracks and blowouts in rigid pipe walls are typically fixed area leaks.

Figure 8 shows an example where 1.0% change in pressure results in a 0.5% change in the fixed area leak flow rate, blue curve.

Fixed Area Leak

K Brothers

FAVAD Components



WLR&A Ltd.

Variable Area Leak

Julian Thornton

Figure 8 Examples of fixed and variable leak areas with FAVAD components.

A 1% change in pressure results in a 0.5% change in fixed area leak flow rate.

Longitudinal splits in pipes with flexible materials and undetectable small background leaks at joints and fittings are typical examples of variable area leaks, red curve, and a 1% change in pressure results in a 1.5% change in leak flow rate, three times more sensitive to pressure change than for fixed area leaks.

Each DMA will have its own mix of fixed and variable area leaks. The proportions will vary with pressure, and also as new leaks occur and are repaired.

The sum of the fixed and variable area leaks in a DMA (brown line) can sometimes appear to be close to a linear relationship, corresponding to N1 = 1.0, between leak flow rate and average zone pressure. However, it is only linear at the pressure where the fixed and variable area curves intersect. In Figure 8, N1 actually ranges from 0.82 at 5 mwc to 1.0 at 10 mwc and 1.31 at 45 mwc.

Power laws have been used for pressure - leak flow relationships for at least 45 years, using fixed values based on the average of a number of N1 night tests (or similar tests). For any assumed value of N1, the implied percentage of fixed area leaks is (1.5 - N1)·100%. A fixed value of N1 = 1.15 (widely used in Japan) implies 35% fixed area leaks and 65% variable area leaks at all times.

For simplified approximate calculations, a fixed N1 of 1.0 is often assumed, implying 50% fixed area leaks and 50% variable area leaks irrespective of changes in DMA pressure. However, the FAVAD concept states that this cannot be generally valid as the leak area term, Equation 8, varies with pressure.

Although the simplified assumption of N1 being fixed at 1.0 may be reasonably reliable for practical predictions of the effect of small changes in pressure on leak flow rates, for DMAs with steady daily average zone pressure profiles (AZP_{Avg}/AZNP ratios close to 1.0) it cannot cope with larger variations and changes in AZP when pressure management or pumping is involved. Significant errors can often be made by assuming a fixed N1 to calculate NDF, and when NDFs are used to predict reductions of leak flow rates after pressure management.

A starting point for reviewing NDF estimates is to assume that many practitioners currently assume a fixed N1 of 1.0, implying a Night-Day Factor of 24 · AZP_{avg}/AZNP. Appendix A uses the full FAVAD concept approach to demonstrate how N1 does actually vary with pressure, and how to rapidly decide, for any DMA:

- Do large uncertainty limits apply to the initial assumption that a fixed N1 = 1.0 and NDF = 24 · AZP_{avg}/AZNP?
- Is a night test always recommended to assess N1 at average zone night pressure and the N1 versus AZP relationship?

3.6 Intermittent supply

Intermittent supply operations and schemes are commonly seen in areas with limited water supply and/or insufficient pressure, which may be due to scarce water resources or worn-out infrastructure. Such intermittent supply is normally maintained by operating a set of valves according to specific alternating schemes so that each area or DMA is supplied at regular intervals, which can be down to as little as four hours hour and up to several days, typically maximum to or three. Different strategies are applied in different countries where it is common in the Middle East that ground tanks of 1-2 m³, acting as a local buffer, are installed at each customer, which allows for longer periods between each supply cycle, and where the customer rarely experience shortness of water. However, in Asia and especially Africa most customers are directly connected to the network, and the interval between each supply cycle is much shorter and the customers often experience shortness of water.

An example of measured inflow and zone pressures from a supply zone with intermittent supply in the United Arab Emirates is shown in Figure 9.

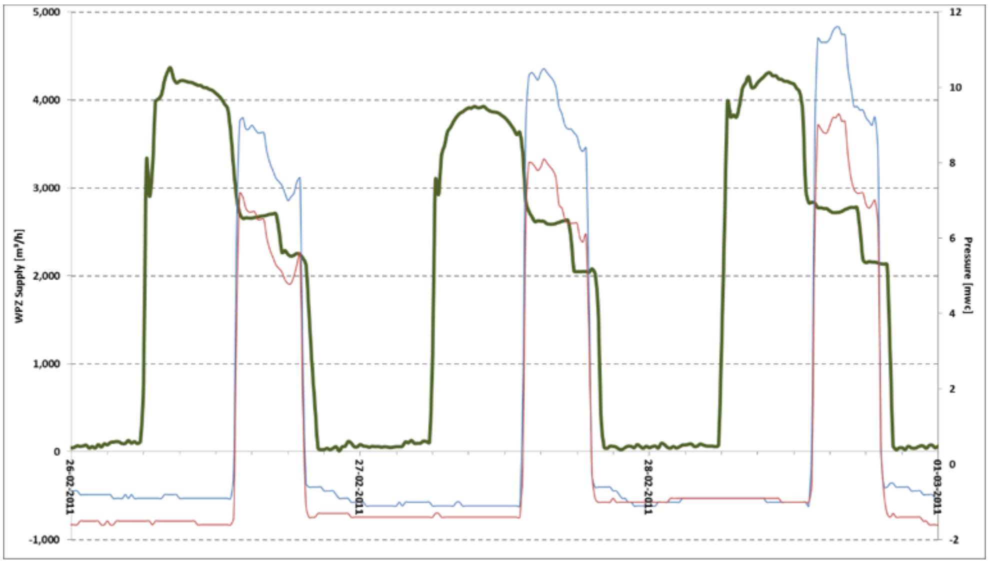


Figure 9 Example of intermittent supply in a pressure zone with customer ground tanks.

The green graph shows the total inflow to the pressure zone and the blue and red graphs show the pressure at two locations inside the zone. Combining the information, it can be seen that:

- The zone is supplied daily from 06:00-18:00.
- Before supply is activated the pressure inside the pipes are at -0.5 mwc and -0.8 mwc, meaning that the pipes are empty.
- When the zone supply is opened, the flow increases immediately to a high level at around 4,000 m³/h, filling the pipes inside the zone, and at the same time water will also start to fill the customer ground tanks.
- Due to the large volume of water that is required to fill the pipes and the ground tanks there is a delay of 7-8 hours until the pressure builds up inside the zone and then the pressure increases within a few minutes to around 10 mwc.
- When the ground tanks are filled and the ball valves closes the tank inlets, the supply drops to around 2,500 m³/h.
- When the zone is disconnected for supply, the pressure drops very fast back to the “initial” around -0.5 mwc to -0.8 mwc.

Leakage control across systems that are fed with intermittent supply regimes will be much more difficult to manage due to the limited time available in undertaking activities related to both quantification of water losses and reducing non-revenue water levels. This limited availability of time is due to long periods, once the water supply is turned on, where the velocities may be very high, as customer tanks are filled rapidly and very low system pressures experienced, as the rapid filling of customer tanks will not allow system pressures to build up. There will therefore often only be a small period of time, towards the end of the rationing period, where undertaking DMA analysis and leak detection activities can effectively be undertaken.

This restricted time will severely impact the process of DMA management and leakage control, as there will be limited periods of time, when the network is operating with minimal system flows, ideal for undertaking DMA analysis and leak detection. In addition, intermittent water supply is governed by fixed rationing schedules, that are publicized for customers, meaning that if leak detection and repair is undertaken during these periods, it may have an impact on the supply of water to customers during the limited time it is available to them.

It is important to highlight as well that intermittent water supply is not only used in distribution systems where water is short, but also in cases where hydraulic capacity of the network is such that it cannot meet critical demands. In the case of networks having extremely deteriorated pipe networks, hydraulic investigation and modelling would be beneficial, especially in deciding which water supply and distribution scenario would provide the most efficient and sustainable operation for the water network.

The performance of some meters, at both bulk and customer levels, may be impacted due to the intermittent water flow in the supply and distribution systems, resulting in a worsening of water meters accuracy and functionality, which might lead eventually to malfunction due to:

- High water velocities generated during the filling and emptying of water pipelines.
- An increase of suspended solids as the initial pipe filling picks up debris from the pipe floor.
- Expulsion of air through the customer meters at high speed.

All will have different effects on metering accuracy and thus water loss quantification and control. It may therefore be necessary to subject these meters to a set of corrections to improve the water loss analysis.

Customer metering and the formulation of an accurate customer information system plays a significant role in DMA management and leakage control, which is no exception under intermittent water supply. It is quite important to consider the metering errors that might be compounded under intermittent water supply conditions, which include but are not limited to:

- Alternation of dry/wet conditions on the meter.
- Air pockets that need to be expelled, as water is introduced to the network.
- Vacuum condition and localized surges, which may affect the meter.
- Turbulence flow imposed on the system, especially when the system is first being filled and velocities are extremely high.
- Under-estimation of flow through meters that are operating under partial flow conditions.
- Calibration of bulk water measurements under such partial flow conditions.

Intermittent supply may also affect customer consumption behaviour, as the intermittent regime may lead to customers consuming as much water as possible, to ensure sufficient storage for the interrupted periods. This may lead to occasional overflows in customer storage tanks, which should be considered as water losses especially if the customer meter is not working accurately. Intermittent supply can also trigger an increase in unauthorized consumption through illegal connections or meter tampering cases, which need to be considered when undertaking DMA analysis.

Minimum night flow analysis is extremely challenging under intermittent water supply regimes, as the main target for most operators, is to supply water to customers as quickly as possible, because of the limited rationing hours. This may also sometimes affect the DMA isolation, due to operators opening and closing boundary valves to meet the demand at critical points. When water rationing is first turned on, the water velocity in the pipes will be relatively high with low pressures, but progressively throughout the rationing period, customer storage tanks will fill up and customer consumption will decrease. This will lead to system flows stabilising and system pressures reaching a maximum, but it is critical at this point to control pressures to ensure that the system does not get over pressurized at any point. This can be done using pressure reduction valves (PRVs), which have been setup from hydraulic analysis of the network, enabling a maximum pressure to be set, thus ensuring no over-pressurization of the network.

Under intermittent water supply conditions, many operators tend to use isolation valves as regulatory ones, through opening and closing of these valves to supply various supply regimes. Regular throttling of these valves will impose extra load on the valve, which will eventually contribute to degrading the life expectancy of the valve. In addition, this constant throttling will affect the tightness of these valves, that will create issues in isolating DMAs and creating hydraulic boundaries. These valves are designed to be only operated as fully open or fully closed and they should not be used during peak demand, under intermittent water supply with limited rationing, to regulate the flow and critical customer supply. Instead, reconfiguration of the network layout, pressure management, network isolation and DMA border adjustment should be undertaken to regulate the flow better.

The ongoing valve operations during the intermittent transitions may also lead to pressure surges being introduced at a high rate which will lead to an increased burst frequency and subsequently increased and leakage level.

One of the challenges that occurs under intermittent water supply is that customers often store more water than is required for the period of non-supply. When the water supply is reconnected, they then get rid of the stored water and collect new water once again. Water consumption per capita per day is therefore often much higher in intermittent supply systems compared to continuous supply systems. Transition into continuous supply will result in lower water consumption, with lower demands required from the water production and on the distribution facilities, which will therefore have a positive effect on the whole supply and distribution systems.

However, converting an intermittent supply network into a continuous supply remains an extremely challenging step, since this course of action will normally require days for the water consumption to decrease to normal (or actual use at household side) levels, due to a lack of confidence from the customers. During the initial period, when demand remains high, system pressures would be greatly reduced, causing people to continue hoarding water until they gain confidence that the water supply will not be cut off again. This issue is something that needs to be considered and developing a transitional phasing toward a continuous supply system is an effective solution. The use of DMAs can be applied to facilitate and streamline this transition from an intermittent to continuous water supply system. Initially, the water utility and operators should consider installing a small number of DMAs, that gradually feed continuous water supply, enabling customers within these DMAs to adjust to the new system and reduce excessive collection of water. This should be supported by demand management and behaviour change campaigns that introduce new water efficiency fixtures and equipment to the households. Once consumption patterns stabilise, the inflow volume into the DMAs should decrease to normal levels.

The water utility should then undertake leak detection activities and customer surveys to reduce water losses to an acceptable threshold, producing spare capacity at the production and distribution systems. This spare capacity represents additional water quantities that can be supplied to new areas, which previously had no supply. Once these first DMAs have successfully been converted to continuous supply and water losses reduced effectively, then the next group of DMAs can be established for transition to continuous supply regimes.

Intermittent water supply makes achieving substantial non-revenue water reduction extremely challenging, since it affects leak survey and detection, pressure management, optimization of repair and maintenance works, asset management and customer metering activities. Therefore, wherever possible, it should be considered to convert the system into continuous supply, before tackling the issue of managing NRW. This will also bring huge benefits to the water utility, in terms of both commercial and technical management, including infrastructure capacity and sustainability.

Although intermittent water supply systems are commonly initially designed to operate under continuous conditions, they are forced to run intermittently due to different flow conditions and fluctuating demand patterns. This generates increased wear and tear on valves and other system assets and as such increased manpower is needed to undertake increased network maintenance and repairs. In addition, the same quantity of water, made available over 24 hours for continuous supply regimes, must now be made available over fewer hours in an intermittent system. This will require distribution pipes with larger diameters, to cope with the increased flow rates, increasing system design and operation costs. Once intermittent service becomes the norm, the supply hours of service will continue to decline, as water losses will continue to increase and operators will supply the same volume into supply, but over an even shorter time period. Intermittent supply systems require higher CAPEX and OPEX costs to run, which must be borne by the water utility, but ultimately, it’s the customers who pay for this inefficiency.

4 Scheme design

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.

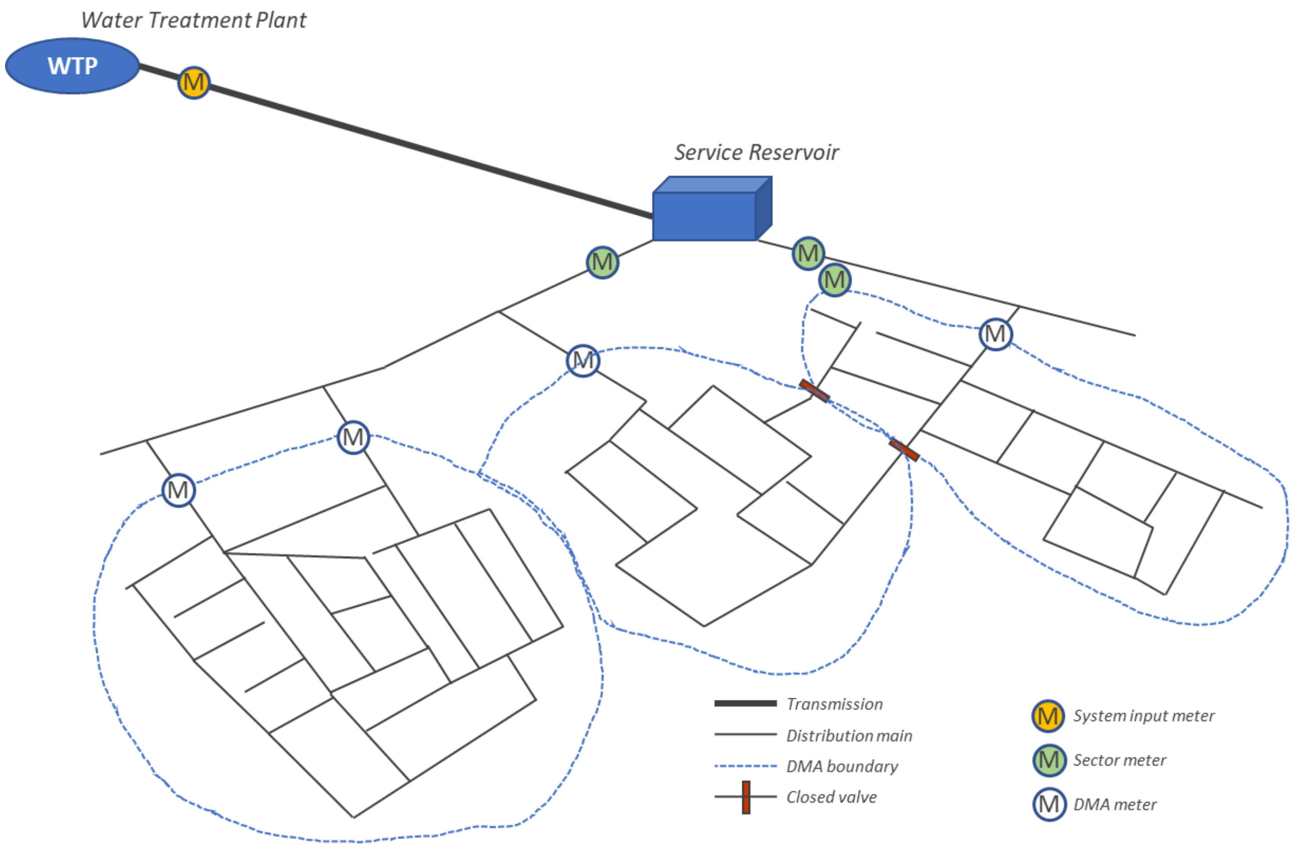


Figure 10 Examples of typical DMA layout and configuration.

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. 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.

4.3 ICT supporting tools

Information and Communication Technology (ICT) tools are technical means to handle information and in the water sector these manifest themselves into three main forms: Geospatial Information Systems (GIS), hydraulic models, and Automated Meter Reading (AMR)/Advanced Metering Infrastructure (AMI). When implemented efficiently these ICT tools make DMA design, planning and operations easier.

Geospatial (or geographical) Information Systems are geo-referenced databases. These tools often serve as the base for other ICT applications and are typically a utility's repository of linear assets. Digital maps enable field crews to quickly view and collect data and they may use mobile devices to eliminate paper forms and improve data entry, which improves workflows. Some manufacturers have even overcome signal limitations by incorporating inertial navigation systems into receivers. In addition to being maps, GIS can store attributes related to specific features such as pipe age, pipe material and/or interconnections. Typical GIS's feature classes including mains (pipes), fittings, valves, hydrants, pumps, and water storage installations. When creating DMAs, GIS systems can assist in developing criteria selection by tying in visible topographic features such as rivers or highways. GIS can also perform topology checks to ensure that pipes connect and do not simply cross over from an aerial view. There are also programs which can suggest DMA design based on pre-set criteria such as DMA size, minimizing valves to isolate DMAs, minimizing flow meter measurements, minimizing ground-level variations, and other set criteria. Automated results should always be checked and adjusted by utilities based on site-specific information or criteria which cannot be weighed by programs, including any political or regulatory considerations. Main considerations with GIS are accuracy, integration with other systems, user-friendliness, and security concerns. GIS is continuously evolving in terms of data integrity, presentation, and data sharing (online, mobile), which means that continuous upgrading of the system and the contained data, needs to be something undertaken by the utility.

Hydraulic models are computer simulations of water distribution networks. Today, most commercial hydraulic modeling software allows for direct GIS data integration, ranging from completely residing within the GIS environment to specific features that allow utilities to import GIS data directly into the hydraulic modeling software. Historically, GIS and hydraulic models were separate. GIS was mainly used for mapping and managing assets, so asset details and accurate locations were critical; knowing the connectivity of facility components was not necessary. Hydraulic models also contain significant data, generally needing physical data such as location, height, diameter, roughness/C-coefficient, and connectivity of pipes; demand data for spatial and temporal use; and operational data such as pump status, storage facility water levels, as well as valve positions. It is generally not necessary or practical to place that information into GIS so hydraulic models are generally reduced or skeletonized, which is a process to decrease the size, complexity, and runtime of the model by removing hydraulically insignificant features. With increased computing power and longer validation periods there is now an increasing trend towards all pipe models which maintain a one-to-one correspondence to the GIS; however, these require longer processing times and better computers as well as programs. There are also a number of ways hydraulic models can be run, including steady-state analysis, configuring the model to analyze the water system over an extended period to take into account shifting demands, and real-time use. Hydraulic models can assist in DMA creation by calculating hydraulic equivalent points, emergency response scenarios, water age as well as other quality/supply simulations. Automated DMA creation programs should always be checked and adjusted by utilities based on site-specific information or criteria which cannot be weighed by programs including any political or regulatory considerations. Typically, the most difficult aspect of hydraulic modeling is calibrating the hydraulic model and keeping up with on-ground operations such as valve position. Calibration includes comparing field results with the model and adjusting the model so that it mirrors reality. This process can include identifying orphaned pipes and nodes, discrepancies in GIS data, connectivity, and valve/operational conditions.

Automated meter reading (AMR) and automated metering infrastructure (AMI) can greatly reduce the work involved with DMA analysis. These two systems automatically collect water consumption and status data from water meters. AMR systems can be either walk-by or drive-by, whereas AMI integrates water meters with communication networks and data management systems, negating the need for utility personnel to collect the data and automatically transmiting the data directly to the utility at predetermined intervals. AMI/AMR can greatly simplify flow balances with DMAs and can enable real-time information, as well as the creation of digital twins.

5 DMA Design

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 safely & efficiently.

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 and sizing of the leaks.
- Limit, or if possible, eliminate, the number of closed valves.
- Incorporate distributed pressure sampling locations.
- Minimise the changes to the hydraulic and qualitative operation of the existing network.
- Enable pressure management within individual DMAs or a group of DMAs

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, length of sector mains and number customer connections).
- Housing type i.e. blocks of flats or single family occupancy housing.
- Variation in ground level.
- Water quality considerations.
- Required (pressure) service level.
- Firefighting requirements and capacity.
- Target (strategic) leakage level.

- Number of (emergency/backup) valves to be closed.
- Number of meters used to monitor flow, ideally minimised.
- Large or VIP customers fed through the DMA.
- Infrastructure condition and sources of descriptive data such as:
    - Material.
    - Soil type.
    - Installation date.
    - Installation contractor.
    - Burst history

The over-riding factor is to successfully create the DMAs without significantly affecting the quality of service to the customers while ensuring you have the supporting information to identify and prioritise areas of high real losses. 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 is something that needs to be considered by the utility before starting a DMA implementation programme, as it has an impact on the cost of creating them. Smaller sized DMAs will require the implementation of more DMAs to cover the entire network. This means higher overall costs, as more valves and flow meters will be required. The future maintenance requirements 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 using night flow analysis.
- The location times can be reduced because it is quicker to carry out detection in smaller DMAs to find a given leak, than a larger 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 3,000 properties.

It has been found that if a DMA is larger than 5,000 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 considered 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.

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 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 critical, large or otherwise special customers.
- 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, which provide good connectivity to the mobile phone networks or a low power wide area network, such as NB-IoT. 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 bursts 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 firefighting 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(s).
4. Set up pressure loggers or gauges at key locations throughout the DMA.
5. Close the DMA inlet(s) 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 preferences.

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 extremely 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 significantly affecting the head losses at peak flows. However, they tend to be the most expensive option and although some require external power supply, most can now be powered by batteries. Ultrasonic meters used to be strapped onto the outside of the pipes, which meant lower installation costs, as there is no need to cut the pipe, but meant a reduction in accuracy. The latest ultrasonic meters come as an entire unit, whereby you can and insert them into the pipe, which although means an increase in cost has meant an increase in accuracy as well. 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
- Estimates of exceptional night use above 500 l/h (for maximum flows).
- Estimates of night use (for minimum flows).
- Estimates of leakage (for minimum flows after leak repair).
- Firefighting 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.

5.8 Pressure management

The Four Pillars of Physical Loss management is well known, with each of the four components contributing significantly to leakage control and DMA management, that includes speed and quality of repairs, asset management, active leakage control and most importantly pressure management, which is considered a fundamental tool in controlling physical losses. Maintaining optimized and managed pressure levels in the water network and distribution systems will reduce the flow rates through leaks, background losses and bursts. In addition, it will establish stable pressures in the network, with minimal fluctuations and surges, which will reduce the burst frequency and extend asset life. These operational conditions also allow for better performance of meters at both bulk and customer sides, along with having controlled flow rates toward those areas that are suspected to illegal users of water. Thus pressure management can also have an effect on unauthorized consumption, through reduced illegal consumption and improved meter accuracy.

In its widest sense, pressure management can be defined as the practice of managing system pressures to the optimum levels of service, ensuring sufficient and efficient supply to legitimate users and consumers, while: reducing unnecessary excess pressures, eliminating transients and faulty level controls, all of which cause the distribution system to leak unnecessarily.

The rate of leakage in water distribution systems is a function of the pressure supplied, typically through a combination of pumping infrastructure, storage tanks and gravity. It is proven that there is physical relationship between leak flow rate and pressure and this relationship is detailed in Section 3.5, explaining the theory of N1 and its importance in the planning of any pressure management system. A simplified N1-model is illustrated in Figure 11 below.

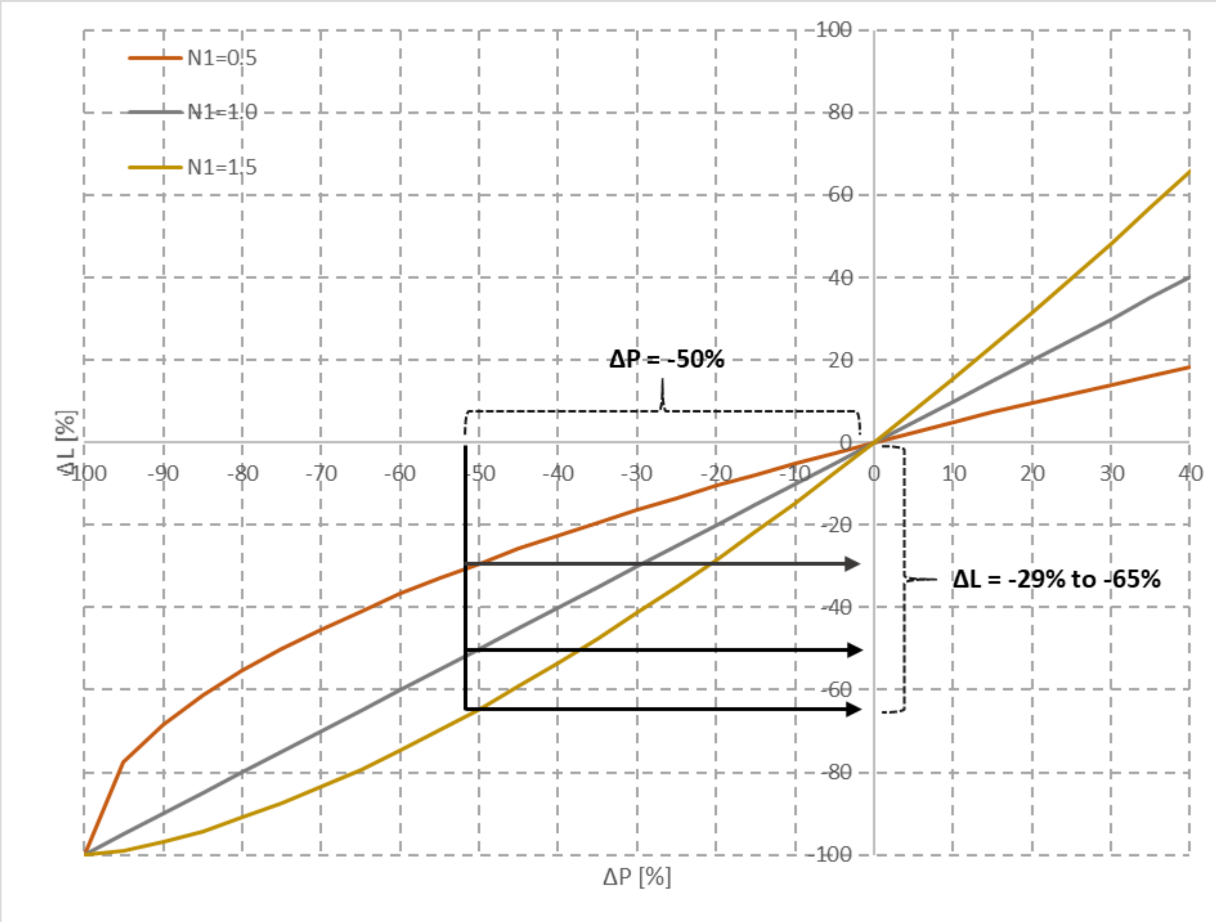


Figure 11 N1-model illustration of the Pressure-Leakage relation.

Figure 11 indicates that a reduction in pressure of 50% will reduce the leakage level by 29-65%. However, when using the N1-model for planning of pressure management the effects of changing the pressure (typically reducing the pressure) on leakage should only be used for relatively small changes of pressure. As the value of N1 in reality depends on the starting pressure, refer to both section 3.5 and Appendix A for details.

DMA management requires good design and planning, starting with a well-established DMA with confirmed hydraulic boundaries, enabling accurate flow and pressure data to be measured. Based on this flow and pressure data, it is possible to estimate how the DMA system pressures can be reduced and thus what reduction on leakage volumes this would have.

In a system with no pressure management, the detection and repair of leaks often results in pressures gradually rising, due to reduce headloss across the network, which will cause new leaks to generate, and therefore, a constant cycle of new leak formation will occur. By implementing a pressure management system, such incidents would be prevented to some extent and pressures stabilized across the water network.

Calibrated hydraulic model are extremely helpful to understand the system pressures and to enable optimization of the water network. These hydraulic models can also provide what/if scenario analysis, where simulation various demand and pressure profiles can be modelled, including the effect of pressure management on intermittent supplies. In these intermittent supply regimes, the models could facilitate understanding of customer tank filling profiles and consumption patterns under the interrupted supply regimes, to fix the gaps that might exist in the current supply and demand management approaches.

There are a number of methods for reducing pressure in the system, including variable speed pump controllers and break pressure tanks. However the most common and cost effective is the automatic pressure reducing valve or PRV. PRVs are instruments that are installed at strategic points in the network to reduce or maintain network pressure at a set level. The valve maintains the pre-set downstream pressure regardless of the upstream pressure or flow-rate fluctuations. PRVs are usually sited within a DMA, next to the flow meter, as shown in the photos below. The PRV should be downstream of the meter so that turbulence from the valve does not affect the meter's accuracy. It is good practice to install the PRV on a bypass pipe to enable future major maintenance works.

As the PRV is feeding into and thus controlling the pressure within a DMA, it is extremely important to have a well-established DMA, by which pressure and flow can be controlled and monitored, and that the DMA is closed and isolated. This is essential, as the method of controlling pressures using a PRV obviously only works if the PRV feeds a closed area and higher pressures cannot feed back through another pipe, which would contradict the effect of the PRV. So each DMA should isolation tested and verified to be closed to ensure pressure management can be efficiently applied.

Another commonly used technique of pressure management is to install pumps with variable frequency drives (VFDs) or variable speed drives (VSDs). These devices control the motor speed or frequency, which can be modified to increase or decrease the outlet pressure of the pump. This type of pump control is frequently used in networks where direct pumping to customers is used. At first, these pumps are controlled on a simple time interval, either automatically or manually by the operator, and outlet pressure is reduced at night when demand is relatively low and increased in the daytime or during peak demand periods. Later, pump outlet pressures can be managed by using advanced monitoring systems and/ or smart networks where operational data is continuously collected and analysed, providing feedback to the pump controllers, such that sufficient pressure supplied as demand requires. Investment in these advanced solutions should be subjected to cost-benefit-analysis to ensure that it is feasible. This should be done over a long lifetime period as often capital costs can be relatively high, but when leakage detection, repair and volumes lost are considered it will prove to be cost effective over the long term.

It is also recommended to phase indifferent levels of pressure management, to reduce initial costs and build up the benefits. For example, at a basic level, eliminating transients and surges, transitioning into continuous supply instead of intermittent, implementing pressure monitoring, and avoiding reservoir overflows. Then at the intermediate level, pressure managed zoning can be formulated, with the development of sub-zones to address elevation issues, and the installation of basic PRVs or variabvle speed pump controllers. Lastly the advanced level can include, time and/ or flow modulation of PRVs and pump controllers, feedback loop from critical nodes, and implementation of smart systems with automatic algorithms.

5.9 Virtual DMAs

Virtual DMAs are analytical constructs and, unlike traditional DMAs, may lack physical hydraulic boundaries. Virtual DMAs are DMAs created exclusively through the installation of flow meters that work by continuously measuring the flow rate and pressure at several points then comparing metered data with known or historical reference values. Virtual DMAs may offer advantages over traditional DMAs because virtual DMAs do not require boundary valve closing and pipe isolation; eliminating potential hydraulic performance, water quality, or energy use issues which may arise from poor planning or site-specific considerations, whilst increasing distribution network resiliency/connectivity as well as operator flexibility. Virtual DMAs, however, lose ancillary benefits DMAs provide such as the quick isolation of drinking water quality incidents.

Virtual DMAs can pose two challenges over traditional DMAs such as the increased propagation of error within measurements, if there are multiple interconnections and data size problem as virtual DMAs, similar to traditional DMAs, require flow rate data within the same time frame to accurately calculate and analyze flow. While DMAs typically have minimal interconnections, this is not necessarily true with virtual DMAs. Problems can arise from temporal data rasterization (the time interval chosen for metering), propagation of error in calculations, and the sheer volume of data needed over traditional DMAs.

6 DMA Establishment

6.1 Proving boundaries

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 Establishing management systems

Once a DMA has been proved, all subsequent work relates to its management, which is 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 and 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. The Night-Day Factor (NDF), or Hour to Day Factor (HDF) has already been discussed in 3.4 and as mentioned 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. 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 daytime.
- 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. Geo-coding of these billing addresses into a GIS map will enable easy automation and updating of this process. 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 a more detailed component analysis of leakage which, when correctly applied, 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. The component analysis as outlined in section 3.4 can overcome these difficulties, and 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.

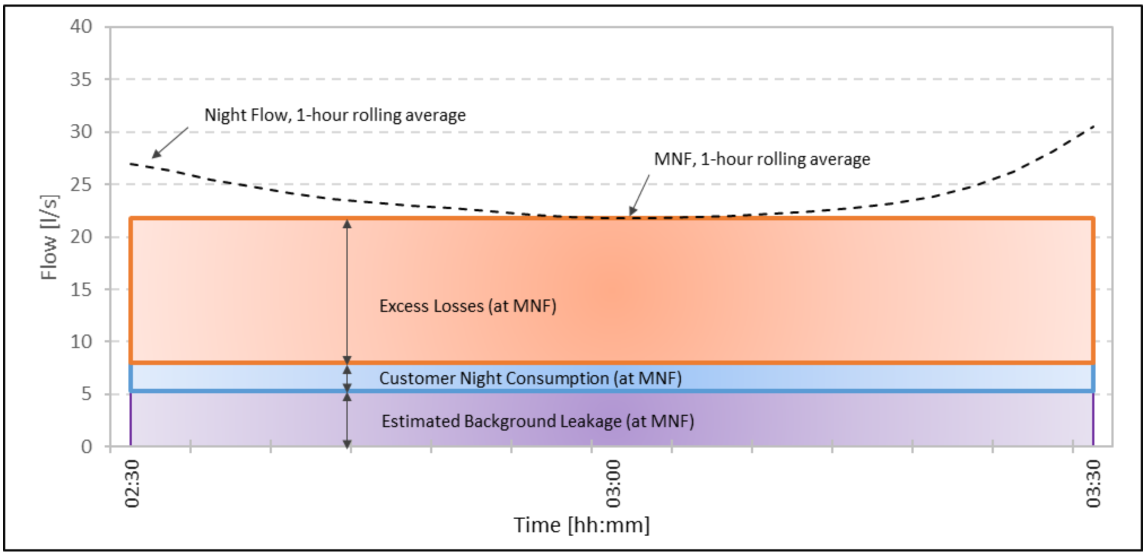


Figure 12 Analysis and quantification of excess losses in a DMA.

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 component analysis, section 3.4, can appear data hungry, the initial application can be simplified by using initial default values until more accurate data is gathered.

Data to establish customer night use comprises the following:

- Population.
- Number of households (i.e. houses and individual flats in buildings etc).
- Number of non-household properties.
- Details of internal plumbing practise.
- Identification of non-households estimated to have night flow above 0.5 m^3/h classed as Exceptional Night Users´.
- Further details of non-household 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.

6.9 Problematic DMAs

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.

6.9.1 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 to 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.

Step	Action	Comments
1	Check internal consistency of metering results.	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. The method by which meter readings are added to give a total flow into the DMA should also be checked.
2	Check basic DMA data.	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.
3	Check leakage calculation.	Using the re-checked DMA data, and the re-checked night flow information, the excess night flow calculation should be re-performed independently of the normal leakage calculation software or system.
4	Check on metering errors.	If the DMA has several metered imports and exports then a calculation of the total metering error would be useful. If the total metering error, using a ± 5 % error, would account for the excess leakage, then consideration should be given to either: 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.
5	Check boundary valves.	Boundary valves should be checked in the same way as they would be checked when setting up a new DMA.
6	Perform pressure zero test.	A pressure zero test should be performed to ensure that no unknown connections exist that breach the DMA boundary.

Step	Action	Comments
7	Short interval flow logging.	Use a short-interval flow logging technique to calculate the time-variable night use. This may show that night use is higher (or lower) than assumed.
8	Verify meter accuracy.	Some of the import or export meters to a DMA may have flows that are verifiable indirectly using other meters or combinations of meters. However, there may be others where no verification is possible. In this case, some verification of flows should be carried out. Verification could consist of replacement of the meter. After the meter is replaced, the new meter results should be used for a new leakage calculation. Another method may be the use of an insertion meter downstream of the existing meter, and comparing the flows recorded. Night-flows could be checked to ensure that no mechanical meters stall at minimum flow. If a stalling meter is an export, this could lead to apparent high leakage. The installation could be checked against manufacturers' recommendations. This includes the required length of straight pipe up and downstream, and situations where jetting could occur. The installation could also be checked for foreign bodies.
9	Illegal use.	If the DMA contains metered non-households, which could potentially use large volumes of water, a survey of these may find some illegal use.
10	Repairs.	Check that repairs to reported leaks and bursts have been carried out.
11	Reconsider night use allowances.	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. 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.

Table 1 Action to ensure that estimated leakage is true.

If the leakage level is shown to be correct, then it is necessary to assess 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.

6.9.2 Very low leakage

If DMAs have very low leakage (much lower than would be expected for a DMA with its characteristics: see section 3.4.2 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 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.

6.9.3 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.

6.9.4 Problematic DMA Troubleshooting

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.

Step	Outcome	Further actions
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 length of main with high night-flow losses.	Further investigation of night use in step. Investigate pressure reduction. Consider service and/or mains replacement.

Table 2 Results and outcomes of leak repair.

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.

7 Glossary

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

Awareness, Location and Repair (ALR). The time taken to become aware of, locate and repair a leak.

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 affected 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 well-defined metered area within the distribution network where flow balance can be monitored. The acronym stands for District Metered Area.

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 can vary widely depending on the daily profile of average zone pressure and the pressure - leak flow relationship.

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: $L_1 = L_0 \cdot PCF$ 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 a reference pressure 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 (NDF)

A power law equation with an exponent N1 is a simplified version of the more hydraulically correct Fixed And Variable Area Discharge (FAVAD) concept. N1 is widely used for practical calculations to relate leak flow rate to average zone pressure AZP in DMAs by using the following relation between leak flow rate (L) and average zone pressure (AZP):

$$L = C \cdot AZP^{N1}$$

Where C is assumed constant and N1 can vary between 0.50 (for 100% Fixed Area leaks) and 1.50 (for 100% Variable Area leaks) in the DMA. Values of N1 up to 2.5 may be observed under special conditions e.g. if the majority of the leaks are located at locations with pressures higher than the average zone pressure'.

An NDF calculation for a DMA ideally requires hourly inflow and pressure at the average zone pressure point to be recorded continuously over a period of e.g. 7 days, whereby:

- Corresponding values of Minimum Night Flow (MNF) and Average Zone Night Pressure (AZNP) can be assessed.
- Estimation of Legitimate Night Consumption (LNC) can be subtracted from the MNF leaving only the leakage flow during the time of MNF (L_{MNF}).
- Corresponding values of L_{MNF} and AZNP can be used to estimate N1.
- Hourly values of AZP can be used to calculate the leakage flow (L) for every hour of the day, summarizing to the total daily leakage flow (L_{Day}).
- NDF can be calculated as L_{Day}/L_{MNF}.

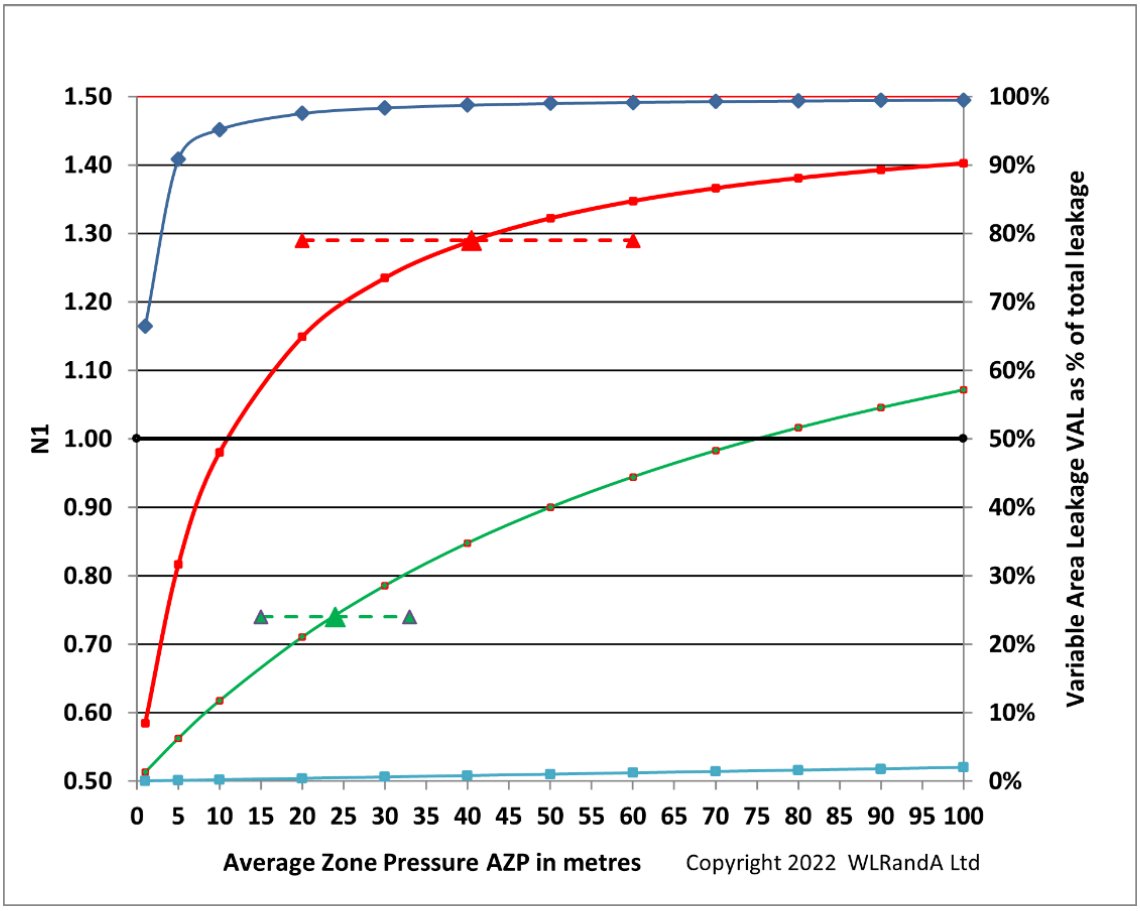
Note that, if N1 is assumed to be 1.0, which is often applied as a first approach, then NDF = 24 · AZP_{Avg}/AZPN.

NDFs within 24 ±10% are frequently derived for DMAs with a limited range of pressure variation, typically AZP_{Avg}/AZNP ratios between 0.9 to 1.1. However, as 24-hour pressure profiles of the AZP can vary on different days of the week, and seasonally, and with different types of pressure management and pumping regimes, the NDF can vary very widely both within and between DMAs. NDFs between around 10 to 80 are possible in the wide diversity of international DMAs.

Interpreting N1 night test values using the full FAVAD concept

The figure below shows two N1 field test results for different DMAs:

- Red triangle: an N1 of 1.29 (left-hand axis) with implied 79% variable area leakage (right-hand axis) at AZNP = 40.5 mwc.
- Green triangle: an N1 of 0.73 with implied 23% variable leakage at 25 mwc.



The general practice since 1995 has been to assume that the N1 in a DMA does not vary with pressure. That is reasonably true for extreme high and low N1 values in the topmost blue curve (N1 = 1.49, 99% variable area leaks) and the lowest blue curve (N1 = 0.55, 95% fixed area leaks).

The red and green curves, derived from full Fixed And Variable Area Discharge (FAVAD) analyses, show how N1 from the two night-test results will vary with pressure. Each test result represents a point on a unique curve for that DMA for its combination of leakage paths at that time. As the AZP changes during the day, the N1 exponent and the percentage of variable leakage will also change. For any intermediate curve such as the red and green examples, N1 is only approximately constant over a quite limited pressure range, particularly at lower pressures.

An assumption that N1 is fixed at the value generated from minimum night flow analysis for a wide range of pressures, as shown by the dashed red and green horizontal lines, will:

- overestimate N1 and overestimate the predicted reduction in leak flow rate for pressures lower than the average N1 from the MNF test, and
- underestimate the N1 and underestimate the predicted increase in leak flow rate for pressures higher than the average N1 from the MNF test.

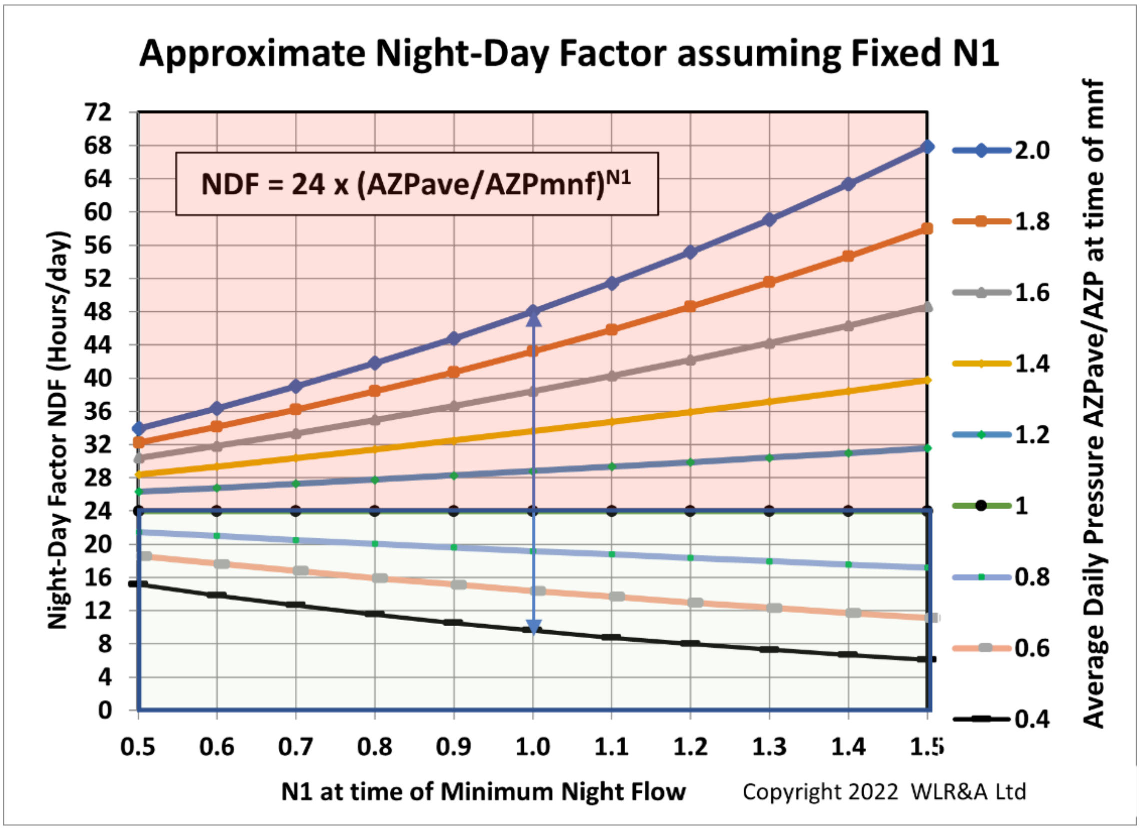
These conclusions would also apply for any assumption of a fixed N1 independent of pressure, whether it be 1.00, 1.15 or any other value between 0.5 and 1.5.

Estimating range of errors when using fixed N1 = 1.00

The figure below shows the approximate range of errors which can occur when using fixed N1 values to calculate NDF, if the simplified equation is used:

$$NDF = 24 \cdot \left(\frac{AZP_{Avg}}{AZNP}\right)^{N1}$$

International $AZP_{Avg}/AZNP$ ratios for DMAs ranging from 0.4 to 2.0 are shown on the vertical axis on the right, both higher and lower values are possible.



In the orange area, where $AZP_{Avg}/AZNP$ ratios exceed 1.0, NDF for an assumed fixed N1 = 1.0 ranges from 24 to 48, shown by the blue vertical arrow:

- If the actual N1 is 0.50, the range of NDFs would be 24 to 34.
- If the actual N1 is 1.50, the range would be 24 to 68.

In the green area, where $AZP_{Avg}/AZNP$ ratios are less than 1.0, NDF for an assumed fixed N1 = 1.0 ranges from 10 to 24, see blue vertical arrow:

- If the actual N1 is 0.50, the range of NDFs would be 15 to 24.
- If the actual N1 is 1.50, the range of NDFs would be 6 to 24.

These are very large levels of uncertainty. Also, a full FAVAD analysis shows that the figure tends to slightly underestimate the range of NDFs for mid-range N1 values derived from MNF analysis.

Two important questions can now be answered:

1. Do large uncertainty limits apply to the initial assumption that a fixed N1 = 1.00 and NDF = 24 · AZP_{Avg}/AZPN? - The answer is clearly 'Yes'.
2. Is a night test always recommended to assess the N1 at the average zone night pressure, and the N1 versus AZP relationship? – The answer is, If the ratio of AZP_{Avg}/AZPN is within the range 0.90 to 1.10, an assessed NDF of 24 is likely to be within around 10% of the actual value. Otherwise, N1 tests are recommended.

The optimum solution for assessing NDFs requires occasional night tests to calculate N1 at the time of MNF, using strict protocols and quality control to ensure reliable pairs of values for N1 at specified Average Zone Night Pressure AZNP:

- Carry out a successful pressure-zero test.
- Ensure average zone pressures are measured and used for the analysis.
- Ensure average zone pressures and night consumption have stabilised before starting tests.
- Always calculate N1 based on reductions of pressure, not on increases.
- Don't over-estimate customer night consumption.

The corresponding N1 and AZNP are then used with FAVAD concept to predict the changing N1 and leak flow rate for each hourly value of AZP, with calculations using both offline and online software. This enables real-time zone inflows to be split between consumption and leakage, and total daily leakage and NDF to be calculated independently (Leakssuite Library, 2022).

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Appendix B - Estimating Average Zone Night Pressure

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 zone pressure (AZP) 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 or pipelength weighted average.

An approach used by one utility to determine AZNP in some 3,000 DMAs was to initially obtain best estimates from local staff and then to gradually improve this estimate using its geographic information system (GIS) to determine the average ground level of the connections in a particular DMA and to then determine the typical pressure (above ground level) 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: Multi-pressure DMA

Consider a DMA consisting of three pressure zones:

- *Pressure zone 1: 500 connections at AZNP of 30 mwc.*
- *Pressure zone 2: 200 connections at AZNP of 70 mwc.*
- *Pressure zone 3: 700 connections at AZNP of 45 mwc.*

Then the average zone night pressure for the entire DMA is estimated as:

$$AZNP(DMA) = \frac{500 \cdot 30 + 200 \cdot 70 + 700 \cdot 45}{30 + 70 + 45}\ mwc = 43.2\, mwc$$

It should be noted that to estimate the AZP/AZNP depends as well as determining proper locations for monitoring of AZP in a robust manner require great care and skill as well as knowledge of local conditions and operation.

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.

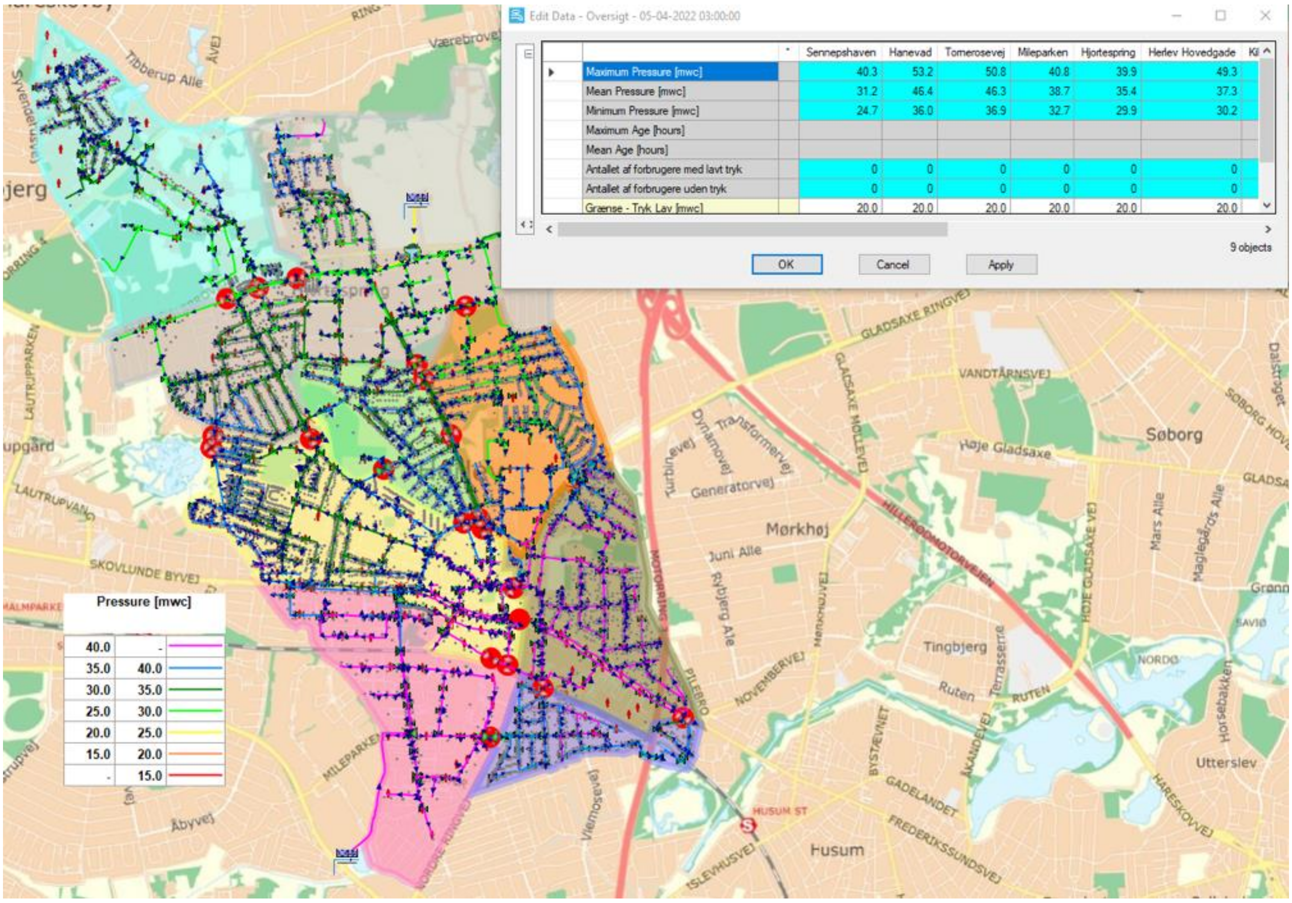
In situations where seasonal variations in pressure are experienced and considered to be significant it may be necessary to undertake pressure logging over a longer period of time to estimate the effect of seasonal variations.

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.

Example: Using a hydraulic model

The city of Herlev under HOFOR (Greater Copenhagen Water Utility) has established a calibrated hydraulic model with interface to SCADA, allowing to conduct simulations using historical data from the SCADA database.

The figure below shows the results of a 24-hour simulation for April 5th, 2022, with 1-hour timesteps where the output of the model automatically calculate the average pressure (weithted by pipeline length), inside each DMA configured, at the time of Minimum Night Flow (03:00-04:00).



Note that the model also automatically identifies and reports the minimum node pressure and the maximum node pressure inside the DMA during the same hour.

Having access to historical data for such use also allows for analysing and considering seasonal variations etc.

For more details and background refer to the detailed guide for good practice for assessment of the average zone pressure point and the average zone pressure:

www.leakssuitelibrary.com/average-zone-point/

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

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.

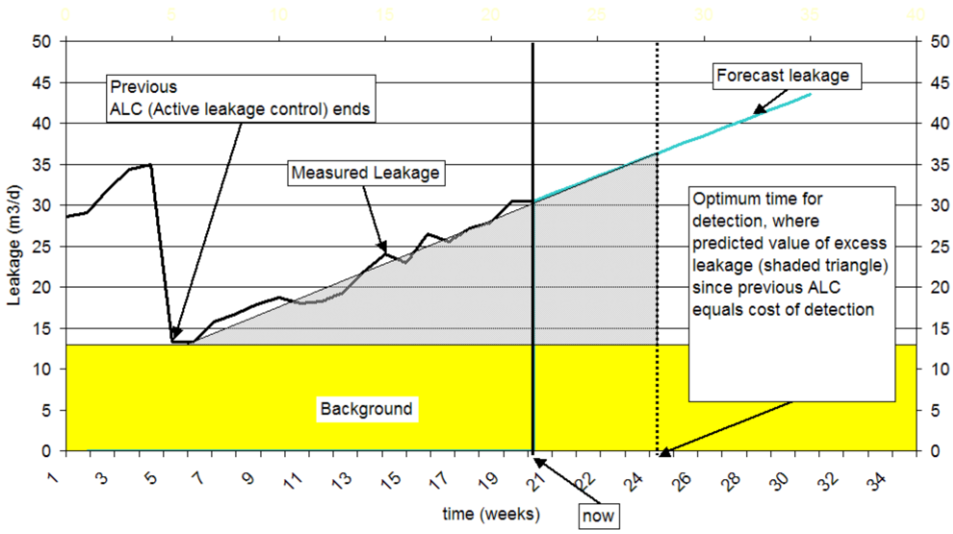
The data required for each DMA is as follows:

- 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 below:



For more details and background refer to the paper:

Using practical predictions of Economic Intervention Frequency to calculate Short-run Economic Leakage Level, with or without Pressure Management

Which can be downloaded for free at:

www.leakssuitelibrary.com/wp-ontent/uploads/2020/11/LambertLalondeHalifaxSep2005.pdf

Appendix D: Night Consumption Estimation: UK Experience

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 the calculation:

$$[House\ hold\ night\ use] = [Number\ of\ households] \cdot [Rate\ of\ household\ night\ use]$$

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 l/property/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 l/property/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:

$$[Non-household\ night\ use] = [Number\ of\ Non-housholds] \cdot 8\ \ l/h$$

The value of 8 l/h per non-household has recently been updated by one UK Company to 10 l/h per non-household 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 users:

$$[Non - household\ night\ use] = \sum_{i=A}^{E} [Number\ of\ non - households]_i \cdot [Category\ night\ use]_i$$

Where the categories, and their night use allowances are shown as listed in the table below:

Category	Category Name	Night use allowance [l/h/non-household]
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	Senior 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 - Examples of successful DMA implementation

The examples set out here outline selected representative projects that have successfully implemented DMAs in 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 Specialist Group as best practice*.

El Dorado Irrigation District , California, USA

	Description of the project
1	A brief description of the location
	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. *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 months from start of DMA design until the DMA was operational.*
2	The level of real losses before and after installing DMAs
	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	Supply arrangements for typical households.
	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.
	Design
4	What influenced the design of individual DMAs?
	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	Was pressure management considered at the design stage?
	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	The methods used for design.

	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 analysed 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.
7	Was a hierarchy of metered zones used?
	N/A
8	How was the integrity of the boundary tested?
	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	How were the boundaries of DMAs defined and managed?
	The DMA boundaries were existing, with significant physical separations due to topography, different pressure zones, and dead-end lines.
10	Do the new boundaries include flushing facilities?
	No new boundaries were established, and the existing boundaries included blow-offs for manual flushing as needed.
11	Are any systems in place to ensure boundary valve operation is recorded?
	N/A
12	How were meters selected.
	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	Describe a typical meter installation.

	  *Picture 1: Pressure regulation station.* *Picture 2: Metering PRV on bypass.* *The lead 150mm PRV on the right in Picture 1 was converted into the metering PRV shown in Picture 2. The installation is underground and includes the isolation gate valves.*
14	How were night use allowances calculated for use in assessing leakage levels (if any).
	Based on the billing data base, 4 types of customers have been identified in the DMA. For each type of customer, a representative sample of meters was read during the MNF test in order to calculate the total MNF consumption.
	DMAs in use
15	How is flow data collected from typical DMA?
	The flow and pressure data (upstream and downstream pressure) at the inflow PRV and the average and critical pressure of the DMA are logged at 5-minute intervals and stored by loggers. These loggers are manually downloaded on a monthly basis and the data is then analysed.
16	How is flow data checked to ensure that it is valid?
	As the flow meter is new, no third-party test on the flow meter has been undertaken so far.
17	Describe how the flow data is interpreted to assess the level of losses.
	The level of losses in the DMA is assessed based on MNF measurements which are supported by minimum night consumption readings. No water balance is used.
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 were selected as a result.
	N/A
19	What happens when DMAs are investigated by leakage control teams but the leakage is not reduced?
	N/A

20	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.
	N/A
21	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.
	Other uses of the DMA for the purpose of the AwwaRF study are the assessment of the ICF after repeated leak detection and repair campaigns and the monitoring of the natural rise of leakage.
	Other aspects
22	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.
	N/A

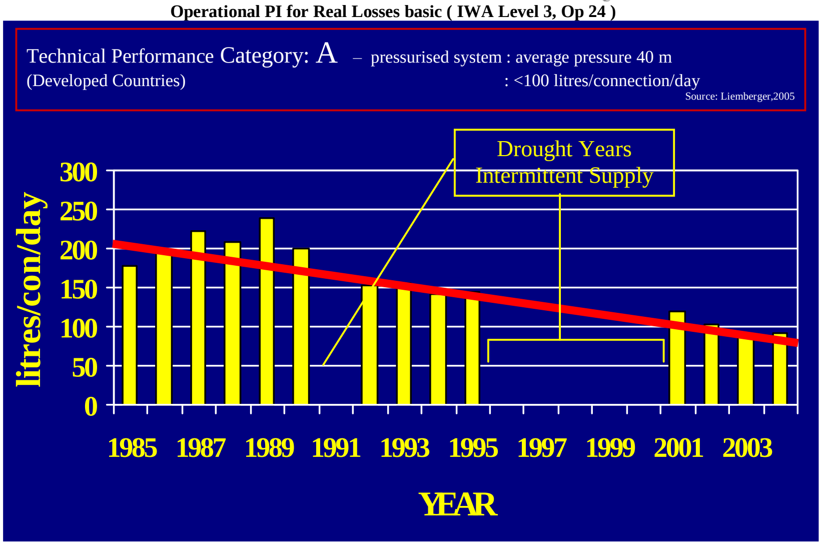
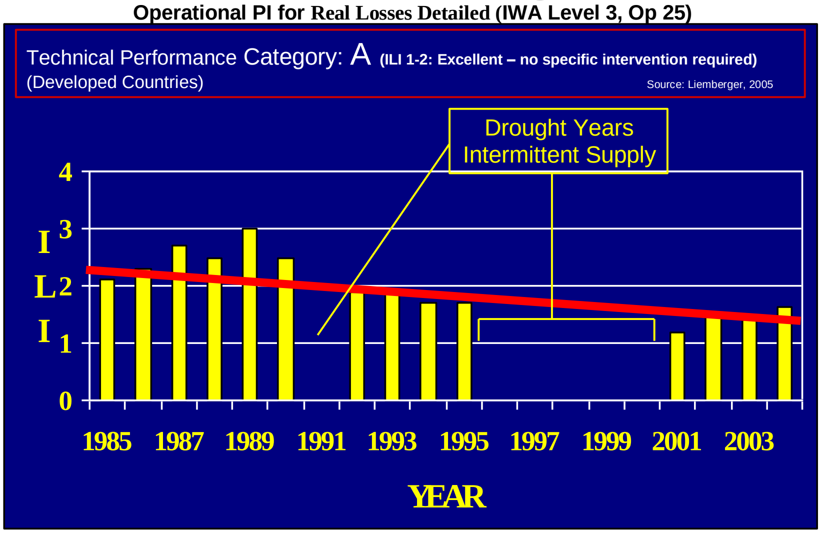
Name of contributor: Reinhard Sturm

Organisation: WSO

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

	Description of the project
1	A brief description of the location.
	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. *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.* *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.* *Today the Water Board covers an area of about 100 km^2 with approximately 800 km of underground mains, with approximately 70,000 registered consumers and annual water production of 13 MCM.*
2	What was the level of real losses before and after installing DMAs?

	Litres/service connection/day Operational PI for Real Losses basic (IWA Level 3, Op 24)  **Infrastructure Leakage Index** Operational PI for Real Losses Detailed (IWA Level 3, Op 25) 
3	Briefly describe the supply arrangements for typical households:
	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 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.
	Design
4	What influenced the design of individual DMAs?

	The following key factors formed the basis of the DMA design: • *Size of the DMA.* • *Minimum variation in ground level across the DMA.* • *Easily identified boundaries that are robust.* • *Area meters correctly sized and located.* • *Single entry point into the DMA.* • *Discrete DMA boundaries.* • *Pressure optimised to maintain standard of service to customers.* • *Degree of difficulty in working in urban area.* *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.*
5	Was pressure management considered at the design stage?
	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. *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 effected.*
6	The methods used for design.
	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.
7	Was a hierarchy of metered zones used?
	All DMAs were designed to function independently with a single point of entry which is metered.
8	How was the integrity of the boundary tested?

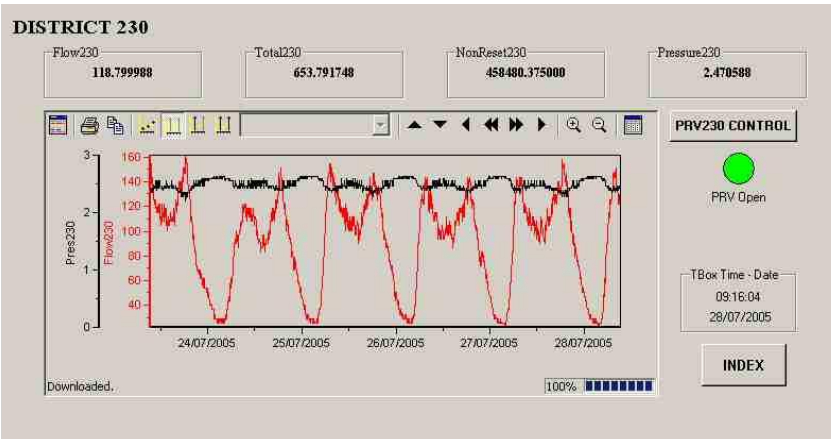
	In order to verify that all interconnecting pipes between DMAs were located and isolated a zero pressure test was carried out which involved closing the valve at the inlet to the DMA thus isolating the DMA and observing that the pressure within the DMA dropped immediately indicating that all interconnecting pipes were isolated. This test was usually carried out between 02:00 and 04:00 in the morning in order not to inconvenience consumers.
9	How were the boundaries of DMAs defined and managed?
	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.
10	Do the new boundaries include flushing facilities?
	Where possible dead ends are avoided for water quality reasons. If this is not possible flushing facilities are provided at these points.
11	Are any systems in place to ensure boundary valve operation is recorded?
	There are no boundary valves. The policy of the Water Board is to have pipe work discontinuity.
12	How were meters selected. This includes both the type of meter and the size selected.
	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 m³/hr. Most DMAs required a 100mm nominal diameter meter with the larger size DMAs needing a 150mm nominal diameter.
13	Describe a typical meter installation.
	
14	How were night use allowances calculated for use in assessing leakage levels (if any)
	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).

<table>
<tr><td></td><td>DMAs in use</td></tr>
<tr><td>15</td><td>How is flow data collected from typical DMA?</td></tr>
<tr><td></td><td>

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:

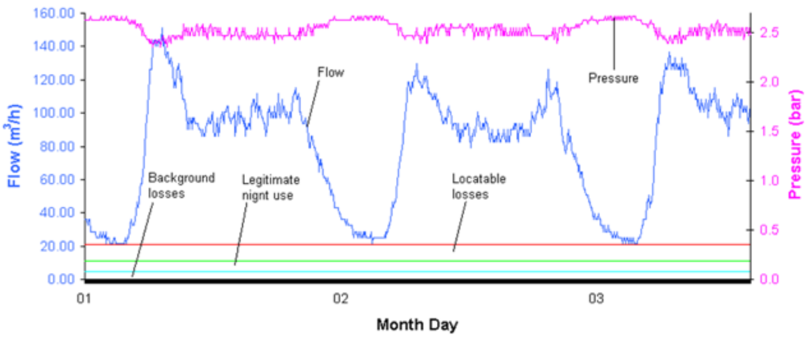
- *Data logging of flow and pressure.*
- *Control (open-close) of PRV.*
- *Communication with the control room at Water Board's offices via a PSTN line, GSM, radio or landline.*

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 here:



</td></tr>
<tr><td>16</td><td>How is flow data checked to ensure that it is valid?</td></tr>
</table>

<table>
<tr><td></td><td>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 here:


</td></tr>
<tr><td>17</td><td>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?</td></tr>
<tr><td></td><td>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 to the assumptions made in both approaches until the level of real losses is the same using both methods.</td></tr>
<tr><td>18</td><td>Describe the process by which decisions are made on which DMAs are investigated by leakage control teams.</td></tr>
</table>

	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 DMAs it is considered uneconomical to investigate for locatable losses as the level of these is below one equivalent pipe burst:

DMA	Actual MNF (m^3/hr)	Background Losses (m^3/hr)	Legitimate Night Use (m^3/hr)	Locatable Losses (m^3/hr)
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	**3.99**
226	6.84	2.55	4.05	0.24
227	10.44	3.38	5.50	**2.56**
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	**6.54**
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

19	What happens when DMAs are investigated by leakage control teams, but the leakage is not reduced?
	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.
20	Describe maintenance processes.
	Data collection is continuous for both flows and pressures through the on-line monitoring. *The following activities are carried out at regular intervals:* • *Checking and cleaning of area water meter strainers every six months.* • *Checking and adjusting if required PRV settings every six months.*
21	Describe the other uses that you put DMAs to.
	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.

	Other aspects
22	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
	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.

Name of contributor: Bambos Charalambous

Organisation: Water Board of Lemesos, Cyprus

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

	Description of the project
1	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.
	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. *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.* *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 &114 m AOD.* *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.* *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.*
2	What was the level of real losses before and after installing DMAs in any or all of the following units: m^3/y, l/connection/day, l/connection/day/mwc, ILI.
	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
3	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.
	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.
	Design

4	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, firefighting; insurance; reliability of supply; maintaining similar pressure (available head) across the whole DMA to facilitate pressure management etc.
	The design of the DMAs was governed by the topography, water quality and the existing network configuration.
5	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?
	Due to the topography, pressure management short term and long term was integrated into the design of the DMAs. The initial opportunities to pressure management 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 maintained 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
6	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.
	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.
7	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?
	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.
8	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.
	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.
9	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?

	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.
10	Do the new boundaries include flushing facilities?
	Where necessary flushing facilities were located by closed valves.
11	Are any systems in place to ensure boundary valve operation is recorded?
	Initial management of the closed valves in the initial period required considerable effort but once the DMA configuration had been established closed valves were recorded on mapping system and requirement to complete status reports if the valves were operated.
12	How were meters were selected. This includes both the type of meter and the size selected.
	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.
13	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.
	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.
14	How were night use allowances calculated for use in assessing leakage levels (if any)?
	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.
	DMAs in use
15	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?
	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.
16	How is flow data checked to ensure that it is valid?
	Comparison against previous flow patterns and checks on adjacent DMA flows.
17	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?

	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.
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 were selected as a result.
	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.
19	What happens when DMAs are investigated by leakage control teams, but the leakage is not reduced?
	If the predicted level of leakage cannot be achieved by a significant level, additional checks are undertaken to ensure boundary integrity, exceptional night users and finally if appropriate a noise logging survey is undertaken.
20	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.
	Data is retrieved daily, and pressure-reducing valves are maintained annually.
21	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.
	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.
	Other aspects
22	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.
	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.

Name of contributor: J A E Morrison

Organisation: on behalf of Dwr Cymru Welsh Water

Johor, Malaysia

Description of the project

	Description of the project
1	A brief description of the location
	Johor is the southernmost state in Peninsular Malaysia. Its water operator, Ranhill SAJ, supplies potable water to 3.8 million population through 1.2 million accounts and 23,000 km of pipeline. *Ranhill Water Services (RWS) has been contracted by Ranhill SAJ to conduct NRW reduction works in Johor since 2005 and has managed to reduce the NRW for the state from 37% down to 24%. The holistic NRW program in Johor covers physical and commercial losses within the selected DMAs.*
2	What was the level of real losses before and after installing DMAs?
	Real losses in DMAs were monitored using Net Night Flow (NNF). Every DMA meter point is equipped with an electromagnetic flow meter, GPRS logger and pressure gauge. Each newly established DMA must contain no more than 20% of real losses before it can be approved for commissions. Thus, RWS is responsible to conduct leak reduction works from the very beginning of the DMA design stage.
3	Briefly describe the supply arrangements for typical households:
	Most of households are equipped with their own elevated storage tank with a minimum capacity of 0.5 m³. A typical residential house will only have two direct supply point; for kitchen tap and storage tank. All consumers are metered, and meter readings are made monthly. All consumers enjoy 24-hour continuous supply with minimum required supply pressure of 10m head.
	Design
4	What influenced the design of individual DMAs?
	Consideration in designing a DMA : • Connection between 500 to 1500 nos. • Single feeder. • Maintaining minimum head at critical point. • Continuous supply of water. • Boundary valve can be located and closed. • Available valves for step testing or to install new.
5	Was pressure management considered at the design stage?

	Prior to establishing DMAs, RWS will undertake pressure survey for the identified zones. The activities to be undertaken consist of the following but not limited to: • *Recording at least 24 hours pressure at highest area, lowest area and farthest area within that particular DMA.* • *Recording at least 24 hours pressure at every route within DMA.* • *Calculate and updating a value of "T-factor" in DMA manual* *The difference between maximum and minimum pressure within the DMA shall be kept as minimum as possible. Should pressure management devices are needed (standard or advanced) it will be stated in the proposal.*
6	The methods used for design.
	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.*
7	Was a hierarchy of metered zones used?
	For DMA with more than 1500 connections, sub-DMAs will be considered.
8	How was the integrity of the boundary tested?
	Existing valves will be used as boundary valves in order to isolate the NRW zone and create a 'single inlet'. Additional boundary valves will be installed if necessary. *A Zero Pressure Test (ZPT) will then be undertaken in order to verify the single inlet. The pressure shall drop to zero when the inlet valve to the DMA is closed.*
9	How were the boundaries of DMAs defined and managed?
	1. *Easily visible topographic features that can serve as boundaries for the DMA, such as rivers, drainage channels, railroads, highways, etc.* 2. *Permanent closed valves to isolate DMA according to desired DMA size (pipe length/connection).*
10	Do the new boundaries include flushing facilities?
	Scour valves are usually available at every pipe end.
11	Are any systems in place to ensure boundary valve operation is recorded?

	Each boundary valve is clearly marked in schematic and GIS drawings. In addition, its chamber will be painted in red colour to avoid confusion. The boundary valves shall remain closed all the time. *However, in certain emergency cases, boundary valve is allowed to be throttled. If this happens, the responsible person shall inform to Info Centre (SAJIC) and keep updating the condition until the valve is closed as its original condition.*
12	How were meters selected. This includes both the type of meter and the size selected.
	Electromagnetic flow meters were selected to be used for flow measurement. 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 more reliable and effective data capturing. Electromagnetic flow meter has been proven to be hassle free maintenance for the past decade since it was installed in Johor 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.*
13	Describe a typical meter installation.
	As electromagnetic meter is maintenance free, it can be either buried underground or installed above ground, depending on the site condition. Meter is installed in line with the pipe with one side connected using flange adaptor. Strainer is not required as the meter is usually full bore.
14	How were night use allowances calculated for use in assessing leakage levels (if any).
	RWS has its own online monitoring platform called AquaSMART. The system collects live data from site, analyses them and display the data in simplified but meaningful format. This operational tool can be access by both operational and management personnel and covers from production meters up to customer meters. *One of the modules in AquaSMART is DMA Monitoring. In this module, information collected from DMA meter are analysed and displayed into interactive and meaningful tables and graphs. Technician will be notified when night use in certain DMA reaches the pre-set threshold and proper actions will be taken immediately.* *In Johor, every minor leak shall be attended to within 36 hours while major leak/burst shall be attended in not more than 18 hours.*
	DMAs in use
15	How is flow data collected from typical DMA?
	Flow data is collected by data logger attached to every DMA meter. The data will then be sent to AquaSMART server through GPRS/4G.
16	How is flow data checked to ensure that it is valid?
	Data sent to AquaSMART will be analysed before being displayed. Invalid data will be labelled in grey colour and sent to response team for further investigation.

17	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?
	Both flow and billing data are used to produce the IWA water balance for each DMA. *NNF is used to calculate the real losses and compared with the result in water balance for verification.*
18	Describe the process by which decisions are made on which DMAs are investigated by leakage control teams.
	A baseline is set for each DMA every two years at the beginning of contract. RWS is required to reduce the DMA leakage by certain amount within the contract period. One of the methods to do reduction is tight monitoring of daily NNF. Certain parameter is set in AquaSMART which will categorise each DMA into coloured priority; red, orange, blue, light green, green and grey. Each colour represents the DMA condition and required action to be taken.
19	What happens when DMAs are investigated by leakage control teams, but the leakage is not reduced?
	1. *To verify DMA data.* 2. *Prove DMA boundaries.* 3. *Prioritise problematic step.* 4. *Deploy electronic equipment.* 5. *Investigate probabilities of commercial loss.*
20	Describe maintenance processes.
	1. *Report from AquaSMART.* 2. *Desktop verification.* 3. *Site investigation when necessary.* 4. *Troubleshoot.*
21	Describe the other uses that you put DMAs to.
	Other Issues.
22	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.

Name of contributor: Muhammad Redha Md Hatta

Organisation: on behalf of Ranhill SAJ

Halifax Regional Water Commission

	Description of the project
1	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.
	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
2	What was the level of real losses before and after installing DMAs in any or all of the following units: m^3/y, l/connection/day, l/connection/day/mwc, ILI.
	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.
3	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.
	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.
	Design
4	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, firefighting; insurance; reliability of supply; maintaining similar pressure (available head) across the whole DMA to facilitate pressure management etc.
	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.
5	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?

	We have just begun implementing flow modulated pressure management and will continue to apply it on a DMA by DMA basis considering Infrastructure Condition Factor, re-break history, average pressure within the DMA, and cost to implement.
6	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.
	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.
7	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?
	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.
8	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 methods.
	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.
9	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?
	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.
10	Do the new boundaries include flushing facilities?
	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.
11	Are any systems in place to ensure boundary valve operation is recorded?
	All systems valves are checked and operated as part of a valve maintenance program; however, boundary valves are checked but not operated.
12	How were meters were selected. This includes both the type of meter and the size selected.

	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, meters must be capable of interfacing with the HRWC SCADA system using either a pulse output or a digital protocol. *Accuracy is a concern with all meters and when required, the meters are field calibrated.*
13	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.
	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.
14	How were night use allowances calculated for use in assessing leakage levels (if any)

Data Entry	Defaults	Calculated values

Standard Parameters for Assessed Night Consumption

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

DMAs in use

15	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?
	DMA meters are polled by our SCADA system at intervals that range from 45-90 seconds. The values are logged in a data historian every minute. In almost all cases, both pressure and flow are recorded.
16	How is flow data checked to ensure that it is valid?
	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.
17	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?
	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.
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 were selected as a result.
	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.
19	What happens when DMAs are investigated by leakage control teams, but the leakage is not reduced?
	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.
20	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.
	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.

21	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.
	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.
	Other aspects
22	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.
	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.

Name of contributor: Graham MacDonald

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

EPAL, Lisbon, Portugal

	Description of the project
1	A brief description of the location
	This case study relates to the City of Lisbon distribution network, which receives treated water via EPAL's bulk supply network from the principal water source at Castelo de Bode, some 120 kilometres north of the capital city of Portugal. The distribution network encompasses around 1.450 kilometres of mains, divided into five pressure zones and supplying in excess of 355.000 clients. *The basis of leakage reduction measures implemented within the Lisbon distribution network is the segmentation of the system into permanently monitored DMAs and equipping of larger consumers with telemetry, in order to assess and quantify potential water losses per sub-zone. This approach benefits considerably from the existence of a reliable and accurate GIS system and universal client metering, whilst DMA interventions are focused not only on real losses through leakage, but also apparent losses such as illegal or unmetered connections and stopped meters. Company policy is to repair every leak identified through active leakage control activities.*
2	What was the level of real losses before and after installing DMAs?
	Approximately 500 l/con/day during the baseline year of 2005, reduced to less than 150 l/con/day and maintained at this level for more a decade
3	Briefly describe the supply arrangements for typical households:
	Every client has a meter for billing purposes and no storage tanks are not used for domestic services. There is a legal requirement for supply pressure at the point of delivery to range from 30 meters to 60 meters, with an average of 51 meters across the whole distribution network. The entire Lisbon distribution network is divided into five pressure zones, reflecting the topography of the city and requirement for each zone to be pumped separately. Due to the hilly terrain of the city of Lisbon, there are sections of the network with excessive pressure and therefore around 30 DMAs or sub-zones (10% network coverage) are equipped with a PRV.
	Design
4	What influenced the design of individual DMAs?

	The design of the DMAs was influenced by several factors; • *The need to maintain the five existing pressure control zone boundaries.* • *DMA size in terms of network length (average 8km of mains with most ranging between 5 and 12km), number of clients (an average of 2.200) and projected net daily consumption not exceeding 1.200 to 1.500 m3/day (balance of DMA entrance/exit meters minus large consumers equipped with telemetry systems)* • *Easily identified, discrete DMA boundaries using existing section valves where possible and limiting the length of sections without consumption/hydrants/discharge valves either side of closed valves, especially in areas with cast irons mains.* • *Limit the number of boundary valves to close* • *DMA meters which can be correctly sized and located at optimal points* • *Preference for single entry point into the DMA, but also unidirectional cascade DMAs and bi-directional DMAs where required due to DMA size and operational considerations, such as varying pumping station origins* • *Pressure optimisation to maintain standard of existing service to customers, raising minimum pressure/reducing maximum pressure where required, whilst also minimising daily fluctuations*
5	Was pressure management considered at the design stage?
	The Lisbon distribution system is a fully pumped network, divided into five pressure zones, at approximately 30 metre incremental height intervals, each with separate pumping elevation to maintain minimum/maximum service pressure requirements. Given the undulating topography of the city, this results in most DMAs having critical supply points which negate the possibility of installing pressure reducing valves (PRVs) to control pressure across the entire DMA. Whilst a relatively small number of PRVs have been installed, given their widely acknowledged benefits in terms of reducing water losses, burst frequency and increasing infrastructure lifecycle, these are restricted to DMAs where the critical supply point has sufficient margin to allow pressure reduction or small sub-zones of DMAs where a clear excess of pressure exists. *Given the excellent overall performance level of the network in terms of water losses, the costs and difficulties of installing and maintaining additional PRVs to sub-divided existing DMAs has been determined as not financially viable under present conditions. However, the issue is subject to regular review and should conditions change, such as an increase in treated water costs or increased burst frequency which impacts on service quality, then policy may be reconsidered.*
6	The methods used for design.
	The initial GIS information available was incomplete, but a parallel upgrade of the system and update of the data contained was essential for the planning process. Overall, the topography and trunk mains network readily determined DMA layouts. Outline network analysis was completed to determine the broad sectorisation of the area into DMAs with field trials undertaken to validate the viability of various proposed layouts. Network modelling using EPANET became available towards the end of the implementation project in order to simulate design proposals.
7	Was a hierarchy of metered zones used?

	Around 75% of DMAs are fed by a single meter off the supplying trunk main. Of the remainder, around 15% are cascade DMAs, where a second meter has been used to sub-divide a large DMA into two, with the DMA fed off the trunk main cascading to the second sub-zone. Around 10% of DMAs are designed for bi-directional flows, allowing for operational changes in terms of the source pumping station. Whilst most bi-directional DMAs have two meters, a small number have up to six meters. These consist of supply DMAs where sections of trunk/semi-trunk mains of up to 400mm diameter are included in the DMA, which may cascade to other single feed DMAs or to the next section of the trunk main.
8	How was the integrity of the boundary tested?
	The integrity of the boundaries was tested by variety of methods, initially a DMA pre-closure validation to ensure that proposed boundary valves were operational with acoustic geophone testing when closed. Routinely, a pressure zero test (PZT) was undertaken during the night following DMA implementation/boundary valve closure and rechecked with acoustic geophone testing. For this test, pressure loggers were installed at high/low points within the DMA and monitored in real-time when the DMA feed/s were closed to ensure that pressure dropped to zero. Only after this successful PZT was a DMA considered to be operational.
9	How were the boundaries of DMAs defined and managed?
	DMA boundaries are formed with closed valves, where the top of the valve key inside the chamber has a plasticised label affixed, indicating the function of the valve (DMA or pressure zone boundary valve). For the valve to be opened, the plastic label has to be removed, with a procedure defined which indicates that the label must be returned to the leakage management area. A technician from this team then reaffixes the label in place after having validated that the valve has been successfully closed again. An annual validation of all boundary valve labels is undertaken.
10	Do the new boundaries include flushing facilities?
	Where necessary flushing facilities (discharge valves or hydrants) were installed near closed valves, if not already present.
11	Are any systems in place to ensure boundary valve operation is recorded?
	All boundary valves are recorded as such in the GIS system, with their function and status recorded, along with date of last opening/closure. Once DMAs had been established, all closed boundary valves were recorded on the GIS and a procedure implemented that requires authorisation from the Network Intervention Centre prior to any boundary valve being operated. This is followed by a status reports circulated to all operational areas when valves were operated.
12	How were meters selected. This includes both the type of meter and the size selected.

	The process of network segmentation required the installation of around 180 monitoring points, featuring battery-powered electromagnetic flow meters, pressure tappings and associated telemetry dataloggers. A number of existing mechanic meters were initially used on pilot single feed DMAs, but after trials with battery-powered electromagnetic flow meters, these were adopted as standard. Subsequently, battery-powered ultrasonic meters became available on the market and these have also been used. All meters and associated telemetry systems are programmed to be bidirectional, even if under normal operational conditions, they will only have flow in one direction. As such, this allows for temporary boundary changes or tests where the flow through a DMA is reversed and the meter is used to feed into a section of trunk main to assess potential leakage. *In general, meters installed were of one diameter inferior to that of the main at which it was to be located. In certain cases where space was limited due to other adjacent service infrastructure, meters of the same diameter as the main were the only option, whilst at a small number of sites, the primary unit of meter was buried, with just a small chamber for the meter interface/EDU unit as well as telemetry and battery. Over subsequent years, resulting from both reduced customer demand as well as leakage reduction effects both in the EPAL network and on the customer side, a number of meters have had to be downsized due to the lower flow rates. With better data to assess normal flow rates and potential maximum flows in the event of operational changes, various meters of two or even three diameters smaller than the main now exist.*
13	Describe a typical meter installation.
	A typical meter chamber will be around 3m by 1.5m and up to 2m deep, with two or three removable access lids. The primary meter unit is normally in the centre of the chamber, with a pressure tapping downstream and the meter EDU/interface unit, battery and telemetry units all affixed on the chamber walls. All the DMA meters installed are to U0D0 specification, but calming sections with five diameters length upstream and downstream are present where possible. A drainage hole is normally provided. Reduction cones and section valves are normally placed outside of the meter chamber. A quick-release style joint fixing is used and a spare 'blank' section of pipe is usually retained on site in case the meter needs to be removed. The accompanying photograph illustrates a typical installation.
14	How were night use allowances calculated for use in assessing leakage levels (if any).
	The main indicator used for prioritising leakage interventions is an estimate of recoverable losses per DMA and target minimum flow nightline. This is determined by deducting two variables from the net minimum nightline for each DMA; these being an allowance for inevitable real losses which cannot be expected to be located using leak detection techniques for which the Unavoidable Background Real Losses (UBRL) formula is used, taking into account a series of DMA variables such as network length, number and length of service connections and average pressure. The second variable is an estimate of authorised nocturnal client usage, with values of 1.08 litre/client/hour per meter size being used for both domestic and non-domestic client. Starting at 1.08 litre/client/hour for the most common, smallest 15 mm meter, this allowance is increase by the same value for each subsequent meter size, so a 20 mm meter has an allowance of 2.16 litre/client/hour, a 25 mm meter has an allowance of 3.24 litre/client/hour and so on. Values have been adopted to local characteristics based on EPAL's knowledge of its customer consumption profiles. This has been a very successful method and it is notable that leakage control interventions rarely recover more than what was estimated as the recoverable target.
	DMAs in use

15	How is flow data collected from typical DMA?
	DMA monitoring involves pressure and flow being registered at fifteen-minute intervals at each monitoring point, with data available daily via a passive telemetry system or on-demand in case of pressure anomalies. DMA telemetry functions independently of the existing SCADA network management system but is supported by the client telemetry network. The installation of more than 4.000 telemetry systems to large volume users, critical clients such as hospitals or any point with significant night-time consumption, such as garden watering and sprinkler systems, which influence DMA nightline evaluations has also been undertaken, using the same 15-minute flow and pressure registration. In terms of water loss control, the objective was to improve DMA analysis through assessing the impact of individual clients and to characterise losses between EPAL and customer networks, given that both incur losses. Data from all telemetry systems and SCADA is integrated with the WONE software application specifically developed by the company to manage all data relevant to network performance monitoring and dedicated to leakage control.
16	How is flow data checked to ensure that it is valid?
	The WONE application produces statistical analysis of both net and total DMA daily total and nightline, pressure variations and alarms. A range of KPIs with practical applications are included, such as the percentage relationship between the daily minimum hour to average hour ratio using a minimum hour running mean calculation based on net values (the balance of DMA input/output meters and any high demand users with telemetry), total and nightline volumes per 1.000 clients or kilometre of network, in order to allow performance ranking, comparison and attribute intervention priorities between DMAs. As such, any anomaly in the data will either be highlighted by the software or identified by any member of the leakage team, who validate data on a daily basis. Events such as open boundary valves, flow zero incidents on the meter/telemetry units or customer meter replacements creating abnormal readings will all affect the range of indicators calculated, thus creating an alert within the system, which will be investigated by the leakage team. *In terms of individual meters, under-reading DMA meters are able to be identified though either the water balance for each DMA, where values may be negative or falsely low, or comparison of DMA meters and large user meters fitted with telemetry.*
17	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?

	Based on detailed DMA and client data available to calculate the practical KPIs available in the WONE software application, as outlined in previous notes, the selection and ranking of DMAs in undertaken on a daily basis, with those with the highest estimated recoverable water losses or percentage ratio between the minimum nightline and average daily flow rate being chosen for leak detection interventions or investigations into excessively high night or daily consumption. *Field teams are issued with pre-intervention DMA Project reports, which include all relevant information required for the intervention, such as the DMA plan, boundary valves, metering, key clients and estimated recoverable losses. Such information assists the field team in deciding the strategy to be applied in each intervention.* *By using the WONE application, leakage teams are directed to specific zones with information on their expected leak reduction targets and potential. Experience within EPAL has confirmed that this information is indispensable for field teams and decisions relating to planning and implementation of leak detection interventions or network diagnostics* *The IWA water balance has been used over recent years on an annual basis at DMA level. This integrates all DMA flow data and customer consumption billing over the same period and is done to provide a second level validation of overall NRW per DMA as well as estimate the division between real and apparent losses. With the expansion in customer telemetry coverage (around 30% of consumption is now measured & billed via telemetry systems), the accuracy of this top down-bottom up approach has increased notably in recent years.*
18	Describe the process by which decisions are made on which DMAs are investigated by leakage control teams.
	Leakage detection intervention prioritisation is based on the level of estimated recoverable losses per DMA, as outlined previously.
19	What happens when DMAs are investigated by leakage control teams but the leakage is not reduced?
	In cases where the estimated recoverable losses are not achieved nor an acceptable reduction in the nightline values, further boundary valve integrity is undertaken, along with further confirmation of DMA and customer telemetry data to identify any anomalies or errors. Should no issues be detected, the most common second round of intervention will see re-zoning between DMAs where a section of one DMA is transferred to a neighbouring area or trunk main. This is an alternative to step-testing and is possible due to the almost continuous DMA coverage of the network. Of note is that step testing is usually only used as a last resort given the impact on supply and potential risks. A noise logging survey may then be undertaken along with acoustic correlation on any sections of larger diameter meters with few/no service connections or access points. Another simple solution applied at times is send a different leak detection team to the DMA, if the initial intervention has not been successful. Different teams and leakage technicians will have differing perspectives and approaches, which may result in varying results when undertaking field investigations. *The leakage recovery ratio after over a decade of work in the Lisbon distribution network is around 65% - namely the leakage volume actually recovered compared with what was estimated as the target recovery volume.*
20	Describe maintenance processes.

	Boundary valves are checked on an annual basis as mentioned previously, with the Operations division responsible for managing a planned discharge and flushing campaigns near closed boundary valves with low/no consumption nearby. *The WONE application and telemetry systems provide low battery alerts for the meters and dataloggers, which permits battery replacement to be undertaken.*
21	Describe the other uses that you put DMAs to.
	DMA monitoring data is also considered in the multi-criteria matrix for identifying priority network rehabilitation areas and is a major source of data for network modelling and the all mains EPANET model which has been developed over the last decade. DMA flow and pressure data is utilised to determine nodal demands within a DMA. *During the COVID-19 pandemic, the existing DMA implementation and monitoring remained unaltered and was used as the basis for undertaking detailed fortnightly assessments of potential areas of the network with a higher risk of water quality problems due to the significant reduction in consumption in some parts of the city. Through analysis of DMA consumption patterns and network characteristics, such as % of cast irons mains within the DMA, recommendations were made to the Operations division as to which DMAs should be subject to an enhanced frequency and/or coverage of flushing and planned discharge interventions.* *Daily consultation of application data by all operational units, emphasizes that the system and indeed entire DMA project, is a network management and diagnostic tool as opposed to one focused solely on water losses control. This reinforces the vision that any leakage reduction project is inherently connected with efficient network management and must not be considered as a stand-alone water loss reduction plan.*
	Other Issues
22	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

	Through this process of network segmentation and increased monitoring and analysis, a far greater understanding of performance and systems dynamics has been obtained, which combined with Active Leakage Control interventions saw NRW reduced to less than one-third of the baseline 2005 level with five year and maintained at such levels for over a decade. EPAL's NRW performance long been comparable with best practice levels obtained by the most efficient European companies and comfortably within both the Economic Level of Leakage, as well as more stringent Sustainable ELL criteria. *The project has also provoked a cultural change at different levels and areas within the company as both technical and commercial areas have adopted to the DMA concept as a management and assessment tool, as well as a permanent distribution network surveillance tool for operational activities.* *Key recommendations are to build capacity within the company, both in terms of physical infrastructure and equipment, but more important, as regards sufficiently trained staff in a dedicated team focused on water loss control, thus allowing the acquired empirical knowledge of the company's network to be maintained within the organisation. Success has been achieved by creating a dedicated water loss control team, supported directly by the management board, with resources and responsibility over the fundamental issues required to build a sustainable monitoring and control system. These key factors being DMA planning, implementation and subsequent management, maintenance of DMA meters, telemetry and boundary valves, leak detection activities and development of the data management software with KPIs directed strictly towards the daily assessment of water losses. Whilst the concept of network segmentation into DMAs is well-known, the challenge of sustainably managing such systems over the long-term with constant vigilance is seen as a key facet, along with a correlation between the size of DMAs implemented and potential achievable water loss reduction.*

Name of contributor: Andrew Connelly

Organisation: On behalf of EPAL, Lisbon, Portugal

Kunming City, China

	Description of the project
1	A brief description of the location
	Kunming City is located in the southwest of China, the capital of Yunnan Province. Kunming CGE (a JV company of Veolia) is responsible for the water supply of the city, with more than 1.5 million water meters, around 500km^2 serving area. *From the year 2018, Kunming CGE began to install DMAs as a measure of water loss control. Up to the year 2022, more than 1900 DMAs are installed.*
2	What was the level of real losses before and after installing DMAs?
	The real losses before DMA is around 80,000 m^3/d, after installing and the following actions basing on the data analysis of DMA, the real losses is reduced to around 20,000 m^3/d.
3	Briefly describe the supply arrangements for typical households:
	Each inlet pipe of the DMA is equipped with a water meter and a pressure gauge. Part of the DMAs contain a secondary water supply system.
	Design
4	What influenced the design of individual DMAs?
	The topography of the network and the number of inhabitants are considered in the design of individual DMA. A residential quarter is a natural DMA as the network is branched and the inhabitants are several hundred to several thousand
5	Was pressure management considered at the design stage?
	The pressure is supervised but not regulated because the service pressure is already low, around 2.5 bar.
6	The methods used for design.
	No special methods, just basing on the topography of the network.
7	Was a hierarchy of metered zones used?
	No.
8	How was the integrity of the boundary tested?
	A zero-pressure test is carried out to ensure the integrity of the boundary of each DMA by closing the inlet valves and measuring the network pressure in the DMA.
9	How were the boundaries of DMAs defined and managed?

	First, find out all the inlet pipes of a DMA; second, carry out a zero-pressure test to insure its integrity; third, install water meters to all the inlet pipes. Normally a DMA has only one inlet pipe, some larger ones have two or three inlets, and it is preferred to install more water meters instead of just closing boundary valves to avoid low pressure problems as the service pressure is already at low level.
10	Do the new boundaries include flushing facilities?
	No need.
11	Are any systems in place to ensure boundary valve operation is recorded?
	Yes, we have network maintenance system which records all the operation in network including valve operation.
12	How were meters selected. This includes both the type of meter and the size selected.
	Half of DMAs are installed with mechanical water meters and half are electronic water meters. The size varies from DN40 to DN200. The accuracy of 0.1 m^3/h is requested.
13	Describe a typical meter installation.
	 
14	How were night use allowances calculated for use in assessing leakage levels (if any).
	We take 2 l/h/inhabitant as reasonable usage.
	DMAs in use
15	How is flow data collected from typical DMA?
	Both flow and pressure data are collected basing on 5min interval and transmitted by way of NB technology to our own server every 6 hours.
16	How is flow data checked to ensure that it is valid?

	An alarm of abnormal data transmission is triggered on the DMA system if the data is missing, then onsite work will be acted to check the problem; an alarm of abnormal flow data is triggered in case of dramatically increasing or decreasing of flow rate. Also, the onsite preventive maintenance of the water meter is regularly carried out.
17	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?
	Three indicators are used in our daily job: Physical Water Loss = Minimum flow – Reasonable flow; Physical Loss Ratio = Physical Water Loss / Total Inlet Volume; NRW = 1- Billed Water / Total Inlet Volume. No detailed water balance is applied.
18	Describe the process by which decisions are made on which DMAs are investigated by leakage control teams.

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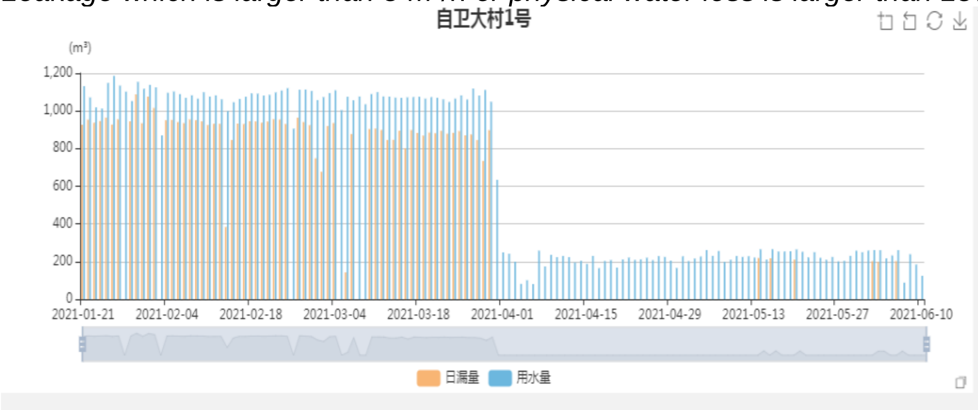
1. *Leakage which is larger than 5 m^3/h or physical water loss is larger than 15%:*



The picture above shows an example of a DMA with high leak level. The leakage was very difficult to find because it was located under a very busy highway and the material is PE, the acoustic method is invalid. Finally, we changed the whole pipe (about 100 meters) with non-excavation technology to solve the problem.

2. *NRW is larger than 25%:*
Investigation of commercial loss is carried out in this case. Example: a DMA named GongXin Square, with 20% physical water loss ratio, and over 40% NRW. After investigation, no leakage found but many illegal connections were found which is used for irrigation of green land, even some water meters were installed (but not installed by water company) to measure the volume, shown as the following illegal water meters: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<td>What happens when DMAs are investigated by leakage control teams but the leakage is not reduced?</td>
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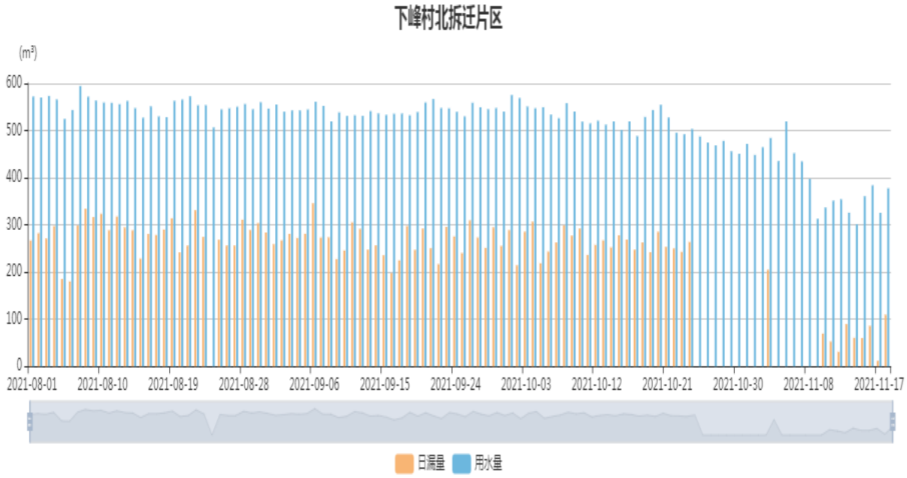
Further action will be taken depending on different situations:

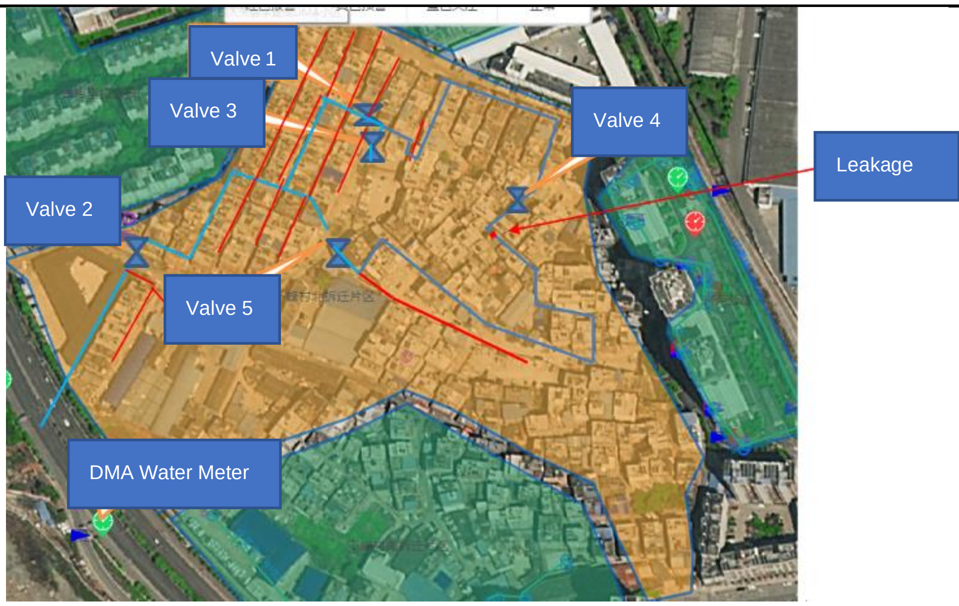
Leak survey team investigated the DMA, but leakage is not reduced, there are several possible reasons and we take different actions:

1. *The "leakage" is after the water meter, which is used for trading, so this kind of "leak" might be an internal leak or certain customers really need to open the tap day and night for a while, so it is not a real loss for water company;*
2. *There is leak, but hard to find. In this case, we will investigate again with some other technology, including acoustic loggers, CCTV or step test to pinpoint the leakage. Example from XiaFengBei Village:*



The picture above is another difficult DMA which named as XiaFengBei Village, the blue column represent the total inlet volume (m^3/d), the orange column shows the leak volume on daily bases. There was a large leak in the village, around 250 m^3/d, 10 m^3/h. Leak control team went to the site several times without finding anything. The problem was that the network in the village was installed by themselves but not by water company, no network information was recorded and as some of the pipes were PE, the pipelines were difficult to be located.

In this case, we take CCTV to locate the pipelines. After two weeks work (pipe detection with CCTV need to cut off water and drilling holes on the network, which takes time), we finally figured out the pipeline and found the leakage, which is located between two buildings (the distance between them is only 1.5 meters! Normally no one will consider there is pipeline in that place).

	   3. *There is no leak, or leakage is not the biggest problem, but illegal usage is. The second example in "18" shows this kind of problem. When leakage detection shows no result, it is possible that a permanent usage existing, then the question comes to whether the usage is metered and billed, if not, it is a commercial loss of water company, so we also do a water meter survey on site. All the actions above are basing on the data analysis combining with the onsite information collected by leak control team, then it will give us tips for next step*
20	Describe maintenance processes.
	Check the water meters every 6 months as preventive maintenance; check certain water meter under the alarm of malfunctions as corrective maintenance.
21	Describe the other uses that you put DMAs to.
	It is used for management on planning of annual leak control, performance monitory and network analysis
	Other Issues

22	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
	N/A

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Foshan City, China

	Description of the project
1	A brief description of the location
	Sanshui of Foshan City is located in Guangdong Province, China. There are two waterworks in the area. The water supply capacity of A waterworks is 450,000 cubic meters per day, and that of B waterworks is 80,000 cubic meters per day. The water supply service area is about 827 square kilometres, the total length of municipal pipe network (DN80 above) is 1,341 kilometres, and the service population is about 803,000. *Sanshui Water Supply Co. LTD planned to build a hierarchy of DMAs in Sanshui District by the end of 2025, and there will be 8 first-level DMAs, 6 second-level DMAs and 151 third-level DMAs in the region. By the end of 2021, 8 first-level DMAs, 3 second-level DMAs and 71 third-level DMAs have been built, that is, the construction of first-level DMAs had been completed, and the second-level and third-level DMAs had completed nearly 50 %.*
2	What was the level of real losses before and after installing DMAs?
	A total of 50 DMAs have been completed and put into application in 2020. The DMA management system and information system have been simultaneously established. The leakage rate was 9.55 per cent in 2020 and 7.59 per cent in 2021, with a year-on-year decreased by 1.96 percentage points. *In 2021, 257 leakage points were found and repaired by DMA management. It is calculated that the repair works can reduce the leakage water by about 34.85 million cubic meters per year.*
3	Briefly describe the supply arrangements for typical households:
	Every household uses water meter to measure water consumption, and the water supply company periodically charges every household according to the meter. *Low-rise buildings below 6 floors are generally supplied water directly through municipal pipelines, with water pressure not less than 0.14 MPa. High-rise buildings with 6 floors and above are generally supplied water by municipal pipelines supply and secondary pressurized water supply. Floors 1-4 are directly supplied by municipal pipelines and floors 5 and above are supplied by secondary pressurized water supply.*
	Design
4	What influenced the design of individual DMAs?

	Construction conditions, area size, pipe materials and age, management requirements, and water consumption characteristics are the main factors. *'Easy before difficult ' means that priority is given to the tree-shaped pipe networks or circular pipe networks with a small number of inlets or where the areas don't need to close valves and disconnect pipelines.* *'Appropriate size' means that the third-level DMAs are generally established from residential areas, industrial parks or natural villages, with no more than 5000 users and no more than 3 water inlets.* *'Key areas ' means to select the high-risk areas through analysis of long service life and frequent emergency maintenance pipelines.* *In addition, the new pipe network construction in the water supply area shall be designed and constructed according to the construction standards DMA of the enterprise.*
5	Was pressure management considered at the design stage?
	Pressure management is considered at the design stage. The pressure data acquisition and transmission devices will be set up in the inlet of DMA. *In DMA areas where pressure demand is not high, water pressure of the inlet is maintained at 0.14 MPa to 0.2 MPa by using a pressure reducing valve. In DMA with the secondary pressurized water supply , the pressure of the inlet is generally maintained in the range of 0.14 MPa to 0.35 MPa.*
6	The methods used for design.
	The administrative region, natural conditions, pipe network operation characteristics, water supply management needs and other factors, are considered comprehensively. Firstly, the preliminary planning scheme of DMA construction is formed. Then, the hydraulic microscopic model of water supply network is used for simulation and optimization. Finally, it needs to be fully demonstrated by the relevant departments of the company to ensure that the scheme is scientific, reasonable and feasible. *The following principles should be followed.* *1.DMAs should be constructed in strict accordance with a 3 levels hierarchy to ensure that the management is not too complex.* *2.In general, the DMA boundary is not formed by closing the valve to avoid the negative impact of water quality and water pressure.*
7	Was a hierarchy of metered zones used?
	There is a 3-levels hierarchy in Sanshui District. • *The first level DMAs are divided by the scope of town.* • *The second level DMAs are composed of a number of the third level DMAs.* • *The third level DMAs are divided by residential areas, villages and industrial parks.*
8	How was the integrity of the boundary tested?
	Close all inlet and outlet pipeline valves in the area and perform zero pressure test for the whole DMA.

9	How were the boundaries of DMAs defined and managed?
	The DMA boundary is mainly based on the location with obvious terrain (road, river, etc.) boundary .
10	Do the new boundaries include flushing facilities?
	Flushing facilities are generally not installed on new borders. The drainage valves and hydrants of the pipelines should be fully used to ensure the water quality of the DMA.
11	Are any systems in place to ensure the operation of the boundary valve?
	The information of DMA boundary valves has been input to the GIS. The operation of opening and closing the valves will be recorded into the information system through the operator's APP.
12	How to select meters. This includes both the type of meter and the size selected.
	For DMA with inlet pipe Diameter ≥ DN500, flowmeter with bidirectional metering function is selected. The mains power supply or solar power supply is preferred, and higher excitation frequency should be selected to ensure the accuracy of meter measurement. If the installation conditions permit, it is advisable to use the tubular electromagnetic flowmeter with accuracy grade of 0.5, where the Water supply can be stopped during flowmeter installation. Otherwise, it is advisable to use the external clamp ultrasonic flowmeter or the plug electromagnetic flowmeter with a precision grade of 1.0, *For DMA with inlet pipe Diameter ≤ DN400, the battery powered electromagnetic flowmeter or electromagnetic water meter is preferred., which should also have bidirectional metering function.* *Compared to mechanical water meters, electromagnetic flowmeters or electromagnetic water meters have excellent small flow measurement performance and reliable integrated data transmission function, which can meet to DMA's monitoring requirements for the minimum flow at night.*
13	Describe a typical meter installation.

	
	Above is a DN300 electromagnetic water meter installed by a DMA. The water meter is an integrated water meter with remote transmission function. The water supply company collects and stores the flow and pressure data of the pipeline by using the "Water Supply Flow Big Data System". The accuracy level of the electromagnetic water meter is grade 2, built-in 3.6V lithium battery for power supply, and is installed with pipe-section flanges. In order to reduce the impact on the appearance of the city, the DMA water meter will be installed in the instrument well, and the water meter waterproof level is IP68.
14	How to calculate night use allowances for use in assessing leakage levels (if any)
	The legal water consumption of residential users at night is measured by sampling in an established DMA. The average experience value of legal night water consumption per household is about 4 l/h. *The number of households in the region * 4 l/h = Legal night water consumption.* *The legal water consumption data of non-resident users at night is collected and obtained through their remote water meters.*
	The DMA in use
15	How to collect flow data from typical DMA?
	The flow data of DMA inlet flowmeter are uniformly collected to the Water Supply Flow Big Data System through the remote transmission device. The collection frequency is generally 1-3 minutes, and the transmission mode is 4G or NB-IOT. *There are two ways to collect consumption water data of users in DMA, one is smart water meter using NB-IOT, and the other is manual meter reading*
16	How to check flow data to ensure that it is valid?

	1. *The continuity of data and abnormal data can be monitored and tracked through the alarm function of Water Supply Flow Big Data System. If an alarm information is issued, the maintenance personnel should check or repair the instrument.* 2. *All flow meters are equipped with data storage chips. When the data is found missing in the Water Supply Flow Big Data System, the data can be copied by the supplement function.* 3. *Equipment maintenance personnel should regularly carry out on-site inspection to check the running status of DMA instrument and equipment.* 4. *The portable ultrasonic flowmeter is used as standard meter to compare the accuracy of DMA instrument. Usually once every six months or when there is an abnormal alarm, the comparison is made immediately.*
17	Describe how to interpret the flow data to assess loss levels. 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?
	A Water Supply Flow Big Data System has been established. This system aggregates all the flow data in the water supply area. According to its data statistics function, the least water consumption between 0 o 'clock and 5 o 'clock at night is regarded as the minimum night flow of the day. The difference between the minimum night flow and the legal water consumption at night is the water leakage at night. If water leakage at night exceeds a threshold, an alarm is issued. *A DMA digital system was established at the same time. This system aggregates multi-source data such as water flow, pressure, pipeline repair and climate data of the DMA. Combined with IWA water balance analysis methodology and the Standard of Water Loss Control and Assessment for Urban Water Supply System in China (CJJ 92-2016), a DMA water consumption benchmark mathematical model was established. It can quantitatively analyse the time and space distribution of DMA leakage water and give leakage warning.*
18	Describe the process by which decisions are made on which DMAs are investigated by leakage control teams.
	Decisions are made mainly based on the night minimum flow warning of Water Supply Flow Big Data System and the results of the water balance analysis given by DMA Digital System. The higher the regional leakage, the higher the priority of leakage detection.
19	What happens when DMAs are investigated by leakage control teams but the leakage is not reduced?
	Further investigation measures must be taken, including: • *Equipment maintenance and management personnel will check the accuracy of regional master water meter measurement.* • *DMA data analyst will check the accuracy of the corresponding relationship between the master water meter and the sub-meters.* • *DMA boundary should be checked whether the conditions of DMA boundary have changed.* • *The sub-meters data should be checked and analysed whether there is illegal water use.*

20	Describe maintenance processes.
	To ensure long-term validity of DMA, the accuracy of meter data and the stability of data are the foundation. Maintenance management personnel need to maintain and manage instruments and monitoring equipment of DMAs effectively. They should routinely conduct troubleshooting and timely deal with the meter off-line alarm and zero water consumption alarm sent by the computer system. *The another most important maintenance work is to establish and maintain the water meter ledger, as well as the relationship between the master meter and sub-meters.* *The portable ultrasonic flow meter is used to compare the regional master meter's accuracy, and the inaccurate meters should be replaced in time. Instruments and monitoring equipment supplied by batteries are regularly tracked the remaining power and timely replaced batteries before they are run out.*
21	Describe the other uses that you put DMAs to.
	• *The enriching flow and pressure data of DMAs helps to optimize the water supply scheduling scheme and the hydraulic model of the pipe network.* • *The hidden leaks or small leaks are detected and repaired in time to avoid the further expansion. It will eliminate the potential safety hazard of ground subsidence caused by leaks.* • *It will improve the water supply company's social image.*
	Other aspects
22	Is there any other important aspects in the design, installation and use of DMAs has not been covered in the questions above? This could include particular problems and how to overcome them.
	1. *The operation and maintenance management after DMA installation is the key to the DMA's success. It is necessary to set up DMA data analysis posts and to increase DMA equipment personnel. It is important to pay attention to the minimum night flow alarm information of DMA every day and deal with the alarm in time.* 2. *DMA data analyst must have a strong sense of responsibility and sufficient professional ability who can continuously accumulate experience and convert his experience into alarm rules. These rules are then built into software to improve the timeliness and effectiveness of alarm.* 3. *We should make full use of big data, AI and other new information technology to build DMA from design to data acquisition and storage, analysis and alarm, until the troubleshooting and disposal.*

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Reducing leakage in Jakarta, Indonesia

This article is taken (with small edits) from the Proceedings of the IWA Specialised Conference "Leakage 2005", Halifax, Nova Scotia, September 2005

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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.

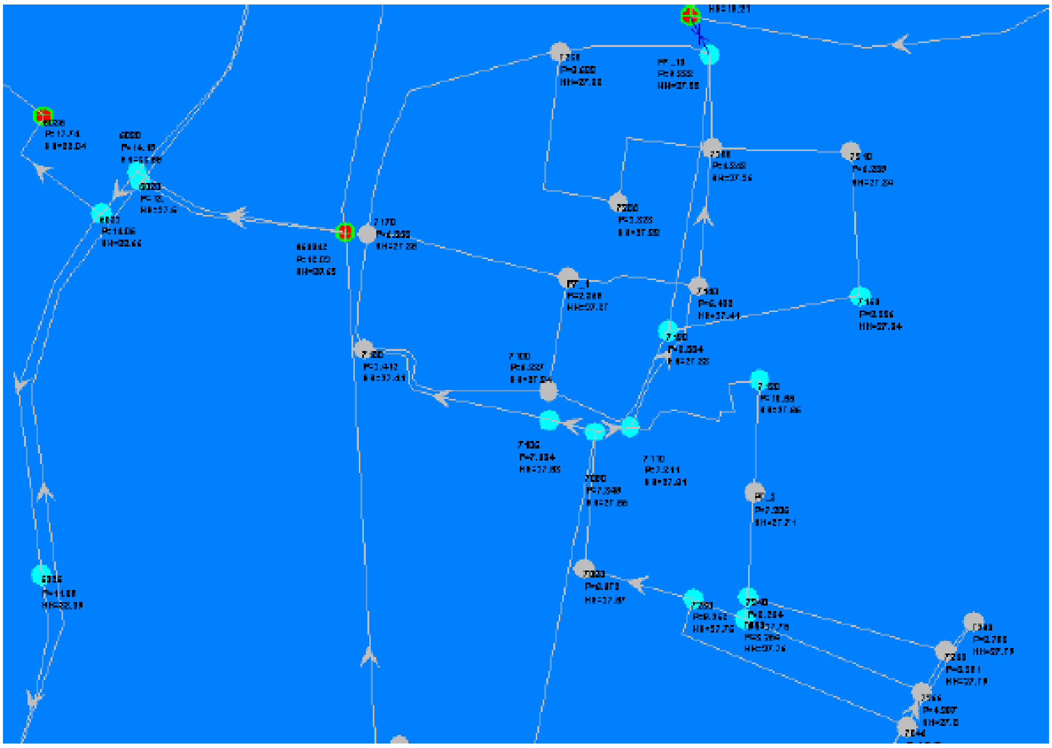

Figure E-4. Mathematical model of Jakarta.

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.

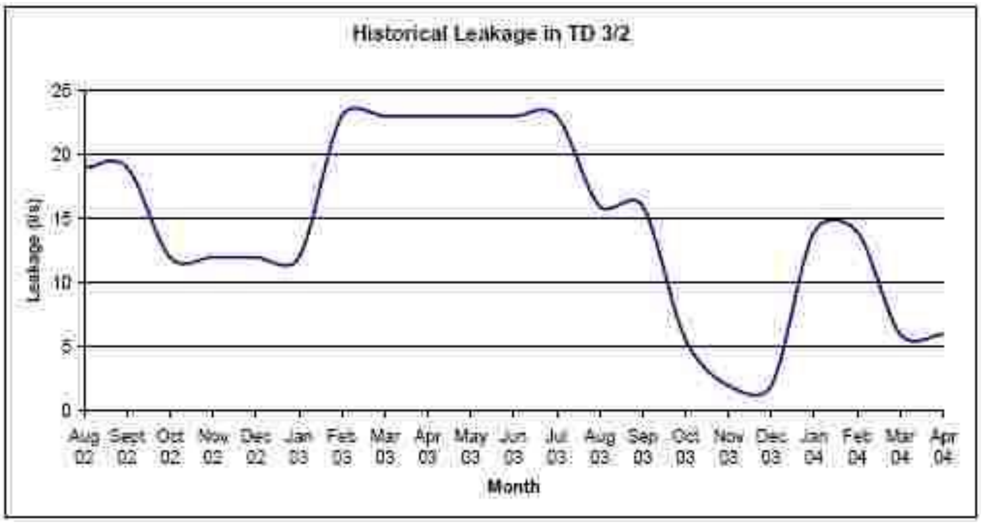

Figure E-5. Variation in leakage level over time.

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].

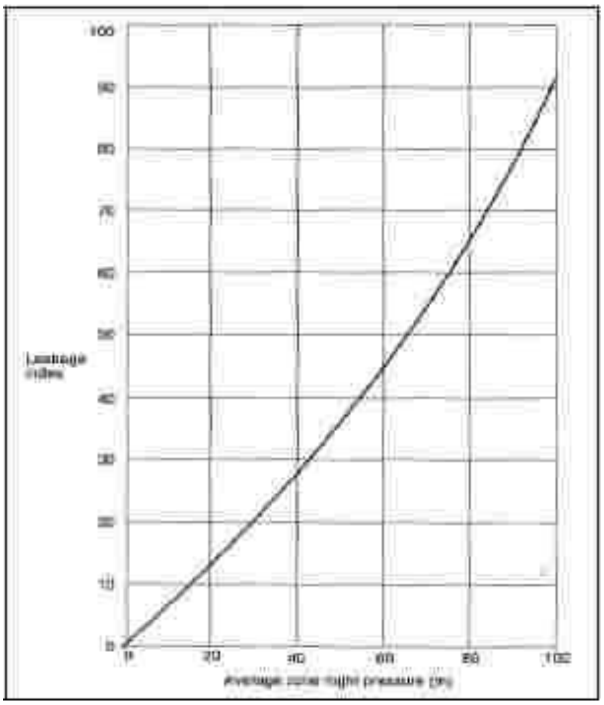

Figure E-6. Typical Pressure – Leakage relationship.

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 head loss 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 head loss 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 the operating pressure are little more than 10 metres and where the minimum pressure hardly registers on a pressure gauge. Furthermore, the creation of an efficient pressure control system requires a single supply, which avoids the potentially dangerous instability, which can result from having multiple supplies. This is even more important in a low-pressure network where the surges could cause the valve to close. But to create such a configuration is clearly much more delicate in a low-pressure system. This is where the use of a mathematical model is essential.

A trial was undertaken in a pilot area of around 20 km. A high quality PRV of the same diameter as the inlet pipe was installed so as to minimise the head loss at peak flows. The results were very positive and showed that not only was the PRV capable of maintaining a constant downstream pressure, but that by lowering further the pressure, it was possible to reduce significantly the leakage. An electronic control unit acting on the PRVs pilot was installed to automatically lower the outlet pressure from 20:00 to 05:00.

Results

The application of a step by step approach has proved very successful in the network of Jakarta. In the first Permanent Area analysed, the leakage level was reduced by over 60 l/s just by eliminating the large leaks as shown in Figure E-7

Figure E-7. Repair of leak.

The size of the leaks identified was a surprise, considering the very low operating pressures. The reason can be attributed primarily to the pipe material and the poor workmanship, particularly regarding the end caps. It also showed that the leakage problem was caused mainly by a small number of large leaks and not a large number of small leaks as at first thought. Not only does this confirm the findings in similar cases in other parts of the world, but means that it is possible to obtain excellent results without an excessively large economic investment.

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.