Standard Definitions for Water Losses

A compendium of terms and acronyms and their associated definition in common use in the field of water loss management

David Pearson

IWA WATER LOSS SPECIALIST GROUP
the international water association

IWA PUBLISHING

Standard Definitions for Water Losses

Standard Definitions for Water Losses

Author: David Pearson

Editor: Andrew Donnelly

Abstract

A compendium of terms and acronyms and their associated definition in common use in the field of water loss management

Published by

IWA Publishing
Alliance House
12 Caxton Street
London SW1H 0QS, UK
Telephone: +44 (0)20 7654 5500
Fax: +44 (0)20 7654 5555
Email: publications@iwap.co.uk
Web: www.iwapublishing.com

First published 2019

British Library Cataloguing in Publication Data
A CIP catalogue record for this book is available from the British Library

ISBN: 9781789060874 (Paperback)
ISBN: 9781789060881 (eBook)

DOI: 10.2166/9781789060881

This eBook was made Open Access in November 2019

Contents

List of Acronyms

AL	Apparent Losses
ALC	Active Leakage Control
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
AOI	Area of Interest
AOP	Average Operating Pressure
AV	Air Valve
AZNP	Average Zone Night Pressure
AZP	Average Zone Point
BABE	Burst and Background Estimation
BU	Bottom Up Leakage Assessment
CAL	Correlating Acoustic Loggers
CAPEX	Capital Expenditure
CARL	Current Annual Real Losses
CLM	Component Loss Model
CLU	Continuous Logged User
CP	Critical Point
DCF	Discounted Cash Flow
DMA	District Metered Area
DPA	Discrete Pressure Area
ELAL	Economic Level of Apparent Losses
ELL	Economic Level of Leakage
EM	Electromagnetic Meter
EoS	Edge of Street
ESPB	Equivalent Service Pipe Burst
FAVAD	Fixed and Variable Area Discharge
FH	Fire Hydrant
GIS	Geographical Information System
GPR	Ground Penetrating Radar
HDF	Hour to Day Factor
ICF	Infrastructure Condition Factor
IHM	Individual Household Monitor

ILI	Infrastructure Leakage Index
IWS	Intermittent Water Supply
LCA	Leakage Control Area
LDNC	Legitimate Domestic Night Consumption
LMS	Leakage Management System
LNC	Leak Noise Correlator
LNC	Legitimate Night Consumption
LNHHNC	Legitimate Non-household Night Consumption
Mabl	Minimum Achievable Night Flow
MCR	Marginal Cost of Revenue
MCW	Marginal Cost of Water
MF	Minimum Flow
MinHist	Minimum Historic Night Flow
MNF	Minimum Night Flow
MNF Method	Minimum Night Flow Method
MUR	Meter Under-Registration
MVW	Marginal Value of Water
NDF	Night Day Factor
NPV	Net Present Value
NRR	Natural Rate of Rise of Leakage
NRW	Non-Revenue Water
OPEX	Operational Expenditure
PCC	Per Capita Consumption
PHC	Per Household Consumption
PIM	Pipeline Insertion Method
PLC	Programmable Logic Controller
PIs	Performance Indicators
PM	Pressure Management
PMA	Pressure Managed Area
PMI	Pressure Management Index
PRV	Pressure Reducing Valve
PSV	Pressure Sustaining Valve
PZT	Pressure Zero Test
RL	Real Losses
SAM	Small Area Monitor
SR	Service Reservoir
ST	Supply Time
SV	Sluice Valve
TD	Top Down Leakage Assessment
TIF Method	Total Integrated Flow Method
UARL	Unavoidable Annual Real Losses
UBL	Unavoidable Background Leakage
UFW	Unaccounted for Water
WMS	Work Management System
WO	Wash Out
WRZ	Water Resource Zone
WSZ	Water Supply Zone

Standard Symbols for Numeric Values

Symbol	Prefix	Name	Value	Scientific
k	Kilo	Thousand	1,000	10^3
M	Mega	Million	1,000,000	10^6
m	Milli	Thousandth	0.001	10^{-3}

Standard Abbreviations for Units

Abbreviation	Unit
Length	
m	metre
km	kilometre (1000 m)
mile	mile
ft	feet
In	inch
Volume	
l	litre
m^3	cubic metre (=1000l)
Ml	megalitre (=1,000,000l, 1000 m^3)
g	gallons (Imperial or US)
ft^3	cubic feet
CCF	100 cubic feet
AF	acre-foot
Time	
s	second
h	hour
d	day
wk	week
yr	year
Pressure	
m	metre
bar	bar
kPa	kilopascal
p	pounds
psi	pounds/$inch^2$
Other	
c	capita (person)
conn	connection
prop	property
hd	household

Notes: There should be no space between the number and the unit, e.g. 7h, 6m, 2wk.
There should be no "s" after the abbreviation when greater than 1, e.g. 7h, 6m, 2wk.
Use "/" for "per", e.g. Ml/d, l/c/d, h/d.

Standard Abbreviations for Pipe Materials

Generic	Abbreviation	Specific	Abbreviation	Normal Application
Cast iron	CI	Vertically cast		Mains
		Spun		Mains
		Cement Mortar Lined	CICL	Mains
Ductile iron	DI			Mains
		Cement Mortar Lined	DICL	Mains
Steel	ST			Mains
Polyvinyl chloride	PVC	Unplasticised	uPVC	Mains
		Modified	mPVC	Mains
		Molecularly orientated	moPVC	Mains
Asbestos cement	AC			Mains
Glass reinforced plastic	GRP	Chopped fibre		Mains
		Filament wound		Mains
Polyethylene	PE	Medium density	MDPE	Mains and services
		High density	HDPE	Mains and services
		Polyethylene terephthalate	PET	Service relining
Lead	Pb			Services
Copper	Cu			Services
Galvanised iron	GI			Services

WATER RESOURCES

Potable Water

Potable water is water that is "safe" for human consumption, usually following treatment and disinfection. Different countries will have different standards for water for human consumption, for example the WHO and EU standards.

NON-potable Water

Non-potable water is water that has not been treated or disinfected in order to make it "safe" for human consumption (see potable water).

Raw Water

Raw water is water abstracted for hu2man consumption but prior to being treated to make it "safe" for human consumption (see non-potable water, potable water)

Yield of Water Resource System

The yield of a water resource system is the rate at which water can be put into supply and that can be sustained through a drought of the design severity. The design severity may be an occurrence once in every 100 years, once in every 50 years, the worst historic or another severity determined by regulators or the operator.

Deployable Output

The deployable output of a water resource system is the water that can be supplied by the system taking into account any constraint on the available yield due to limitations in treatment capacity, transfer or transmission capacity.

Available Supply

The available supply is the total of the deployable output from all the sources within a water resource zone taking into account planned outages that might be expected.

Outage

Outage is the loss of available supply when a piece of plant, such as a borehole pump, treatment works, service reservoir or distribution pump for example, is not available for use. Outage could be caused by external factors such as interruptions to electrical supply, chemical availability etc. or may be due to internal decisions such as planned maintenance or when plant is unavailable due to unforeseen circumstances such as mechanical failure. Outage can have a severe impact on available supply and hence reliability of supply (see headroom).

Demand

Demand is the total of consumption and real losses.

Water Resource Zone (WRZ)

A water resource zone is an interconnected area of supply, often with multiple sources, where all customers have the same reliability of supply. The ELL should be evaluated at the WRZ level.

Water Supply Zone (WSZ)

A water supply zone is the area where all the customers in that zone are receiving water supplied from a single source or combination of sources. It is usually defined for water quality monitoring purposes.

Author: David Pearson
doi: 10.2166/9781789060881_0001

Supply Reliability

Supply reliability is defined as the ability of a utility to provide a consistent supply of water at the required time. The level of supply reliability can be assessed using headroom.

Headroom

Headroom is the difference between available supplies and demand within a water resource zone. There will be a design headroom for a WRZ taking into account the likely short-term rise in demand during a drought, possible drought restrictions to limit or mitigate demand, the type of water supply system and actions that could be taken in the event of a drought in order to enhance/sustain supplies. The balance between actual headroom and design headroom defines the supply reliability.

Water Supply Coverage

Water supply coverage delineates the area and properties that are connected to the water supply system. In an area where only part of the population is served this refers to the ratio between the supplied population and total population in the administrative area of the utility. The area supplied is referred to as the Water Operational Area.

Water Supply Network

A water supply network is a collection of assets, such as impounding reservoirs, boreholes, treatment works, aqueducts and any necessary associated pumps and pumping station delivering raw water to the treatment works for purification. It usually includes the treated water assets down to and including the service reservoirs prior to the water distribution network. This would include trunk mains and possibly pumping stations. Although the demarcation between supply network and distribution network is often used within utilities for organisational purposes, the water supply network can be considered to include the water distribution network that delivers water to customers from a logistical point of view.

Water Distribution Network

A water distribution network is a collection of assets, primarily mains and service pipes but may include booster pumping stations, which deliver water from a water supply network to customer premises.

Network Hierarchy

The network hierarchy defines the different levels from sub-DMA through DMAs and zones within a water supply network and their association all the way up to the utility as a whole. It is essential for the reporting of key parameters, such as leakage, at different levels within the utility. It is a fundamental component of a leakage management system.

Drought

A drought is a prolonged period of low rainfall that places supply reliability at risk.

Drought Restrictions

Drought restrictions are actions that can be taken by a utility, following the necessary legal approval, to restrict normal legitimate use by customers during a drought. An example of a drought restriction would be, for example, a hosepipe ban for garden watering.

Supply

Supply is the provision of potable water into the water distribution network for consumption by customers.

Rotational Supply

A system with regular intermittent water supply such that there is a relatively consistent pattern as to when supply is available. See also rotational supply designation.

Rotational Supply Designation

In systems with rotational supply, namely a consistent pattern of when supply is available, it is often useful to describe the availability pattern of supply in the form of hours per day and days per week, i.e. h/d×d/wk. Thus, a pattern of supply of 8 hours per day every day would have the designation of 8×7 and a system with 24-hour supply for 2 days a week would have the designation 24×2. This pattern is therefore aligned with the common use of 24×7 to designate customer service that is available at all times.

Supply Time (ST)

The average period per day that the system is pressurised in intermittent water supply situations. A system is defined as being pressurised when there is sufficient pressure in the system to maintain supply to customers. The figure is used in the calculation of performance indicators (ILI, l/conn/d, m^3/km/d) to ensure that the PI reflects the fact that the system may not by pressurised for the full day and therefore leakage will appear lower if the time that the system is pressurised is not taken into account. Supply time can be calculated from the rotational supply designation as (h/d×d/wk)/7. Thus, a system which is pressurised for 4 hours a day, 3 days a week has a supply time of (4×3)/7=1.7 h/d.

Intermittent Water Supply (IWS)

Intermittent water supply is a course of action where the supply to parts of a water resource zone is cut off, usually in rotation, with the intention of preserving limited resources. This is an action that would be considered where the actual headroom is significantly less than the design headroom. Intermittent supply is not always managed and may occur when the service reservoir runs empty. The extent of IWS will depend on the degree of this deficit. IWS usually takes the form of rotating supply to different areas so that the restriction is suffered by all customers, though it is common to arrange for supply to critical customers, such as hospitals, to be maintained at all times. It is also frequent for areas to be shut off entirely. The repeated emptying and filling of the system causes severe problems with bursts and thus leakage, due to pressure fluctuations every time the system is recharged. Thus, the action can be, to a certain extent, self-defeating. It is recommended that complete shut off is avoided if possible and that a minimum pressure is maintained in the system. It is recommended by the IWA Water Loss Specialist Group (WLSG) that all possible methods of reducing leakage and controlling demand are employed so that continuous supply is maintained and IWS avoided. See also rotational supplies and rotational supply designation.

DISTRIBUTION NETWORK ASSETS

Aqueduct

An aqueduct is a generic term for a system for transferring water. It has a very wide definition, often being used to describe the conduit for transferring non-potable water from source to treatment works but occasionally it may be used for the conduit transferring potable water to a conurbation. It may be in the form of an open or closed conduit, channels, tunnel sections, multiple pipe sections, etc.

Transmission Main

A transmission main is used for the transfer of potable water between treatment works and service reservoirs or between service reservoirs. It is normal practice for utilities to avoid supplying water to customers from transmission mains unless there are particular circumstances or reasons for doing so. Transmission mains are referred to as trunk mains in the UK and as primary mains in some countries.

Service Reservoir (SR)

A service reservoir is a structure that holds water and is usually located at the edges of towns or within towns and defines the start of the water distribution network. A service reservoir is fed by a transmission main and will feed distribution mains or possibly a transmission main to another service reservoir. The main functions of a service reservoir are to provide the necessary head so that water can be supplied to customers within the supply area by gravity, to even out the diurnal demand pattern in order to minimise the maximum capacity needed at treatment works and transmission mains and also to provide emergency capacity to improve security of supply to the distribution network in the case of failure at the treatment works or a burst on the transmission main. Smaller service reservoirs are sometimes referred to as tanks. See Figure 1.

Main

A water main or distribution main is a pipe used for the "general" supply of water, usually supplying several properties and being within the reticulation of the network. A utility can be requisitioned to allow a connection for domestic purposes from a water main and be reimbursed for the cost. It may become difficult to decide the demarcation as to whether a pipe is a

Figure 1 Typical service reservoirs (Sources: K Atkinson (1, 2, 3, 5) and D Pearson (4)).

main or a service pipe at the very end of a rural network. Sometimes referred to as a water main, distribution main or secondary main (as opposed to trunk main).

Edge of Street (EoS)

The boundary of the street in which a main is laid.

Service Pipe

A service pipe is the section of pipe which connects a water main with a building. It includes both the service connection and private service pipe, see Figure 4.

Service Connection

That part of the service pipe that runs from the main to the edge of street, see Figure 4. There will usually be an external stop tap, and possibly a revenue meter, at the demarcation between the service connection and the private service pipe.

The service connection may run up to the building wall itself if this is at the edge of the street, see Figure 5. In this case the external stop tap, and possible revenue meter, may be above or below ground or may be just inside the building itself.

A service connection may supply one (see Figure 4) or more than one property (see Figure 5). This generally applies in organised systems or developed countries and is the ideal arrangement, but may however be less well defined in some other countries.

The service connection is owned by the utility and the maintenance of it is their responsibility. The service connection is referred to as a communication pipe in the UK.

Shared Connection

A service connection that supplies more than one property, see Figure 5.

Short-side Connection

A service connection from a main taken to premises that are on the same side of the road as the main, see Figures 1.4 and 1.5.

Long-side Connection

A service connection from a main taken to premises that are on the other side of the road to the main, see Figures 1.4 and 1.5.

Private Service Pipe

The private service pipe is the pipe that runs from the street boundary where the main is laid, to the internal stop tap in a property or supply location, see Figure 2. This pipe may often be laid underground and referred to as the underground private service

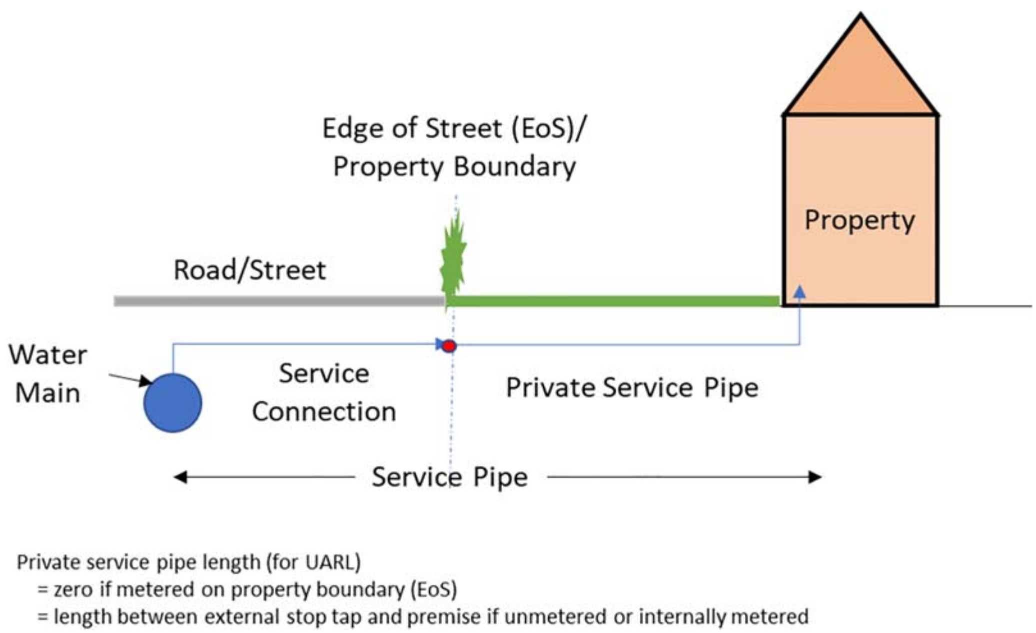

Figure 2 Diagram of a service connection Case 1 (Source: D Pearson).

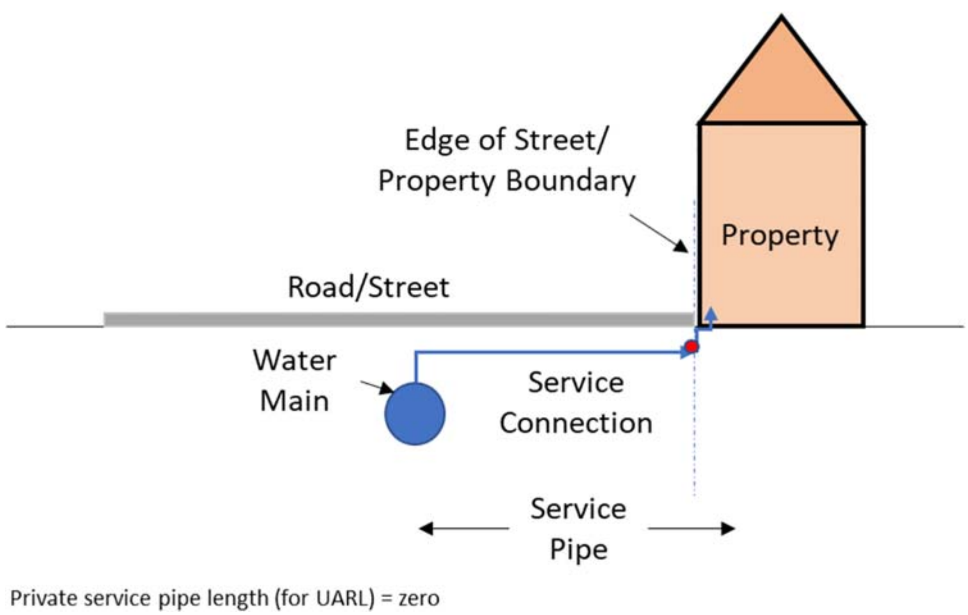

Figure 3 Diagram of a service connection Case 2 (Source: D Pearson).

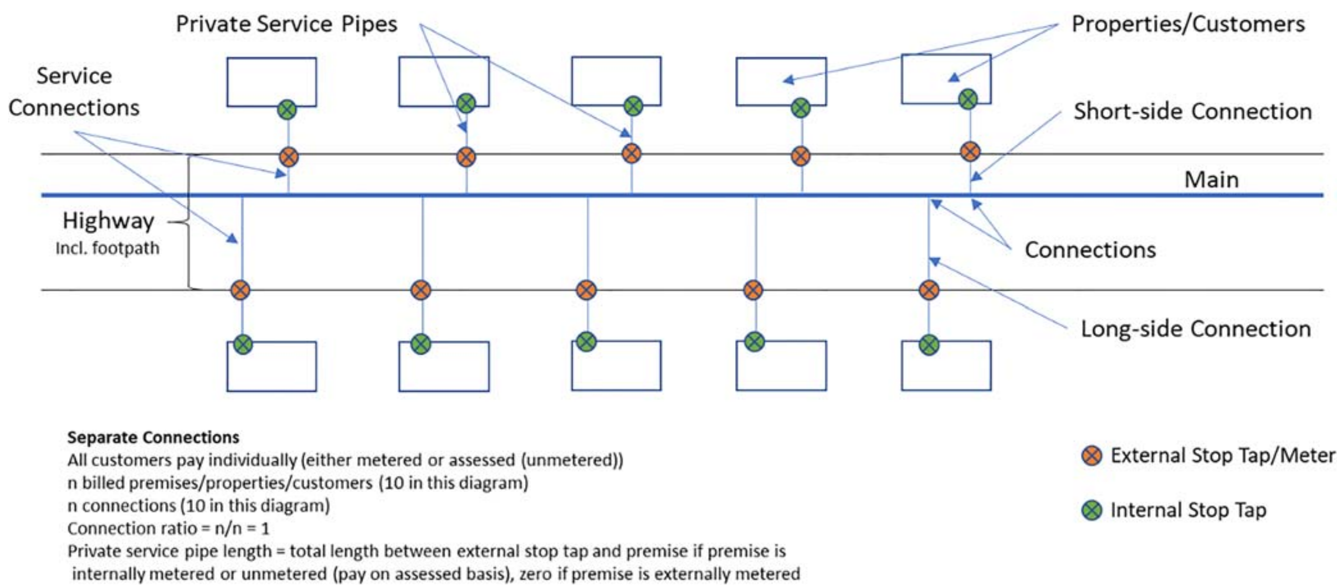

Figure 4 Diagram illustrating separate connection of properties to a water main (Source: D Pearson).

pipe, but can also be above ground, such as in a block of flats, see Figure 6. The supply pipe is owned by the owner of the property and maintenance is their responsibility. The private service pipe is referred to as a supply pipe in the UK.

The service connection is owned by the utility and the maintenance of it is their responsibility. A service connection may supply more than one private service pipe, see Figures 1.2 and 1.3. Referred to as a communication pipe in the UK.

Common Private Service Pipe

A private service pipe that feeds more than one customer, see Figure 6.

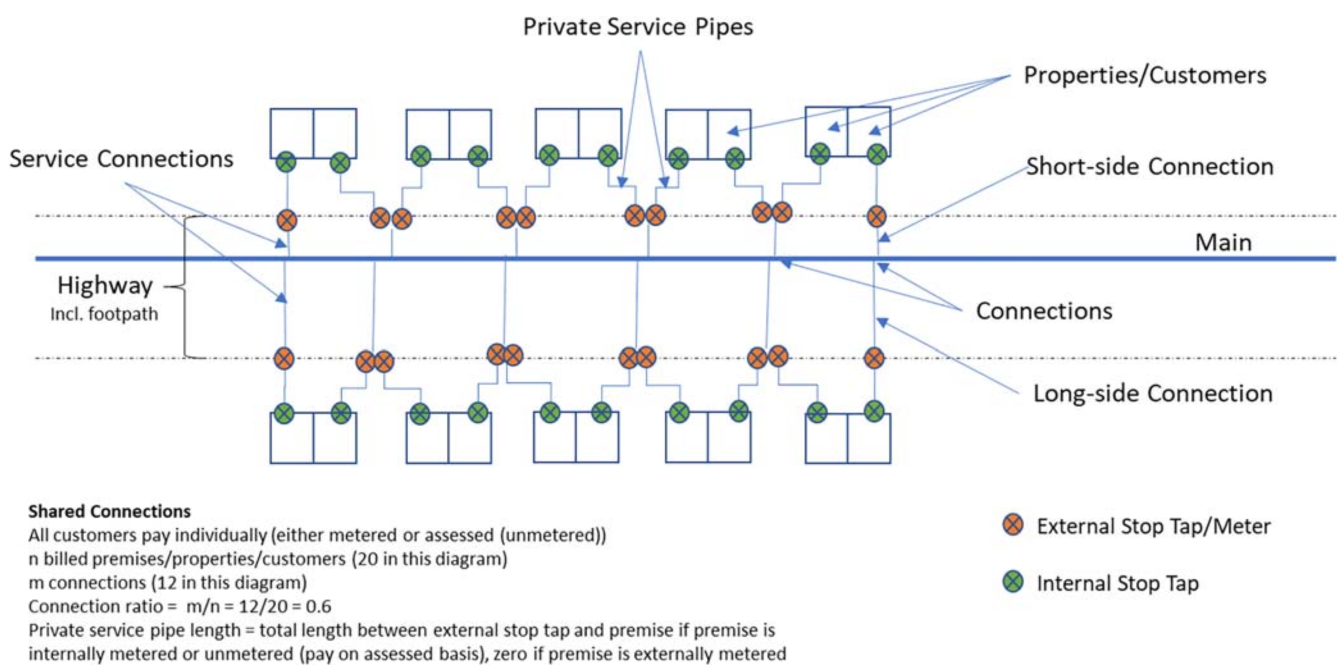

Figure 5 Diagram illustrating a shared connection to two properties (Source: D Pearson).

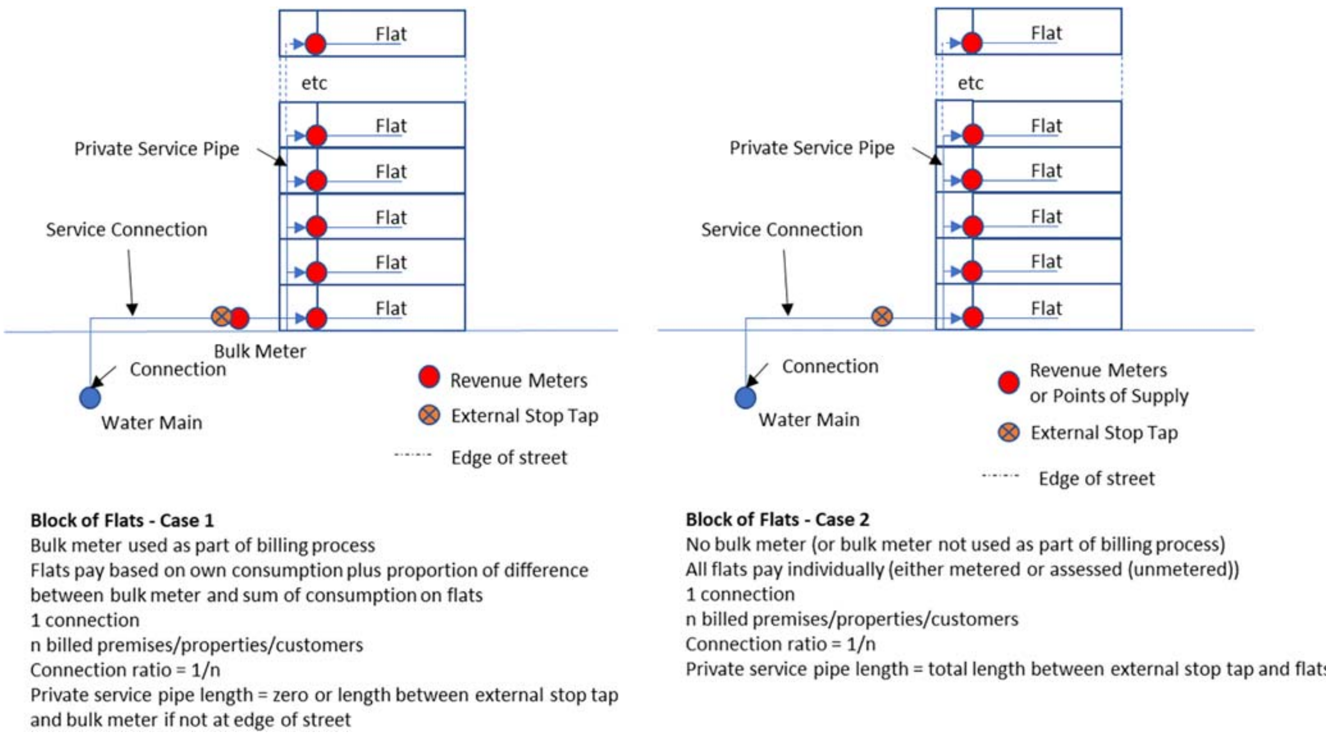

Figure 6 Diagram to show the private supply pipe arrangement for blocks of flats (Source: D Pearson).

Private Service Pipe

The length, in a utility or zone, of the private service pipes between the external stop tap and the point of supply. It is used in the calculation of UARL and UBL. The private supply pipe length for different supply arrangements is shown in the relevant diagrams (Figures 1.2–1.7). Care has to be taken in the estimation of private service pipe length when the properties are internally or externally metered (Figure 4 and Figure 5) and in the case of flats (Figure 6) or multiple properties (see Figure 7).

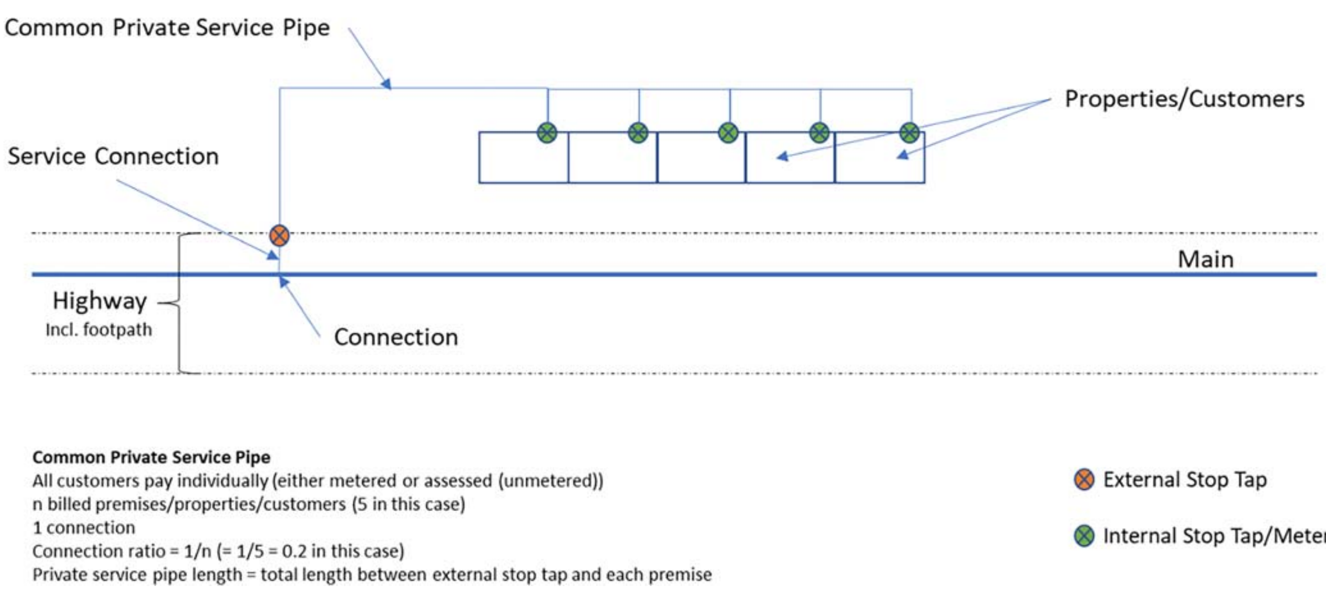

Figure 7 Diagram showing a common private service pipe (Source: D Pearson).

Connection

A connection is where a service pipe is connected to a main by a tapping point. A connection can be either legal or illegal.

Legal Connection

A connection which has been installed onto a main or another service pipe by or with the permission and authority of the utility.

Illegal Connection

A connection which has been installed onto a main or another service pipe without the permission or authority of the utility.

Connection Density

The ratio of the number of connections per unit length of main, i.e. no/km. Utilities do not generally know the number of connections on their system and therefore it is more common for them to express connection density in the form of connected properties or customers per unit length of main. This can however distort the value depending on the connection ratio and it is best to make it clear whether connection or property density is being used.

Connection Ratio

The ratio of connections to the number of properties or billed premises in an area of supply, such as a WRZ, DMA or other zone. The connection ratio will have a value from 0 to 100% and will be dependent on the predominant supply arrangement For example, the supply arrangement in the case of separate connections (Figure 2) would have a connection ratio of 1 or 100% whilst the supply arrangement in the case of shared services (Figure 3) would have a connection ratio of 0.6 or 60%. The connection ratio In the case of common private service pipes (Figure 6) or a block of flats (Figure 7) will only be a few percent.

Active Property

A property that is occupied, either continuously or occasionally, and which therefore could have consumption. A second home would be classed as active, as it will have consumption even if only occasionally.

Inactive Property

A property which is vacant and therefore has no consumption. Sometimes referred to as a void property.

Property

The definition of property can be complicated in practice. For the purposes of leakage management, it is easier to obtain the count of billed accounts from the customer billing system and it is therefore sensible to use a definition that reflects this, i.e. a property is synonymous with a billed account; be that a house, flat, industrial premise or commercial unit.

Property Density

The ratio of the number of billed properties (i.e. customers) per unit length of main, i.e. no/km.

Occupancy

Occupancy is the estimated population in an area (e.g. DMA, zone etc.) divided by the number of domestic properties (billed accounts) in the same area. The estimated population can be difficult to obtain but some countries have good quality census data. The billed accounts are obtained from a mapping of the area boundary between the GIS and the customer billing system.

Step Valve

A sluice valve used to shut off a step in a step test.

Circulating Valve

A sluice valve used to isolate sections of a DMA in order to create steps for a step test.

Boundary Valve

A sluice valve which is shut in order to create the boundary of a zone, PMA or DMA.

Meter Box

The piece of furniture located at the property boundary that usually contains a revenue meter and external stop tap, see Figure 8. Sometimes referred to as a boundary box.

Figure 8 Typical external meter box and Installation (Sources: Plasson (1), J Parker (2), Mueller Water Products Inc. (3)).

Stop Tap Chamber

The piece of furniture located at the property boundary that provides access to the external stop tap, in countries where the external stop tap is located below ground and where the property is not externally metered, see Figure 9. It is often

Figure 9 Typical external stop tap chambers (Sources: Plasson (1), Mueller Water Products Inc. (2)).

constructed of concrete segments or plastic ducting. Alternatively, it may be an integral part of the stop tap that brings a telescopic spindle up to the surface thereby avoiding the risk of the chamber filling with water and debris. Sometimes referred to as a stop tap box.

External Stop Tap

A stop tap that is at or close to the street boundary. This stop tap is owned by the water utility and maintenance is their responsibility. In some countries the water utility meter and associated stop tap must be within 1 metre of the first draw off from a service, hence their location inside the property. Additionally, in some countries, a separate water utility stop tap is not used, with the cock on the tapping point being used to isolate the main. Sometimes referred to as a stop cock. In the United States, this is referred to as a curb stop.

Internal Stop Tap

A stop tap that is adjacent to the outside wall of a property or immediately inside the property. This is owned by the owner of the property and maintenance is their responsibility.

Stop Tap

A stop tap or stop valve (see Figure 10) is used to regulate or control the flow of water from a main into and within both residential and commercial buildings. Sometimes referred to as a stop valve.

Figure 10 Typical external stop taps (Sources: Plasson (1, 2, 3) and Mueller Water Products Inc (4)).

Tapping

Tapping is the process of drilling through the pipe wall of a water main to provide a means of connection to the main. This could be a small diameter tapping (~20 mm) for a service connection (tapping point) or it may be a larger diameter (~60 mm) for the purpose of installing an insertion meter, see Figure 11.

Tapping Point

Tapping Point is the generic name for the connection from the main to the service connection. It can be either a ferrule or a tapping tee.

Tapping Tee

A tapping tee is the name for the connection from the main to the service connection in the case of PVC or PE mains. It is normal to have some form of saddle which is either fixed mechanically or welded to the main in order to provide support to the connection. The fitting usually contains its own cutter (self-tapper) which is wound down to drill through the plastic pipe to make the connection. The fitting may well contain a ferrule so that the supply can be turned on or off once the main has been tapped, see Figure 12.

1 Demo with gauging probe 2 Installation on pipe

Figure 11 Typical large diameter tapping (Source: K Atkinson (1, 2)).

1 2 3 Installation

Figure 12 Typical tapping tees and installation (Sources: Aliaxis UK (1), Mueller Water Products Inc. (2), J Parker(3)).

Ferrule

A ferrule is the connection from the main to the service pipe in the case of a metallic pipe. They are usually made from brass and are tapered, see Figure 13. The main is drilled and the ferrule is then tapped into the main. Some ferrules may include a valve so that the supply can be shut off at the main. In such cases, they are referred to as ferrule cocks or corporation stop cocks.

Figure 13 Typical ferrule and installation (Sources: Mueller Water products Inc. (1), K Atkinson (2)).

Appurtenances

A generic term to describe apparatus that is attached to mains. This includes sluice valves, hydrants, air valves and PRVs.

Fittings

A generic term to describe tees, bends and couplings etc. on mains.

Wash Out (WO)

A wash out is either a sluice valve or a hydrant which has been provided by the utility, usually but not necessarily at dead ends, for the purpose of flushing or emptying the network.

Fire Hydrant (FH)

A fire hydrant, sometimes called a fireplug, is a hydrant by which firefighters can gain access to a supply of water. It may be paid for by the fire brigade and is normally also maintained by them. It is normally designated and labelled FH.

Hydrant

A hydrant is a fitting positioned on a main or on a short branch to the side of the main from which water can be discharged. There are two prime purposes for a hydrant, namely, firefighting and mains flushing. If a hydrant is provided by the utility for the purposes of mains flushing it is normally designated and labelled WO. A hydrant can be above or below ground, as depicted in the following illustrations, see Figure 14. A hydrant provides access to the main which can be useful for the purposes of measuring pressure, correlating a leak using a hydrophone, access for intrusive leak detection equipment or internal inspection of pipe condition.

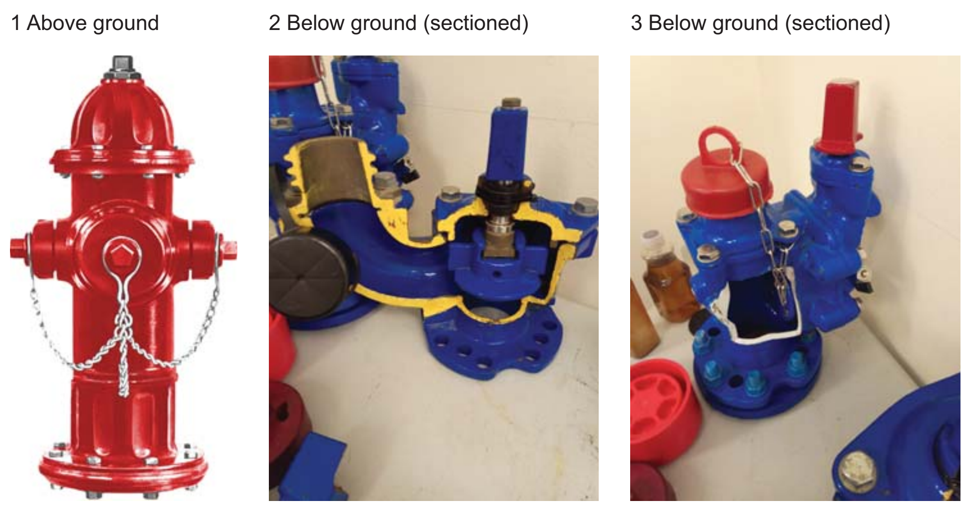

Figure 14 Typical hydrants (Sources: Mueller Water Products Inc. (1), K Atkinson (2, 3)).

Air Valve (AV)

An air valve is a valve designed to allow air, that may have accumulated at high points in a water main, to be expelled or allow air into the main when these are drained for maintenance or repair. They may also be installed at other strategic points, other than at the highest point on a main, see Figure 15.

Sluice Valve (SV)

A sluice or gate valve is a valve which opens by lifting an internal gate or wedge allowing water to pass through and when in the closed position prevents water from passing, see Figure 16. They are located on the network by the utility for the purposes of isolating or separating lengths of pipe for maintenance or repair of leaks, other interventions such as step tests or for the creation of district metered areas or waste areas. Large diameter (~350 mm) sluice valves can be fitted with a small bypass valve to equalise pressures across the valve before attempts are made to open the principal valve. Also referred to as a gate valve.

Figure 15 Typical air valves (sections) (Source: Mueller Water Products Inc.).

Figure 16 Typical sluice valves (Sources: Mueller Water Products Inc. (1, 2), K Atkinson (3, 4)).

Butterfly Valve

A butterfly valve is a valve that is operated with a disc turning through 90 degrees to allow or to stop the flow of water, see Figure 17. It is generally fitted on larger diameter mains where a sluice valve would be too large such that it might be close to or above ground level. Butterfly valves can be fitted with a small bypass valve to equalise pressures across the valve before attempts are made to open the principal valve.

Pressure Control Valve

The generic family of control valves that operate on the basis of pressure within the water supply or water distribution network. These include pressure reducing valves, pressure sustaining valves, pressure relief valves and altitude control valves.

Altitude Control Valve

A type of pressure control valve that is controlled by the absolute pressure at a location on the network. They are used to control the filling of service reservoirs.

1 2 Manual 3 Motorised

Figure 17 Typical butterfly valves and installation (Sources: Mueller Water Products Inc. (1), K Atkinson (2, 3)).

Pressure Sustaining Valve (PSV)

A type of pressure control valve that is used to ensure that the pressure at a point in the network is sustained.

Pressure Reducing Valve (PRV)

A pressure reducing valve is a control valve that reduces the pressure of water to a desired value at its outlet as it passes through, see Figure 18. They are sometimes referred to as pressure management valves. Pressure reducing valves are a specific application within the more generic family of pressure control valves.

1 2 Installation 3 Controllers

Figure 18 Typical PRV and installation (Sources: Mueller Water Products Inc. (1), K Atkinson (2, 3))

Pressure Relief Valve

A pressure relief valve is a control valve that relieves the pressure of water to a desired value by allowing the water to be discharged from the network.

FLOW METERING

Volumetric Meter

A volumetric meter is an instrument which measures either directly or indirectly, the volume, as opposed to the mass, of water passing through the instrument. Many volumetric meters actually measure the velocity of flow rather than directly measuring the volumetric flow rate. A positive displacement meter is an example of a direct volumetric meter and a turbine meter is an example of an indirect volumetric meter.

Positive Displacement Meter

A positive displacement meter uses a fixed volume chamber, or chambers, which is filled with water when it passes through the meter. The meter estimates the flow by counting the number of chambers that are filled in a given time period. It is a type of volumetric meter that directly measures the volumetric flow rate.

Turbine Meter

A turbine meter uses a turbine to measure the speed of water flowing through the meter. The meter can have single or multiple jets driving the turbine. The volume is estimated from the velocity using the cross section of the meter. It is a type of volumetric meter that indirectly measures the flow rate.

Electromagnetic Meter (EM)

An electromagnetic meter is a meter that uses the principle of Faraday's Law to estimate the velocity of water passing through the meter. A current is generated as the water flows through an electromagnetic field with the current being proportional to the velocity of the water. The volume is estimated from the velocity using the cross section of the meter.

Ultrasonic Meter

An ultrasonic meter uses the principle of the Doppler effect or transit time to estimate the velocity of water flowing through the meter. The meter has transmitters that emit ultrasound both with and against the direction of flow. For a Doppler ultrasonic meter, the velocity of flow is proportional to the difference in the amplitude of the sound received by sensors after passing through the water. For a transit time ultrasonic meter, the velocity of flow is proportional to the difference in travel time between the two signals. Ultrasonic meters are available as either a fixed full-bore meter inserted into the pipeline or as a meter strapped on or bolted around the outside of the existing pipe. This could be a permanent or temporary arrangement.

Full-bore Meter

A full-bore meter is a meter where the full flow passes through the meter. The installation therefore involves replacing a whole section of the pipe by the meter. They can be used on mains and service pipes. Installation costs can be high on existing large diameter mains.

Insertion Meter

An insertion meter is a meter that can be inserted into an existing pipe through a tapping on the top of the pipe, see Figure 19. It is used on larger diameter mains and not service pipes. The tapping and meter insertion can be made under pressure and therefore there is no disruption to supply to customers and costs are minimised. This type of meter can therefore cost significantly less than a full-bore meter for the same diameter main. On very large diameter mains, a multi-point insertion probe with more than one velocity sensor can be used. The velocity sensor, which is located on the insertion probe, may be a turbine meter, an electro-magnetic or an ultrasonic meter. The accuracy of an insertion meter is less than that of a full-bore meter because it is necessary to allow for the velocity profile across the main either by sampling at different depths, using a standard depth, or by integrating the velocities from multiple sensors.

1 Turbine insertion probe 2 Probe and loggers

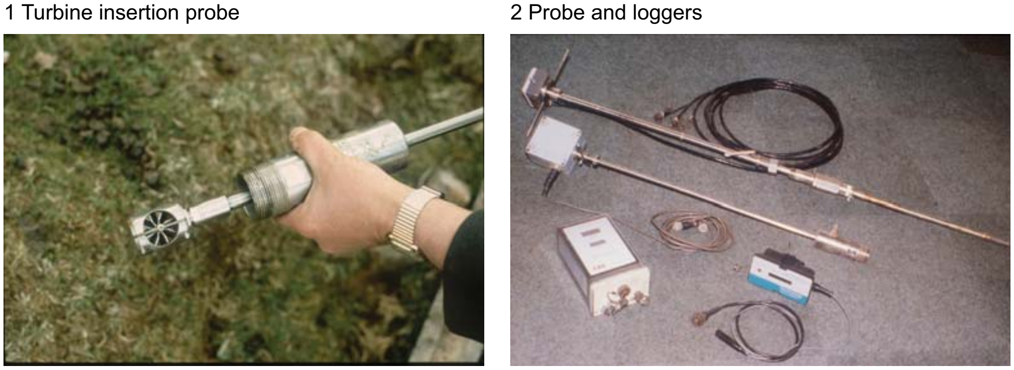

Figure 19 Typical insertion probes (Source: D Pearson (1, 2)).

Meter Calibration

Over time, meter performance can drift away from the manufacturer's original calibration. Meter calibration is the process of checking that a meter's calibration coefficients are as defined by the manufacturer when the meter was supplied. A good earth connection is also critical for all electronic meters and therefore should be checked during the calibration process.

Meter Verification

Even though a meter may be calibrated correctly, it may not measure flows accurately because of the installation arrangement. Meter accuracy is very susceptible to poor installation, for example, incorrect orientation, or being located too close to bends, pumps or other installations which may affect the water flow. Meter performance should therefore be verified on a regular (say ~1–3 years) basis. This could simply be by comparing the measured flow to flows measured at other meters either upstream or downstream. Where this verification indicates that there may be problems, then more sophisticated verification should be undertaken. This could involve installation of multiple insertion probes near the meter, using a temporary external strap-on ultrasonic meter or checking the volume registered through the meter against that registered in a service reservoir supplied or emptied solely via the meter.

Flow

Flow is the rate at which water passes a particular point in the network. Units of flow are typically L/s, m^3/h, gal/min.

Flow Meter

A flow meter is a device for measuring the flow of water at a point in a system. It may be a meter installed to aid management of a water supply network or water distribution network or it may be a revenue meter.

Flow Logger

An electronic device that can store the readings from a flow meter, for later interrogation or uploading to a central computer system or cloud based application, such as a leakage management system. The flow that is recorded will be the average flow registered on the flow meter over the relevant time period, often 15 minutes but can be some other time period.

Pulse Unit

An electronic device that is attached to a flow meter and converts the output of the meter into an electronic output that can be recorded on a flow logger.

Abstraction Meter

A meter that measures the volume of raw water abstracted from a source, such as a borehole, river intake or sea water intake.

Production Meter

A meter that measures the volume of potable water put into supply at a treatment works or desalination plant.

Distribution Input Meter

A meter that measures the flow that defines the input into the water supply network of a utility. It will normally be a production meter but may be a meter measuring any imports to or exports from the utility.

DMA Meter

A meter that measures the flow into or out of a DMA.

Bulk Meter

A bulk meter is any meter on the water supply network or water distribution network that is not a revenue meter.

Non-revenue Meter

Any meter that is not a revenue meter, for example a DMA meter, bulk meter, or production meter.

Revenue Meter

A revenue meter is a meter that is used for the purpose of billing consumption to properties, be that for domestic, commercial, municipal or industrial purposes. It will invariably be a full-bore meter on a service pipe.

Meter Reading Lag

Manual revenue meters are often read on a regular cycle. Reading cycles may be monthly or may be read at much less frequent intervals. For example, in the UK, domestic customer meters are only read once every six months. This means that the water supplied and water consumed figures can be out of phase, a phenomenon referred to as meter lag. The longer the meter reading cycle the higher will be the potential impact of the meter reading lag. The impact of meter reading lag is more significant during periods of fluctuations in demand such as short-term weather-related demand or when drought restrictions are introduced. The use of rolling 12-month average rather than spot monthly top down leakage will reduce, but may not entirely remove, the impact of meter lag.

Automatic Meter Reading (AMR)

Automatic meter reading is the technology of automatically collecting consumption, diagnostic and status data from revenue meters and transferring that data to a customer billing system for billing, troubleshooting and analysis. In general, AMR is used to describe the process where revenue meter data is downloaded automatically replicating the normal billing cycle, possibly on a more frequently basis, for example, volumes every day, week, month or quarter.

Advanced Metering Infrastructure (AMI)

Advanced metering infrastructure is the collective term to describe the whole infrastructure from true smart meters to two-way communication networks to control centre equipment and all the applications that enable the gathering and transfer of water usage information in near real-time.

Smart Meter

In strict terms, a meter is considered to be smart if it can be controlled by a network operator, allowing for example, consumption to be controlled in periods of high demand. In practice the word smart is commonly used for meters without this control function, but where 15-minute (or more frequent) data can be remotely collected. Because of the immediacy and frequency of data collection, Smart meters are more useful to support leakage management than AMR meters.

IWA STANDARD WATER BALANCE

The IWA Water Loss Specialist Group has developed a standard water balance, see Figure 20, and standardised terminology and definitions for the components of the water balance. In order to ensure consistency of assessment and reporting of losses, it is paramount that this water balance and respective definitions of the components are adhered to when undertaking any form of water loss study, auditing or reporting.

System Input Volume

The system input volume is the volume of treated water, be that produced by the utility themselves or imported into the area from another utility, input to the section of the water supply system to which the water balance calculation relates. It is a component in the IWA Standard Water Balance, see Figure 20.

Authorised Consumption

The volume of metered and/or unmetered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorised to do so by the water supplier, for residential, commercial, municipal and industrial purposes. This also includes water used by the military, government and other users, even if these are provided free of charge. It also includes water exported across the utility's boundaries.

Authorised consumption may include items such as water taken for firefighting, fire training exercises, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains and frost protection, amongst others. These may be billed or unbilled, metered or unmetered. It is a component in the IWA Standard Water Balance, see Figure 20.

<table>
<tr><td rowspan="11">System Input Volume (allow for known errors)</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed metered consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed unmetered consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled metered consumption</td><td rowspan="9">Non-Revenue Water</td></tr>
<tr><td>Unbilled unmetered consumption</td></tr>
<tr><td rowspan="7">Water Loss</td><td rowspan="4">Apparent Losses</td><td>Unauthorised consumption</td></tr>
<tr><td>Data handling and billing errors</td></tr>
<tr><td>Underestimation of unmeasured consumption</td></tr>
<tr><td>Customer metering inaccuracies</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on transmission and distribution mains</td></tr>
<tr><td>Leakage and overflows at utility's storage tanks</td></tr>
<tr><td>Leakage on service connections up to the point of customer metering</td></tr>
</table>

Figure 20 The IWA Standard Water Balance (Source: IWA).

Revenue Water

The volume of water for which income is obtained. It is the sum of billed authorised consumption including water exported across the utility's boundaries for which income is received. It is a component in the IWA Standard Water Balance, see Figure 20.

Billed Authorised Consumption

Those components of authorised consumption which are billed and produce revenue. It is equal to billed metered consumption plus billed unmetered consumption and also known as revenue water. It is a component in the IWA Standard Water Balance, see Figure 20.

Billed Metered Consumption

All metered consumption which is also billed. This encompasses all groups of customers such as domestic, commercial, industrial or institutional and includes water exported across the utility's boundaries which is metered and billed. It is a component in the IWA Standard Water Balance, see Figure 20.

Billed Unmetered Consumption

All billed consumption which is calculated based on estimates or norms but is not metered. This may be a very small component within fully metered systems, for example, billing based on estimates for the period a customer meter is out of order but can be the key consumption component in systems without universal metering. This component may also include water exported across the utility's boundaries which is unmetered but billed. It is a component in the IWA Standard Water Balance, see Figure 20.

Unbilled Authorised Consumption

Unbilled authorised consumption are those components of authorised consumption which comprise legitimate usage, but which are not billed and therefore do not produce revenue. Unbilled authorised consumption is equal to unbilled metered consumption plus unbilled unmetered consumption. It is a component in the IWA Standard Water Balance, see Figure 20.

Unbilled Metered Consumption

Unbilled metered consumption is metered consumption which is, for any reason, unbilled. This may, for example, include metered consumption by the utility itself or water provided to institutions free of charge, including any water exported across the utility's boundaries which is metered but unbilled. It is a component in the IWA Standard Water Balance, see Figure 20.

Unbilled Unmetered Consumption

Unbilled unmetered consumption is any kind of authorised consumption, including any water exported across the utility's boundaries, which is neither billed nor metered. This component typically includes items such as firefighting, flushing of mains and sewers, street cleaning or frost protection, amongst others. In a well-run utility, it is a small component of total authorised consumption. It is a component in the IWA Standard Water Balance, see Figure 20.

Non-Revenue Water (NRW)

Non-revenue water are those components of system input volume which are not billed and do not produce revenue, i.e. not revenue water. It is equal to unbilled authorised consumption plus real losses and apparent losses. It is a component in the IWA Standard Water Balance, see Figure 20.

Unaccounted for Water (UFW)

The term unaccounted for water (UFW) was commonly used in the past, but because of the widely varying interpretations and definitions of the term, it is strongly recommended, by the IWA WLSG, that this term no longer be used.

Water Losses

The difference between system input volume and authorised consumption. Water losses can be considered as a total volume for the whole system, for partial systems such as transmission or distribution schemes, or individual zones. Water losses consist of real losses and apparent losses. It is a component in the IWA Standard Water Balance, see Figure 20.

Non-technical Losses

This is a term used in some counties for apparent losses. However, it is a confusing and misleading term since many of the issues relating to apparent losses are in fact technical. The IWA WLSG therefore recommends that this term is no longer used.

Apparent Losses (AL)

Apparent losses include all types of inaccuracies associated with customer metering as well as data handling errors, such as meter reading and billing, plus unauthorised consumption from theft or illegal use. It is a component of water losses in the IWA Standard Water Balance, see Figure 20. Apparent losses are often referred to as commercial losses in low- and middle-income countries and by development banks.

Unauthorised Consumption

Unauthorised consumption is any unauthorised use of water. This may include water illegally withdrawn from hydrants, for example, for unauthorised construction purposes, illegal connections, bypasses to consumption meters or meter tampering. It is a component of apparent losses in the IWA Standard Water Balance, see Figure 20.

Data Handling and Billing Errors

The volume of true consumption which is not recorded on the billing system due to billing or data handling errors. These could include transcription errors, consumption on premises that have not been registered on the billing system due to internal procedural errors, premises incorrectly flagged on the billing system (e.g. flagged as demolished but still live), etc. It is a component of apparent losses in the IWA Standard Water Balance, see Figure 20.

Underestimation of Unmeasured Consumption

The volume by which the true consumption of unmeasured customers is underestimated. This may be household or non-household use. This will be a particular problem where unmeasured consumption is high, for example in countries where domestic premises are not metered, or where there are unmeasured communal water supplies in improvised housing areas. In practice true consumption may be overestimated in which case apparent losses (and possibly real losses) could be understated. It is a component of apparent losses in the IWA Standard Water Balance, see Figure 20.

Customer Metering Inaccuracies

The volume by which meters under-record the true volume consumed by customers. The level of customer metering inaccuracy depends on meter type, meter class, meter sizing (in relation to the flow), meter age, installation details (e.g. close to bends, near pumps etc.) and the size of roof tanks, if the meter feeds roof tanks. The actual in-situ performance is assessed as meter under registration. It is a component of apparent losses in the IWA Standard Water Balance, see Figure 20.

Technical Losses

This is a term used in some counties for real losses. However, it is a confusing and misleading term since many of the issues relating to apparent losses are also technical. The IWA WLSG therefore recommend that this term is no longer used.

Real Losses (RL)

Real Losses from the pressurised system (transmission mains, mains and service pipes) and the utility's service reservoirs, from the distribution input meters up to the point of supply. It is a component of water losses in the IWA Standard Water Balance, see Figure 20. Real losses are often referred to as physical losses in low- and middle-income countries and by development banks.

Leakage and Overflows from Utility Storage Tanks

Water lost from leaking storage tank structures (service reservoirs) or overflows from such tanks caused by operational or technical problems, for example, a failed level control mechanism or leaking tank joints. It is a component of real losses in the IWA Standard Water Balance, see Figure 20.

Leakage on Service Connections up to the Point of Customer Metering

Water lost from leaks and breaks of service pipes from and including the tapping point up to the point of supply. Leakage on service pipes may be reported breaks but will predominately be small unreported leaks which may run for long periods, often years. They may be leaks that are below the level of detection and therefore contribute to background leakage. It is a component of real losses in the IWA Standard Water Balance, see Figure 20.

Leakage on Transmission and/or Distribution Mains

Water lost from leaks and breaks on transmission and distribution pipelines and appurtenances. These may either be small leaks which are still unreported, such as leaking joints, or large bursts which were reported and repaired but obviously leaked for a certain period before that. It is a component of real losses in the IWA Standard Water Balance, see Figure 20.

Point of Supply

For an unmetered property, the point of supply is typically taken to be at the first point of use, usually the kitchen sink. However, for metered properties, the point of supply is taken to be the outlet of the revenue meter; whether this is at the property line or within the building, see Figure 4.

Plumbing Losses

Plumbing losses constitute the element of consumption which is not used within the premise. They are made up of losses such as dripping taps, overflowing cisterns or leaks on pipework downstream of the point of supply. Plumbing losses will be included in the consumption if the premise is metered. Plumbing losses will be included in the night flow measured on a DMA or waste area.

Consumption

Consumption is all water taken into premises, whether domestic, commercial, industrial or institutional among others, be that for use or because of plumbing losses. When considering the water balance for a whole system, then consumption will include all consumption on premises together with water directly taken off the system, whether recorded, billed, unbilled, authorised or unauthorised, namely being the equivalent to authorised consumption plus apparent losses, see Figure 20.

Per Capita Consumption (PCC)

Per capita consumption is the average daily consumption per person in an area, be that a DMA, zone or any other level in the network hierarchy. If all the properties are metered then this value can be obtained from the billing system using the following equation:

$$PCC_{est} = \frac{Measured\ Consumption\ on\ metered\ domestic\ properties}{Number\ of\ metered\ domestic\ properties \times occupancy}$$

When domestic properties are not metered it is necessary to estimate PCC (or PHC) in order to provide an estimate of the unmeasured household consumption, which will be a significant component of billed unmetered consumption, to be used in the IWA Standard Water Balance. Estimation of PCC is usually carried out using a small area monitor or individual household monitor studies. It is critical that consumption does not include non-household consumption nor any leakage on the mains or service connections. Typical units of PCC are l/c/d or gal/c/d.

Per Household Consumption (PHC)

Per household consumption is the average daily consumption per domestic property in an area, be that DMA, zone or any other level in the network hierarchy. If all the properties are metered then this value can be obtained from the billing system using the following equation:

$$PHC_{est} = \frac{Measured\ Consumption\ on\ metered\ domestic\ properties}{Number\ of\ domestic\ properties}$$

PHC is more reliable than PCC where occupancy rates are not known. When domestic properties are not metered it is necessary to estimate PHC (or PCC) in order to provide an estimate of the unmeasured household consumption which will be a significant component of billed unmetered consumption, to be used in the IWA Standard Water Balance (Figure 20). Estimation of PHC is usually carried out using a small area monitor or individual household monitor studies. It is critical that consumption does not include non-household consumption nor any leakage on the mains or service connections. Typical units of PHC are l/prop/d or gal/prop/d.

Small Area Monitor (SAM)

A small area monitor is used to estimate either PCC or PHC of unmeasured customers. Each SAM usually comprises approximately 50–100 domestic properties in order to reduce the risk of leakage on the mains or service connections. Flows are monitored into the area and the PCC or PHC evaluated. A mix of property types and socio-economic groupings of occupants across the SAMs should be used in order to ensure a representative sample of the population as a whole.

Individual Household Monitor (IHM)

An individual household monitor is used to estimate either PCC or PHC of unmeasured customers. An IHM comprises a number of domestic properties (usually several hundred), distributed across the area being considered, where the customer is metered, either internally or externally, but is not charged on their consumption, with the hope of them not changing their water use. Consumption is monitored and the PCC or PHC evaluated. An IHM needs to include a mix of property types and socio-economic groupings of occupants in order to ensure a representative sample of the population as a whole.

Diurnal Demand Pattern

The term relates to the normal pattern of demand over a day which exhibits a distinct pattern of higher consumption during the day and significantly lower consumption at night, see Figure 21.

LEAKAGE MANAGEMENT

Leakage management is the process of managing leakage from measurement, monitoring, prioritising detection and leakage detection itself. Strategic leakage management looks at establishing the optimum balance of activities, such as pressure management and leakage detection, to achieve targets or the necessary headroom in order to secure reliable supplies or avoid intermittent supplies.

Leakage Control

Leakage control is the process of undertaking a series of activities to control the actual level of leakage. The main activities that can be used to control leakage are: active leakage control, pressure management, effective and speedy repairs and mains rehabilitation. These can be represented diagrammatically as acting on the level of leakage, see Figure 22.

Leakage

Leakage is the loss of water from a water distribution system due to leaks.

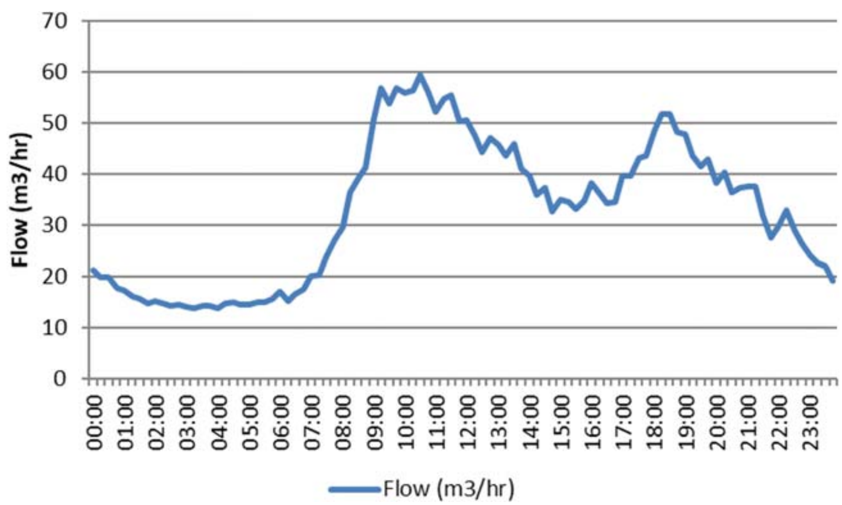

Figure 21 Typical diurnal demand pattern (Source: D Pearson).

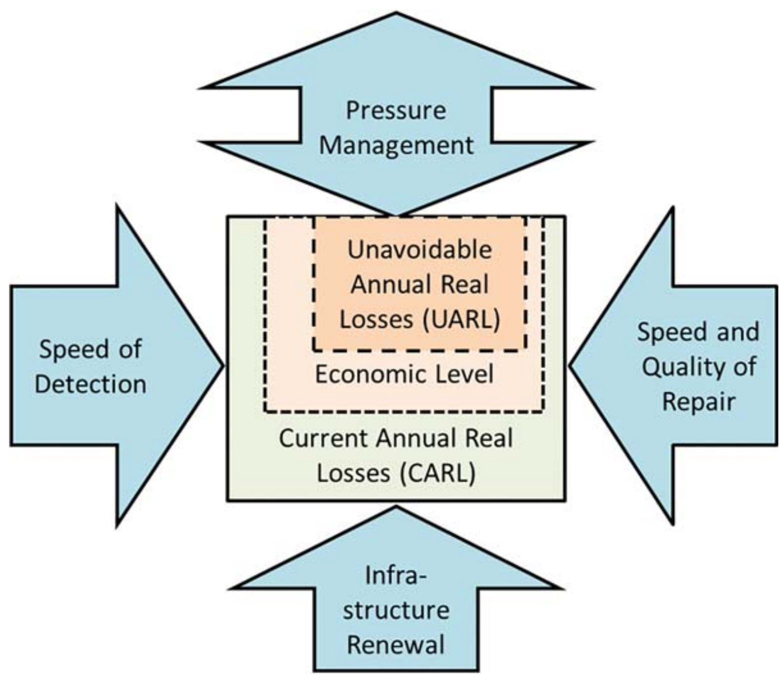

Figure 22 The four primary methods of managing real losses (Source: D Pearson).

Daily Leakage

The daily volume of leakage, usually calculated at DMA level but can be evaluated at zone level, assessed either using the TIF method, or from the night leakage multiplied by the HDF. The most commonly used units would be, for example, m^3/d, Ml/d or gal/d.

Night Leakage

Night leakage is the leakage during 1 h at the time of the minimum flow, which usually occurs in the middle of the night. It is assessed using the minimum flow method, usually at a DMA level but can be evaluated at zone level. The most commonly used units would be, for example, m^3/h or gal/h.

Zone

Zone is a term that is often used for larger sections of a network, which may comprise several DMAs or which may not have any DMAs at all, but which is too large to be considered as a DMA.

District Metered Area (DMA)

A DMA is a section of the distribution network, commonly where sluice valves have been shut off, usually permanently, so that demand in the area can be monitored by the flow through one or more meters for the purpose of leakage management, see Figure 23. There may be more than one DMA meter measuring the flows into and out of the DMA. All unmetered connections along the boundary of the DMA must be valved off (closed). There is no fixed rule on the size of DMAs. If they are too small then there is a higher cost for monitoring (meters, pulse units, flow loggers) and analysis. If they are too large then the resolution for discerning when leakage is accumulating is reduced. It is generally recommended that DMAs are between 6–10 km and 500–2500 properties. DMA boundaries should be chosen to take advantage of natural hydraulic boundaries in order to minimise the number of meters. They should be chosen to separate domestic and industrial/commercial areas where possible. They should also be designed along the contours of the area in order to minimise the difference in elevation across the DMA to aid pressure management. DMAs are sometimes referred to as sectors and the process of setting up DMAs referred to as sectorisation.

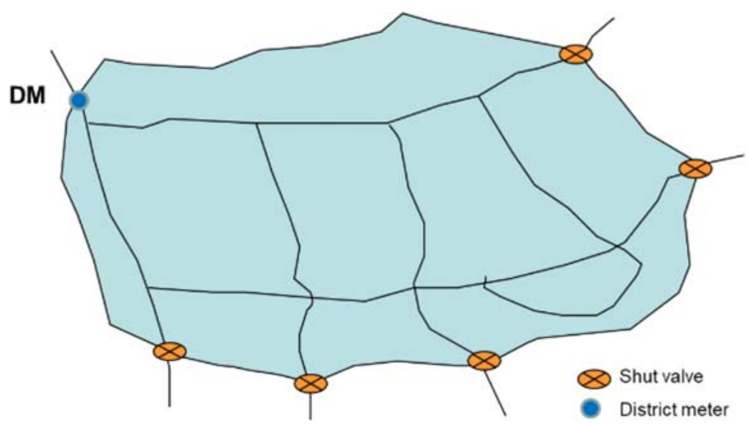

Figure 23 Illustration of a district metered area (Source: D Pearson).

Net Flow

The net flow is the flow into an area (e.g. zone, DMA or sub-DMA) taking into account the additions and subtraction of flows measured at the inlet and outlet meters of the area. It is equivalent to the demand on the area. It is now common usage to use "net" rather than "nett" in the English language.

Sub-DMA

A sub-DMA is an area within a DMA that is monitored in order to localise the area where a leak may have broken out within the DMA. The valving and/or recording of the flows of a sub-DMA may be temporary or permanent. The metering of a sub-DMA may be temporary, using a meter installed on a trailer and an overland bypass between hydrants. Previously referred to as a waste area or leakage control area.

Attributes

Attributes are the physical parameters of a particular area, be that a zone or a DMA. Typical attributes are length of mains, number of properties, number of connections, AZNP and HDF.

Minimum Night Flow (MNF)

The minimum night flow is the minimum 1 h flow rate recorded during the night period, normally defined as being between midnight and 6am. The minimum night flow in urban situations normally occurs during the early morning period, commonly between 2 and 4am, see Figure 24. The term minimum night flow is therefore common parlance for the minimum flow because of this. The minimum night flow is the most meaningful piece of data as far as estimating night leakage is concerned, see minimum night flow method. The term night line is also often used for Minimum Night Flow. See also minimum flow.

Tracking the minimum night flow over a period of time can show whether unreported leakage is accumulating on the area (DMA, sub-DMA or Zone) and is therefore a key activity in leakage management.

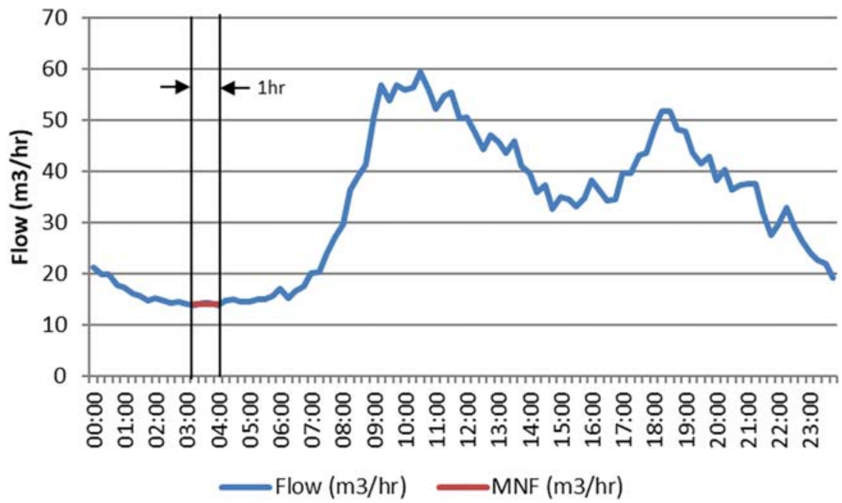

Figure 24 Diagram illustrating minimum night flow period (Source: D Pearson).

Figure 25 shows a plot of 15 minute interval net flow into a DMA, i.e. as per Figure 24, for a period of around 20 weeks. This shows that the minimum night flow has a distinct weekly cycle with the MNF on a Saturday night about 2 m^3/h higher than during the week. It is therefore essential not to believe that this increase could be a leak and respond too quickly. Second, the graph shows that there has been an increase in the MNF from about 13 to 19 m^3/h over the analysis period, thus indicating a rise in leakage due to unreported leaks during this period. It is also interesting to note that the amplitude of the diurnal demand pattern has remained consistent during the period. This indicates that there has been no change in the status of the DMA during this period and that the boundary has remained tight.

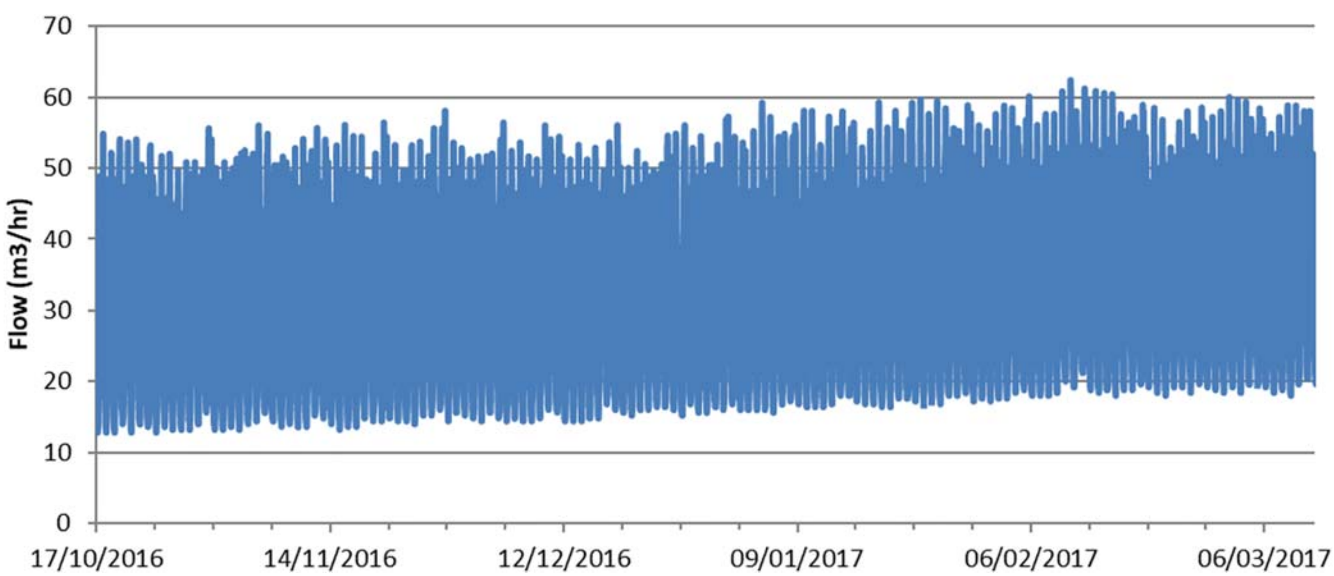

Figure 25 Typical pattern of 15 minute flows over a period of 20 weeks (Source: D Pearson).

Minimum Flow (MF)

The minimum flow is the minimum 1 hour flow rate recorded during a 24-h period. The minimum flow in urban situations normally occurs during the early morning period, commonly between 2 and 4am and is referred to as the minimum night flow. However, in some locations the minimum flow may occur outside of this night period due to other water use demands, such as agriculture or the use of night time electricity, and therefore the more generic title of minimum flow is more suitable. In the case of systems with intermittent water supply, the minimum flow has to be taken during periods when the system is pressurised, although even then customer tanks may still be filling and therefore this flow has to interpreted with care.

Total Integrated Flow Method (TIF Method)

The total integrated flows are the daily volumes of the water balance components, such as the average daily net flow and measured consumption. Leakage in an area, such as a DMA or zone, can be estimated by carrying out a water balance using the TIF components and comparing this to the estimate derived from the using the minimum night flow method (see also operability test).

Minimum Night Flow Method (MNF Method)

The minimum night flow method is used to estimate night leakage in a DMA or zone using the minimum night flow, provided there is no service reservoir in the zone which could be filling or emptying during this period. During the minimum night flow period, consumption is at a minimum and therefore leakage is at a maximum proportion of the total flow, see Figure 21. Estimation of the leakage component of the minimum night flow is undertaken by subtracting from the minimum night flow, an assessment, estimated or logged during the period of minimum flow, of night consumption for all the customers connected in the DMA or zone being studied.

The minimum night flow method cannot generally be used with systems with intermittent water supplies, as the system may be shut off or depressurised during the period of minimum night flow and therefore there will be little or no leakage at that time. Even if the system is pressurised during the night, the consumption pattern can be unreliable as customers cisterns may be filling or customers may be storing water ready for the next period without supply.

Legitimate Night Consumption (LNC)

Legitimate night consumption is the consumption of authorised users during the period when the minimum night flow is assessed. Total night consumption is the sum of both domestic night consumption and non-household night consumption. It has been given the label “night” as this is the most common situation. The label “minimum” cannot be used as it must be the consumption assessed at the time coincident with the time when the minimum night flow is assessed, which may not actually be the minimum consumption. Night consumption will include plumbing losses as well as actual customer use. The term is normally prefaced by the word “legitimate” in order to imply that it is assessed for the case of normal legitimate use and not unauthorised use, e.g. theft.

Legitimate Domestic Night Consumption (LDNC)

Domestic night consumption is the assessed consumption of authorised domestic users during the period when the minimum night flow is assessed. Domestic night consumption is generally consistent and can be estimated from data taken from a statistical sample of domestic users. It is normal to express this in the form of l/prop/h in situations where domestic properties are generally unmeasured but expressed in the form of a percentage of the average daily consumption where domestic properties are generally metered. See also night consumption. The term is normally prefaced by the word “legitimate” in order to imply that it is assessed for the case of normal legitimate use and not unauthorised use, e.g. theft. The night consumption will include plumbing losses in addition to customer use.

Legitimate Non-household Night Consumption (LNHHNC)

Non-household night consumption is the assessed consumption of all authorised users other than domestic (i.e. commercial, municipal and industrial etc.) during the period when the minimum night flow is assessed. It is normal to express this in the form of l/prop/h for unmetered non-household types and in the form of a percentage of the average daily billed volume in the case of metered non-household types. The latter ratios are usually estimated from data taken from a statistical sample of non-household users, often stratified by type and size. If the consumption of a particular user is not consistent from one night to another it is often necessary to continuously log this user in order to establish their night consumption. The term is normally prefaced by the word "legitimate" in order to imply that it is assessed for the case of normal legitimate use and not unauthorised use, e.g. theft. The night consumption will include plumbing losses in addition to customer use.

Continuous Logged User (CLU)

When a particular non-household customer's use during the minimum night flow period is significant and variable then it may be necessary to log the user on a continuous basis so that their consumption can be subtracted from the minimum night flow. The general availability and deployment of smart meters is making this aspect of leakage management easier.

Operability Test

The operability test is a technique used to give confidence as to whether a DMA is correctly isolated, verify that there are no meter scaling errors and that the DMA attributes are reasonably correct. In the test, leakage assessed using the minimum night flow method is compared to that derived using the total integrated flow method components on the same area. Either the leakage from the two methods is compared or the implied household consumption from equating the leakage is compared to the expected household consumption as the pass/fail criteria for the operability test. It is usually assessed on an individual DMA basis but can then be accumulated to higher levels in the network hierarchy.

Top Down Leakage Assessment (TD)

The assessment of leakage in a zone by carrying out a water balance on that zone as a whole, namely water in minus water out. The IWA Standard Water Balance should be used for this assessment.

Bottom Up Leakage Assessment (BU)

The assessment of leakage in a zone by adding up the leakage assessed on the individual components, such as DMAs, service reservoirs and trunk mains. Allowance must be made for leakage in areas that are not monitored and also for leakage in areas where data is believed to be inaccurate.

Downstream Leakage

This is the leakage in the area of the network covered by DMAs.

Upstream Leakage

This is the leakage in the water supply network upstream of DMAs. This, therefore, can include leakage on transmission mains, service reservoirs and on distribution mains between service reservoirs and DMA meters. It will include leakage on unmonitored areas if these are not estimated as part of downstream leakage. Monitoring of upstream leakage includes the whole system from distribution input meters down to the DMA meters.

Minimum Achieved Night Flow

The minimum achieved night flow is the minimum night flow that has been achieved in a DMA over a long period, usually greater than four years, provided that the DMA boundary, pressure regime and water use regime have not changed significantly within this period.

Minimum Achievable Night Flow (Mabl)

The minimum achievable night flow is an assessment of the minimum night flow that may be expected in a DMA, considering a realistic estimate of the infrastructure condition factor, average zone night pressure and assessed night consumption.

Unavoidable Annual Real Losses (UARL)

The volume of unavoidable annual real losses represents the lowest technically achievable annual volume of real losses for a well-maintained and well-managed system. The standard equation for calculating UARL for individual systems was developed and tested by the IWA Water Loss Task Force (the predecessor of the IWA WLSG). It allows for:

- Background leakage – small leaks with flow rates too low for acoustic detection if not visible
- Leakage from reported leaks – based on average frequencies, typical flow rates and target average durations
- Leakage from unreported leaks – based on average frequencies, typical flow rates and target average durations
- Pressure/leakage rate relationships, with a linear relationship being assumed ($N1=1$)

The UARL equation requires data on only four key system-specific factors:

- Length of mains including all pipelines, except service pipes (L_m) in km
- Number of connections (N_c)
- Length of private service pipe between property boundary and customer revenue meter or notional point of delivery (L_p) in km

Note: This is not the same as the total length of service pipes. Losses on the service connection, between the tapping point on the main and the property boundary, are included in the allowance per service connection. The additional allowance for the private service pipe was included to take into account longer leak run-times in situations where visible leaks would not be seen by the public. In most urban situations, if the customer revenue meter is at the property boundary, then the length of private service pipe between property boundary and customer revenue meter will be nil.

- Average operating pressure (AOP) when system is pressurised (wsp) in m

The formula for UARL is:

$$UARL(l/d) = (18 \times L_m + 0.80 \times N_c + 25 \times L_p) \times AOP_{w.s.p.}$$

A second order adjustment of the coefficients in the equation can be applied if it is considered that a linear relationship to pressure is not appropriate. The formula can also be adjusted for use with very small zones (<3000 connections).

Background Leakage

Background leakage is the sum of individual small leaks, such as weeps and drips, that persist with flow rates too low to be detected by an active leakage control campaign, unless either detected by chance or until they gradually worsen to the point that they can be detected. Background leakage should not be confused with unavoidable losses (UARL) as the latter includes an allowance for losses from bursts in addition to background leakage. The level of background leakage depends on the overall infrastructure condition, the pipe material(s), the quality of installation and the soil. It is, furthermore, heavily influenced by pressure, with N1 being typically 1.5 or higher.

Unavoidable Background Leakage (UBL)

The UBL is the estimate level of background leakage that may be expected on the area being monitored (zone, DMA or sub-DMA) using the IWA WLSG's background leakage factors used in the estimation of the UARL, taking the actual AZNP (when system is pressurised) into account using an N1 equal to 1.5.

The unit factors for UBL recommended by the IWA WLSG are:

Mains	20l/km/h at 50 m pressure
Service connections	1.25l/connection/h at 50 m pressure
Private Service Pipes	33.3l/km/h at 50 m pressure

The formula for UBL is:

$$UBL(l/h) = (20 \times L_m + 1.25 \times N_c + 33.3 \times L_p) \times AZNP_{w.s.p.}{}^{\wedge 1.5}$$

where L_m is the length of mains in km, N_c=number of connections, L_p is length of private service pipe in km and AZNP is pressure at the average zone point at the time of the minimum night flow in m.

Infrastructure Condition Factor (ICF)

The infrastructure condition factor is the ratio of the actual background leakage to unavoidable background leakage that may be expected on the same area (zone, DMA or sub-DMA). ICF can be estimated at DMA, and then evaluated at higher levels in the network hierarchy. The ICF can provide a reflection of asset condition. New fully welded PE systems could be expected to have an ICF close to 0, whereas the ICF for an older system in poor condition may be about 3. Where ICF on a DMA is estimated to be greater than 3, there should be rigorous checks to ensure that the attributes are correct and that the boundary valves are closed. ICFs of greater than 3 can indicate that there are active leaks running in the DMA.

Burst Frequency

The IWA WLSG recommend that utilities use appropriate work management systems to record whether leaks occur on mains, service connections, private service pipes or appurtenances. This level of detailed record keeping can then be used to compare system performance to that used in the calculation of the unavoidable losses and support decisions on the benefits of pressure management, the need for refurbishment, the selection of materials and the appropriateness of construction details.

Mains Burst Frequency

The average frequency (i.e. number per year) of bursts that occur on the mains in a network or part of a network, e.g. DMA. In order to provide a statistically robust estimate it is better if this frequency is the average over several years (>~4 years). It is essential that the pressure regime and network boundary is consistent over this period. See also normalised mains burst frequency.

Service Pipe Burst Frequency

The average frequency (i.e. number per year) of bursts that occur on the service pipes in a network or part of a network, e.g. DMA. In order to provide a statistically robust estimate it is better if this frequency is the average over several years (>~4 years). It is essential that the pressure regime and network boundary is consistent over this period. It is often useful to split the frequency of bursts between those occurring on service connections and those occurring on private service pipes. See service connection burst frequency and private service pipe burst frequency. See also normalised service pipe burst frequency.

Service Connection Burst Frequency

The average frequency (i.e. number per year) of bursts that occur on the service connections in a network or part of a network, e.g. DMA. In order to provide a statistically robust estimate it is better if this frequency is the average over several years (>~4 years). It is essential that the pressure regime and network boundary is consistent over this period. See also normalised service connection burst frequency.

Private Service Pipe Burst Frequency

The average frequency (i.e. number per year) of bursts that occur on the private service pipes in a network or part of a network, e.g. DMA. In order to provide a statistically robust estimate it is better if this frequency is the average over several years (>~4 years). It is essential that the pressure regime and network boundary is consistent over this period. See also normalised private service pipe burst frequency.

Natural Rate of Rise of Leakage (NRR)

The natural rate of rise of leakage relates is the underlying rate at which leakage increases within a system given the absence of any interventions to reduce leakage. It is caused by the gradual growth of existing leaks and the breaking out of new leaks. The most common NRR is if no unreported leaks were detected and repaired. This is referred to as NRRd (or simply NRR) where "d" stands for detected. It is feasible to consider NRRg which is the gross NRR if no leaks, either reported or unreported, were repaired.

Smart Network

A smart network contains built-in diagnostic equipment or systems, such as remotely monitored flow, sound and pressure sensors or remote-controlled valves, which allow the system to be managed or controlled from a remote location for efficient management, thus allowing it to perform in an economic and efficient manner. With ever developing technology, digitisation has accelerated the collection and dissemination of actionable information both on the supply and the demand side to all stakeholder groups including utilities managers themselves, their workforce, their contractors, their customers and owners. This will have a profound effect in the future and the phrase "digital water" has been coined to reflect this. In many respects the more sophisticated leakage management systems could be considered as being a "digital twin" of the network holding, for example, a hydraulic model of the network as well as inventories and details of all the sensors and assets within the network.

LEAKS

Circumferential Break

A break on a pipe that runs around the circumference of the pipe.

Longitudinal Break

A break on a pipe that runs along the direction of pipe.

Split

A failure where a crack opens and runs along the direction of the pipe. It is common on a plastic (PE and PVC) pipe.

Other Failure Modes

There are other failure modes such as flaps, corrosion holes or blow outs, depending on the pipe material and operating conditions.

Leak

A leak is a failure of the water supply network such that there is an unplanned loss of water from the water supply network. It is a generic term that can be used on any size or type of asset, from a service pipe to a trunk main or service reservoir or any fitting from a gate valve to a customer meter. In some utilities, the word "burst" may have a specific connotation in relation to a leak that is large enough to cause a supply disruption or severe impact on customers or general public. The word "break" is common parlance for a leak on a pipe in North America. From the leakage management perspective there is no difference between leak, burst or break.

Leak on Main

A leak that has occurred on a water main by either a pipe break or failure at this point – this includes joints, pipe breakage or at the tapping point connection. The latter may be caused by the tapping point failure, which should be assigned as a leak on service connection, or a split in the main where the tapping point is located, which should be assigned as a leak on main. This would be confirmed on excavation. Figure 26 shows a typical leak on main.

Leak on Service Connection

A leak that has been located on a service connection, namely a leak that is after the connection to the main. This includes leaks at the tapping point itself and anywhere on the service connection up to the stop tap/meter at the customer boundary. Sometimes referred to as a leak on communication pipe (UK) or a mains side leak.

Leak on Private Service Pipe

A leak that has been located on the private service pipe which runs from the customer boundary or meter to the internal stop tap of the property. This is considered to be on private property and the repair is, thus, usually the responsibility of the owner. Sometimes referred to as a leak on a supply pipe (UK) or a property/customer side leak.

Leak on Appurtenances

This the generic term for leaks on assets such as external stop taps, customer meters, DMA meters, PRVs, gate valves and hydrants. A work management system will usually identify which asset is leaking, although the allocation may have to be corrected following excavation.

Reported Leak

A leak that has been reported to the water utility by means of a notification from the public, often as a visible leak, leakage management software (i.e. alarm management or critical event management routines) or other technology such as remote sensing or permanently deployed acoustic loggers, among other means.

Some utilities only use this term for leaks actually reported by customers, whilst others use the term visible leak or surfacing leak. It is feasible that a visible or surfacing leak may not be reported by the public and is found by active leakage detection. The critical factor is how long the leak is likely to run before being located. A reported leak will have an awareness and location time of only a few days (say $\sim<10$–20 days). These leaks are sometimes referred to as reactive leaks.

Figure 26 Typical leaks (Sources: Severn Trent Water (1, 3, 4, 5), K Atkinson (2)).

It is recommended that only the term reported leak is used in the categorisation of leaks, with a relatively short awareness plus location time, within a work management system and leakage management system, in order to aid the construction of a component loss model.

Unreported Leak

A leak that has been found that was not made aware to the water utility by any means and has had to be found by active leakage detection in response to rising night flows. It is usually found using acoustic means.

Some utilities use the term non-visible leak or non-surfacing leak for a leak found by acoustic sounding only and where there is no indication of a leak being present by any water visible in the vicinity, other than possible sustained vegetation growth. An unreported leak will have a long awareness and location time, usually of the order of 100 or more days.

It is recommended that only the term unreported leak is used in the categorisation of leaks, with a relatively long awareness plus location time, within a work management system and leakage management system, in order to aid the construction of a component loss model.

Leak Duration

The total length of time a leak runs from the time of breaking out until the water loss stops, usually by it being repaired. The length of time for which a leak runs consists of three separate time components – awareness, location and repair time, see Figure 27.

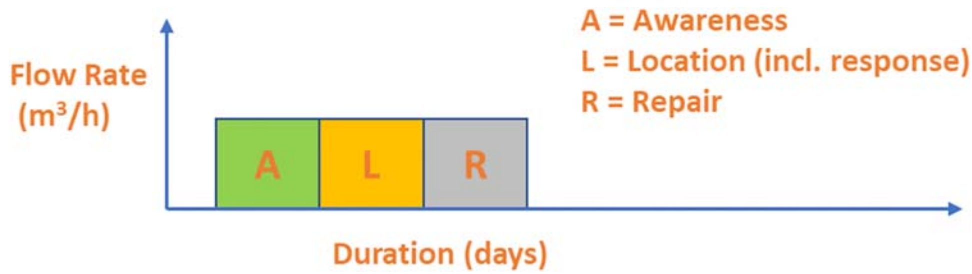

Figure 27 Representation of the duration of a leak (Source: D Pearson).

Awareness Time

Awareness time is the time from when a leak breaks out until the water utility becomes aware of its existence. The utility may become aware of a leak from customer contact, an alarm from leakage management software, an alarm from permanently deployed noise loggers or simply from visual inspection of the night flow. The awareness time is influenced by the type of monitoring system that is adopted. Where there is no monitoring system and the utility relies purely on regular sounding to identify if a leak has broken out, then the awareness time of an unreported leak will be very long and equal to half the time between regular surveys.

Location Time

The location time is the time between a utility being aware of a leak until it is pinpointed and the repair request issued. For reported leaks, this is the time it takes for the water utility to investigate the report of a leak and to correctly locate its position so that a repair can be undertaken. For unreported leaks in systems with no monitoring and hence high awareness times, the location time will be short, simply being the time to pinpoint any leak. For unreported leaks in systems with monitoring the awareness time will be low, but the location time will include the time between the utility being aware of the leak and the time before the leak is pinpointed. This can be very long (several months), awaiting the DMA being allocated for an active leakage control survey. It will then also include the time to localise and pinpoint the leak. Often, not all leaks will be found on the first survey and these will continue to run until the next survey.

Repair Time

The repair time is the time that a leak runs between being pinpointed and when the water ceases being lost. Generally, the latter is the time when the leak is repaired, but in some circumstances the leak may stop running by being valved off.

LEAKAGE DETECTION

Leakage detection is the process of locating and pinpointing water leaks.

Active Leakage Control (ALC)

Active leakage control is the process of undertaking leakage detection surveys on a targeted or regular basis in order to manage leakage within a water distribution network.

Leakage Detection Survey

A leakage detection survey is the activity of proactively and systematically searching for leaks using planned leak detection exercises to localise and then pinpoint the position of suspected leaks within a DMA, a sub-DMA or any other area. The trigger for a leakage detection survey may be the time since the previous survey, when the process is referred to as regular sounding, or when the net flow registered on a DMA has reached some threshold. It is usually expected that a leakage detection survey should find more than one leak. It is also referred to as an intervention.

Regular Sounding

Regular sounding is the process of carrying out a leakage detection survey on a regular time basis, e.g. once every 12 months, rather than based on the minimum flow or other measure on a DMA.

Passive Leakage Control

Passive leakage control is the name of the process of managing leakage purely by carrying out reactive surveys within a water distribution network.

Reactive Survey

A leak detection exercise that is only completed in response to customer contact or supply difficulties, namely it is reactive, usually with the intention of finding only one specific leak. It has no planning, targeting or programme of works.

Locate, Localise, Pinpoint

The process within a leak detection survey in which the location of a potential leak is systematically narrowed down from within a DMA or sub-area to a particular street or section of main and, finally, pinpointed to a precise reference location, such as in front of a specific house number. When a leak has been pinpointed it is normal for a cross or square, with or without letters showing reason, to be spray painted on the ground to confirm the location for the repair team to excavate.

Area of Interest (AOI)

An area of interest is an approximate location where a leak is suspected and awaiting validation to confirm whether it is in fact a leak or not, and if a leak accurate pinpointing. AOIs may have been identified by acoustic loggers or other detection technique. All leak positions remain as an AOI until they have been confirmed either to be a leak or positively confirmed not to be a leak.

Equivalent Service Pipe Burst (ESPB)

An equivalent service pipe burst is the flow rate expected from a service pipe leak, being 1.6 m^3/h at 50 m pressure, adjusted for the actual pressure, using $N1 = 0.5$. The rate at which the minimum flow on a DMA is above the expected target (possibly the minimum achieved night flow) is converted into the number of ESPBs. This value gives the detection technician an indication of the number of leaks that they would expect to locate during a leakage detection survey.

LEAKAGE DETECTION TECHNIQUES

Leakage detection techniques are the methods and technologies available to leakage detection technicians to localise and pinpoint leaks during a leakage detection survey or a reactive survey.

Leak Noise Correlator (LNC)

A leak noise correlator (or simply "correlator") is a piece of equipment that indicates the position of a leak along a main by analysing the sound heard at two appurtenances, typically valves and/or hydrants, see Figure 28. The correlator can use either accelerometers or hydrophones to pick up the noise. An accelerometer is attached magnetically to the fitting and will pick up noise transmitted through the pipe wall, whereas a hydrophone must be in contact with the water through an opened hydrant or connection on the pipe and listens to the sound transmitted through the water itself.

Referring to Figure 29, the position of the leak is given by the formula:

$$L = (D - (V \times t))/2$$

where L = distance of the leak from Sensor 1; D = distance between the two sensors; V = velocity of sound between the two sensors; and t = time shift between the sound arriving at Sensor 2 compared to Sensor 1

Information on pipe material and pipe length between the listening devices is required in order to evaluate V. The more accurate this information then the more precise will be the predicted location of the leak. A three-point correlator, as shown in Figure 28, will make the estimation of V, and hence the predicted location of the leak, more accurate. The location should always be confirmed by surface sounding.

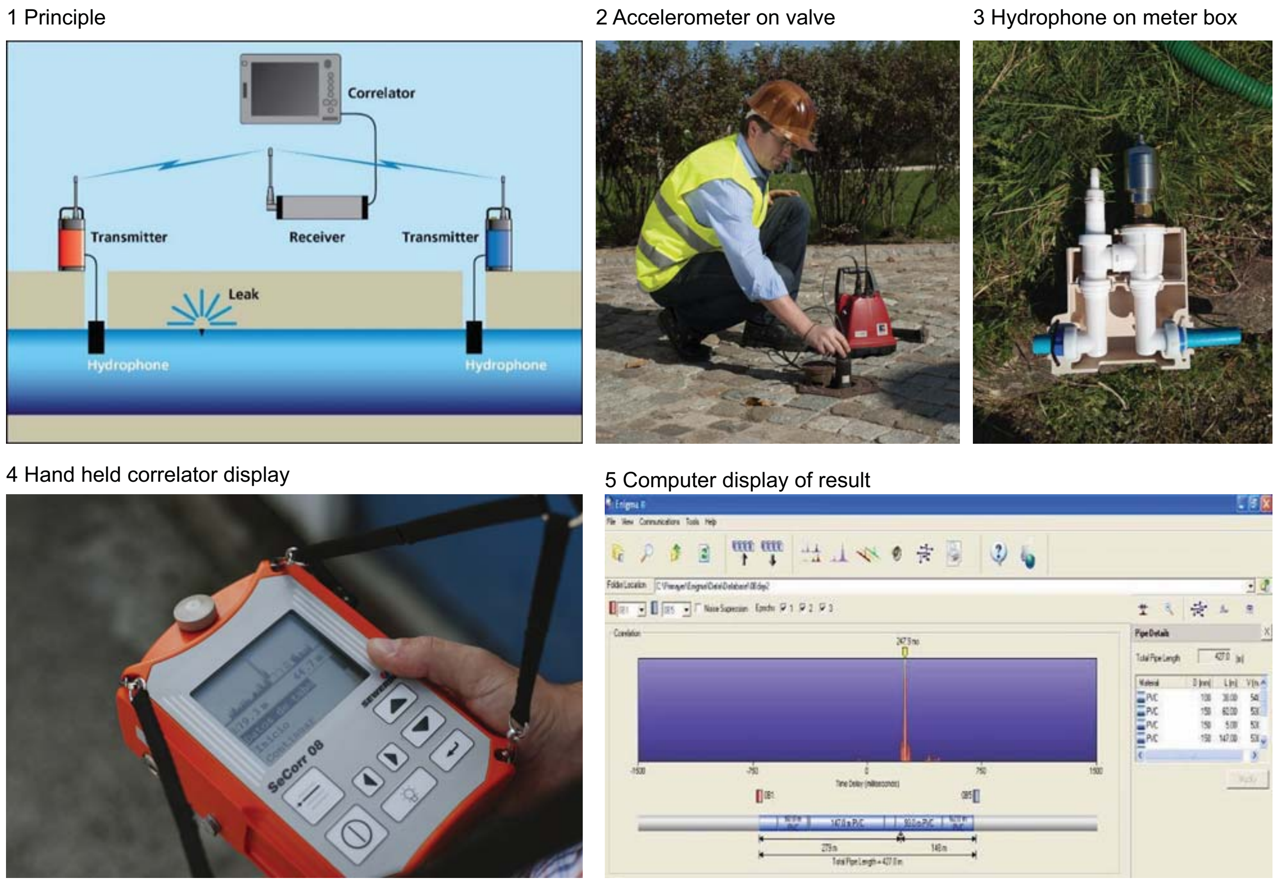

Figure 28 Photographs showing use of leak noise correlator (Sources: Primayer (1, 5), EPAL (Lisbon) (2, 4), K Atkinson (3)).

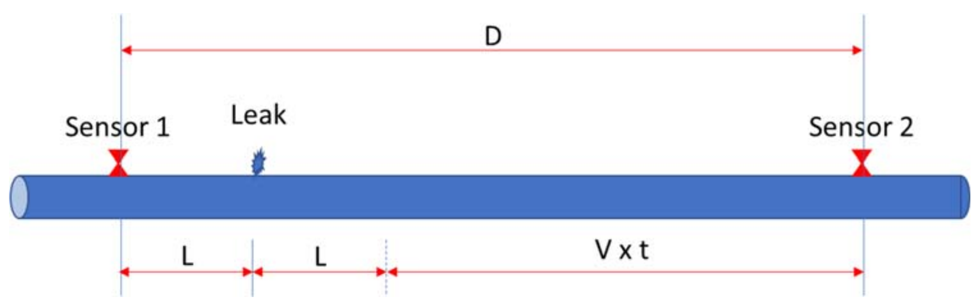

Figure 29 Evaluation of position of leak using a correlator (Source: D Pearson).

Correlator Survey

A correlator survey is a mode that can be used to quickly scan an area in order to localise the position of a leak. In this mode it is not necessary to identify pipe material and lengths accurately and so the survey can be effected quickly. Once the leak has been localised, then more precise information on pipe material and lengths can be provided and the correlator used to more accurately estimate the location of the leak.

Stop Tap Sounding Survey

Stop tap sounding, colloquially referred to as "stop tap bashing", is the process of using a sounding stick to sound every external stop tap in order to test for noise from any leaks. It is essential in this process that the end of the sounding stick makes good contact on the head or crutch of the stop tap. This high-resolution method generally finds the greatest number of leaks.

Mains Appurtenances Only Sounding Survey

This activity covers the low-resolution sounding on appurtenances only and is used mainly for locating leaks on metallic mains. This approach should not be used if the pipe material is non-metallic or the main between listening points contains a section of non-metallic material such as a plastic piece-through repair, as the sound does not travel along the pipe as well in these circumstances.

Surface Sounding

The process of sounding the ground surface with a manual listening stick or electronic listening stick in order to pinpoint the position of a leak.

Manual Listening Stick

A listening stick is a stethoscope that is used to sound appurtenances, stop taps or the ground surface to help confirm the presence of a leak by transmitting the sound up to the operative's ear, see Figure 30. There are diverse types of sticks using different materials such as wood and/or metal and some have different earpiece attachments to transfer the sound to the operator's ear. Operatives tend to have their own personal preference of type of stick. It can also be used to check whether a sluice valve is passing water, when checking DMA boundary valves or carrying out a step test.

Figure 30 Photographs showing use of manual listening stick (Sources: K Atkinson (1), United Utilities (2)).

Electronic Listening Stick

An electronic listening stick is a rod that uses electronic filtering and amplification to listen for leak noise, available in several levels of sophistication, see Figure 31.

Ground Microphone

A piece of equipment that uses a microphone together with electronic filtering and amplification to listen for leak noise when placed on the ground surface. They are used for confirming and pinpointing the precise location of a leak following a correlator survey. Often colloquially referred to as an "Elephant's Foot", see Figure 32.

Pressure Zero Test (PZT)

A pressure zero test is a process used to confirm that boundary valves which have been shut in order to create a DMA are in fact still shut and not passing water in or out of the DMA. Initially the valves are sounded using a listening stick to ensure there is no sound being emitted from a potential water passage. A pressure gauge is then fitted to a hydrant within the DMA and the main inlet(s) and outlet(s) to the DMA are closed, see Figure 33. The pressure on the gauge should drop gradually to zero. Should pressure be sustained or fall dramatically to zero, then this indicates that one or more of the boundary valves are open or not water-tight. It can be useful to install a pressure gauge on a hydrant outside the DMA to confirm that the pressures recorded

Figure 31 Photograph showing use of electronic listening stick (Source: S Hamilton).

1 2 3

Figure 32 Photographs showing use of ground microphone (Sources: EPAL (Lisbon) (1), K Atkinson (2), S Hamilton (3)).

are different. The pressure gauge should be left in place for a period of approximately 15 minutes to ensure that the system does not pressurise through a passing valve. It is also recommended that pressure loggers are installed along the boundary both inside and outside the DMA. These can be downloaded later as a check and also for audit purposes. In some countries, this may be referred to as a Zero Pressure Test (ZPT).

Acoustic (Noise) Loggers

Acoustic loggers are electronic devices used to record the noise on appurtenances, such as valves and hydrants, see Figure 34. They can be programmed to listen at certain times of the day, such as the middle of the night, when there should be limited extraneous noise on the system. They can also be programmed to interpret sound in terms of consistency, noise level and

1 Manually read 2 Logged

Figure 33 Photographs showing hydrant being used during a PZT (Source: K Atkinson (1, 2)).

1 2 Installed on hydrant 3 Installed on valve

Figure 34 Photographs showing of acoustic loggers (Sources: EPAL (Lisbon) (1), K Atkinson (2, 3)).

frequency and thereby infer whether the noise would indicate that there is a leak in the vicinity. They have a magnetic base so that they can be attached to the metallic spindle of a valve or hydrant.

Correlating Acoustic Loggers (CAL)

These are loggers that have combined the functionality of acoustic loggers and correlators. This has been possible because of the improved time stamping on GPRS networks and the use of GPS technology. The data from the correlating loggers is combined with information about pipe lengths and materials (derived from the utility's GIS) in order to provide a more precise area of interest about a leak for confirmation and pinpointing. These loggers can be installed on a lift and shift basis or installed on a permanent basis and communicate over proprietary radio networks, or cellular (2G, 3G or 4G). When installed on a permanent basis they can change the economics of the active leakage control process significantly. See Figure 35.

Remote Sensing

Remote sensing is a generic term that is used to describe several techniques which do not involve physical leak detection on the ground. The techniques include flying over the area using a plane, helicopter or drone, as well as satellite surveillance. The

Figure 35 Photographs showing correlating acoustic loggers (Sources: Mueller Water Products Inc (1, 2), Anglian Water/ Primayer (3), Primayer (4), Gutermann (5)).

technology usually uses different wavelengths, including infra-red, in order to look for areas where vegetation is being sustained or where ground reflection is different and therefore identifies an area of interest for further investigation.

Non-Intrusive Leak Detection

Any leak detection technique, such as gas detection, correlation, stop tap sounding; that does not involve having a sensor passing down the inside of the pipe. See intrusive leak detection for comparison.

Intrusive Leak Detection

The process involves a sensor travelling along the inside of the pipe. The sensor identifies the existence and location of a leak either through sound or the change in the pressure profile within the pipe. The sensors can be either tethered or free floating. The sensors are usually tracked at ground level using technology such as Bluetooth. Intrusive detection techniques require access to the water within a main in order to "launch" the sensor. This can be either through an existing hydrant, new or existing pigging chambers, or new or existing tapping points. Free floating equipment will also require some form of reception arrangement for the recovery of the sensor. There are a number of proprietary intrusive leak detection techniques and associated equipment available. Also known as in-pipe leak detection.

Ground Penetrating Radar (GPR)

There have been many attempts at developing ground probing radar with the hope of identifying the location of a leak. Various types of ground probing radar have been investigated, either independently or combined, including ground penetrating imaging radar and surface magnetic resonance sensors. It is generally accepted that the results from the technology have been disappointing, being both difficult to interpret and often inconclusive.

Gas Injection

Gas injection is a technique where gas, usually a mixture of hydrogen or helium and nitrogen, is injected into the water main or service pipe. The ground above the main is then swept using a sensor that can pick up the presence of the gas, see Figure 36. The gas must be approved for use with potable water.

Figure 36 Gas injection leak detection technique (Sources: Primayer (1, 3), EPAL (Lisbon) (2)).

Step Test

A step test is a technique used to localise a leak within a DMA. It is designed so that sections of a DMA can be shut off in sequence by the closing of a single valve. This may involve identification, usually as part of the design process, of what are referred to as ***circulating*** valves so that the DMA is reduced to a series of "branches". When the circulating valves have been shut, the ***step*** valves are shut in sequence and the flow at the DMA meter is noted, logged or transmitted to the operatives. As each step valve is shut the flow through the DMA meter is given time to stabilise, which may only take a few minutes. As the step valves are shut, the preceding step valves can be opened or left shut. The step with the largest drop is the one that contains the greatest leakage, but if there are several steps with drops in flow, then this indicates that there are several leaks rather than a single large leak. A step test should be carried out at night or when there is minimal consumption in order to reduce any disruption to customers. Any known essential night users must be identified, and temporary arrangements made to maintain supply. In some cases, customers will need to be notified, such as by placing of cards through doors beforehand, to warn them of possible loss of supply or discoloured water in the morning. However, such risks can be minimised by using real time data transmission and careful valve operation. See also temporary DMA rezoning test.

Temporary DMA Rezoning Test

The temporary DMA rezoning test is a development of the "traditional" step test, which involves the sequential transfer of sections of a DMA that would have been isolated by closure of step valves in a normal step test, onto the adjacent DMA so that supply is maintained. This process therefore avoids service cuts and loss of pressure in the network.

LEAK REPAIRS

A leak repair is the process of repairing the fault that is causing the leak. Leaks on mains are repaired by either a single repair clamp or with a new section of pipe in what is referred to as a piece through repair. Leaks on appurtenances such as valves and hydrants usually require repacking of the gland or complete replacement of the fitting itself. Leaks on service connections are usually repaired by replacing the defective pipe section with a new one using two compression couplings, equivalent to a piece through repair. In exceptional circumstances it may be deemed appropriate to replace the whole service connection. This method is often chosen if the service connection is made of a non-preferred material, such as lead. Repairs are not normally carried out for leaks on private service pipes as these are the responsibility of the owner of the associated property, but if they are carried out by the utility for whatever reason, then they would be the same as the repair of a leaks on service connection.

Repair Clamp

A repair clamp is a fitting that normally comes in two halves and includes a gasket over the full length of the clamp, see Figure 37. The clamp is split and placed round the main at the leak location. It is then clamped and tightened so that the gasket is squeezed around the pipe over the hole in order to stop the leak. A repair using a clamp can be undertaken without shutting off the water, thereby reducing the risk of contamination and pressure transients on refilling, though it will usually require pressure to be significantly reduced while the repair is undertaken. A repair clamp can be used to repair a hole but is not recommended for a circumferential split. A repair clamp will not significantly affect noise transmission along the pipe wall and will therefore have little impact on leak detection.

1 Mains 2 Services 3 Installation

Figure 37 Typical repair clamps and installation (Sources: Plasson (1, 2), K Atkinson (3)).

Piece Through Repair

A piece through repair involves cutting out a section of pipe and inserting a new one in the original pipe using a coupling at each end, see Figure 38. It is common to use a short length of plastic pipe (PE or PVC) for the insert even if the original main is metallic. Unfortunately, this can make future leak detection more difficult as the section of plastic pipe acts as an insulator and reduces noise transmission along the length of the original pipe. The use of plastic pipe in a piece through will also reduce the accuracy of the location of a leak using a correlator. A piece through requires a complete water shut off and hence care with disinfection and recharging.

1 Mains 2 Services 3 Installation on main

Figure 38 Typical repair couplings and installation (Sources: Mueller Water Products Inc. (1), Plasson (2), D Pearson (3)).

PRESSURE MANAGEMENT (PM)

Pressure management is probably the most cost-efficient method of controlling leakage. Pressure management includes all the processes involved in monitoring and controlling pressures within the supply and distribution networks. The knowledge associated with pressure management is now so well developed that the savings to be expected from the deployment of pressure reduction can be readily predicted.

Pressure Gauge

A gauge connected to a water main or service pipe for measuring pressure in the main or service pipe. The pressure can be read manually or recorded on a pressure logger.

Pressure Logger

An electronic device that can store the readings from a pressure transducer, for later interrogation or uploading to a central computer system or cloud based application, such as a leakage management system. The pressure that is recorded will be the instantaneous pressure registered on the pressure transducer at the relevant time.

Pressure

Pressure is the force exerted by the water within a pipe. It is equivalent to how high the water would rise in an open tube if this was connected to the side of the pipe at the point of interest. Pressure is measured on the network using a pressure gauge. The units of pressure are typically m, bar, psi (pounds per square inch).

Transients

Transients are very high frequency pressure surges within the distribution network created by operational changes, pump starts or stops or draw-off from the network. The surges can be of very high amplitude, i.e. pressure range, and therefore can cause severe shocks and stress to the system and create leaks, see Figure 39. They require high frequency logging of at least 10 times per second to detect their presence. They can usually be mitigated, if not removed, by improved pump start controls, improved operation of valves, installation of surge suppression vessels or replacement of equipment on customer draw-offs with soft closing solenoids rather than simple rapid-acting solenoid valves or float valves.

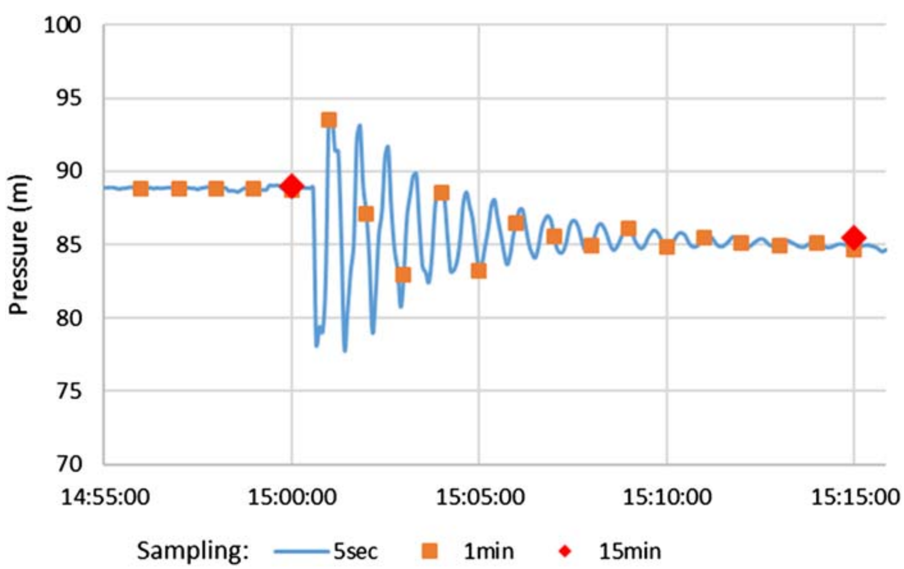

Figure 39 Graph showing typical pressure transient (Source: United Utilities).

Pressure Reduction

Reducing pressure in a network has a significant impact on leakage as it reduces flow from existing leaks or new leaks when they occur. It also reduces losses from background leakage and the frequency at which new leaks break out on mains and services. Pressure management is a very economic method of leakage control. Pressure management may be achieved through the installation of break pressure tanks, pressure reducing valves or through pump controls. The use of PRVs is the most common technique.

There are four primary methods of pressure management using a PRV; namely: fixed outlet, time modulated, flow modulated and critical pressure control. When considering the impact of pressure management on leakage, it is necessary to consider the impact on the pressure over the day as a whole. The conversion from hourly leakage to daily leakage using the hour to day factor is critical and must be considered.

Fixed Outlet Pressure Management

In fixed outlet pressure management, the PRV is set to deliver a set pressure at the outlet of the valve. This is the simplest form of pressure management, see Figure 40. The HDF for fixed outlet pressure management will be below 24 hours and is typically between 20–23 hours. In the example in Figure 40 it is 22.6 hours.

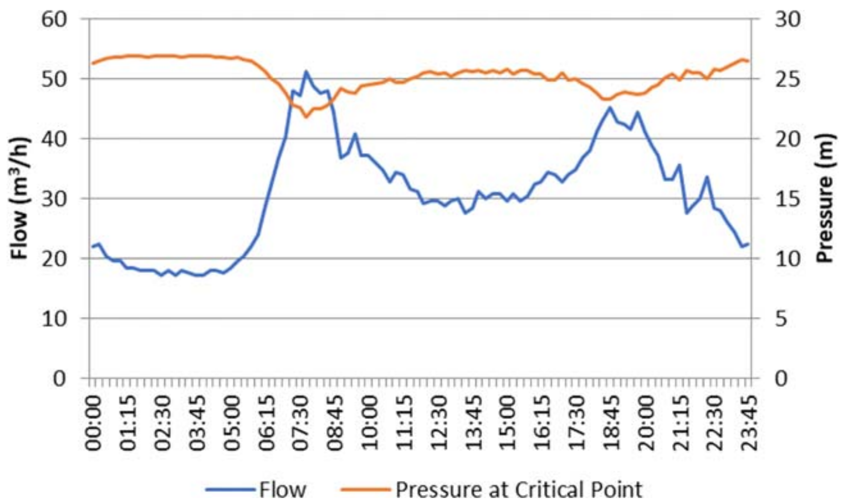

Figure 40 Example pressure profile with fixed outlet pressure management (Source: D Pearson).

Time Modulated Pressure Management

In time modulated pressure management, the pressure setting at the PRV outlet is changed based on the time of day. The most common modulation regime is to reduce pressure at night when consumption is low and pressure would normally rise. It is common to reduce pressure between midnight and 6am although these hours may be changed to suit local circumstances, see Figure 41. In the case of time modulated pressure control the HDF will be greater than 24 hours and is typically in the region of 26–30 hours or even higher. In the example in Figure 41 it is 32.1 hours.

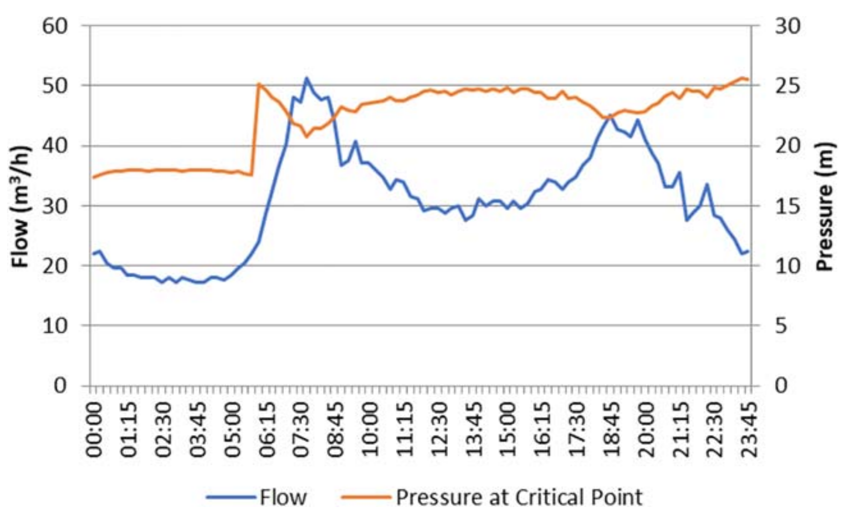

Figure 41 Example pressure profile with time modulated pressure management (Source: D Pearson).

Flow Modulated Pressure Management

Flow modulation is a more sophisticated method where the pressure setting at the PRV outlet is based on the flow through the valve, normally being measured by a flow meter next to the PRV. In this case, control can be set to inversely mirror the hydraulic variation of pressure across the PMA as a function of demand in the area. Control can be based on pressure at the average zone point or the critical point. Under flow modulation the pressure at the relevant control point will be relatively constant and vary slightly around the desired control level, see Figure 42. With flow modulation, the HDF is much closer to 24 hours and will typically be between 23–25 hours. In the example in Figure 42 it is 24 hours.

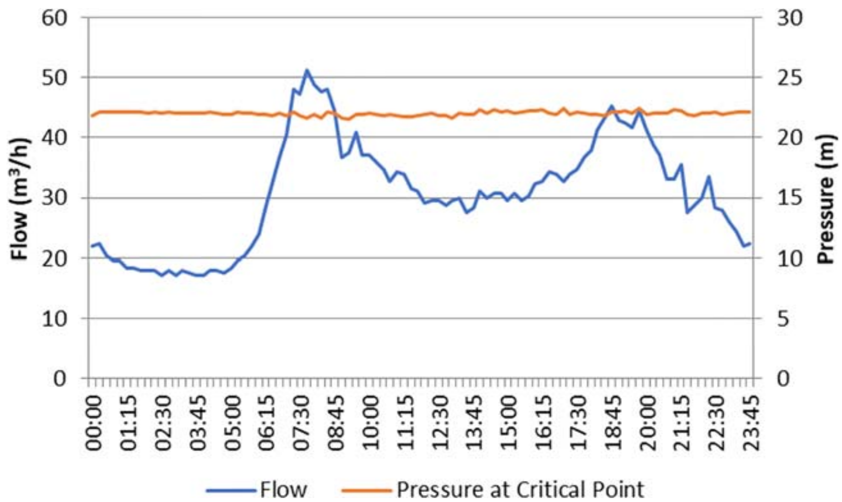

Figure 42 Example pressure profile with flow modulated pressure management (Source: D Pearson).

Critical Pressure Control Pressure Management

In critical pressure control, the PRV or pump may be controlled to deliver a certain minimum pressure at a remote point within a PMA, usually either the average zone point or critical point. This requires a control loop and some sort of control unit such as a programmable logic controller (PLC). With critical point pressure management, the HDF is much closer to 24 hours. A more generic title used in North America is remote node control pressure management.

Discrete Pressure Area (DPA)

A DPA is a discrete area within the network where pressure is subject to the same pressure regime, either natural or managed through a PRV. Many water utilities may refer to these as hydraulic zones.

Pressure Managed Area (PMA)

A PMA is a DPA where the pressure regime is controlled by one or more PRVs.

Critical Point (CP)

A CP is the point of lowest available head within a DPA. Monitoring the pressure at the CP is useful in establishing whether the Standard of Service for pressure is being delivered to all customers. It is also useful for setting the controls of a PRV if the DPA is pressure managed.

Average Zone Point (AZP)

The AZP is the point in a DPA which is representative of the average pressure experienced by all properties in the DPA. The average height of properties in a DPA can be calculated using GIS, if this contains the height of each property, or manually by counting the properties between contours on a map.

Average Zone Pressure

The average pressure measured at the average zone point over a day.

Average Zone Night Pressure (AZNP)

The AZNP is the average pressure across a DPA during the period when the leakage is assessed for leakage monitoring purposes using the minimum night flow method. This will normally be during the night but not necessarily, see minimum night flow. The pressure will also normally be at its maximum at the time of minimum flow, ***but not necessarily***, depending on the type of pressure management. The AZNP should be measured at the Average Zone Point. The AZNP of an area such as a zone or a DMA with several DPAs, should be calculated by property weighting the AZNPs of all the individual DPAs that make up the area.

Average Operating Pressure (AOP)

In the case of a system with continuous supply, the AOP is the average pressure experienced by all the properties in a DPA over an entire day and is equivalent to AZNP × HDF/24. The AOP for areas such as a zone or a DMA with several DPAs should be calculated by property weighting the AOPs of all the individual DPAs that make up the area.

In the case of systems with intermittent water supplies, the AOP should only be evaluated for the period when the system is pressurised.

Hour to Day Factor (HDF)

Leakage can be assessed either from a water balance using the TIF components or from using the minimum night flow method. One of the most common errors in leakage calculations is the assumption that night leakage per hour can simply be multiplied by 24 hours/day to assess daily leakage; or that daily leakage from a water balance can be converted to night leakage by dividing by 24 hours/day. Given that leak flow rates and the N1 exponent vary with the average zone pressure, an hour to day factor of 24 hours/day is only valid when the average zone pressure is constant, or almost constant, over 24 hours in a day. The equation relating daily leakage to night leakage (measured during the hour of minimum night flow) is:

$$DailyLeakage(volume/day) = NightLeakage(volume/hour) \times HDF(hours/day)$$

In practice, the HDF can vary from less than 10 hours/day for gravity systems with high leakage and frictional losses, to more than 60 hours/day for flow modulated systems. Therefore, the assumption of a fixed HDF of 24 hours/day can introduce large systematic errors into leakage calculations based on night flows.

The HDF is calculated by summing the correction factor $(P_i/\mathrm{AZNP})^{\mathrm{N1}}$ for each hour or quarter hour during the day where the pressure P_i is assessed at the average zone point at time i. N1 should be assessed from an NI step test or by taking a view on the mains material type and the level of leakage. In the absence of any other data, then it is sensible to use N1 = 1.

The HDF for an area such as a zone or a DMA with several DPAs should be calculated by property weighting the HDFs of all the individual DPAs that make up the zone. Also sometimes referred to as the night day factor or T factor, although it is considered that hour to day factor is preferable.

Fixed and Variable Area Discharge (FAVAD)

FAVAD stands for Fixed and Variable Area Discharge relationship. It was developed by John May in 1994. It describes the fact that leakage on the network will occur through a mixture of holes, some of which will have paths which do not vary with pressure and some of which will have paths that do vary with pressure.

N1 Factor

The N1 factor is used to calculate the leakage versus pressure relationship:

$$L_1 = L_0 \times (P_1/P_0)^{\mathrm{N1}}$$

where L is the leakage and P is the pressure. The higher the N1 value, the more sensitive existing leak flow rates will be to changes in pressure. N1 factors range between 0.5 with corrosion holes only in metallic systems and 1.5, with occasional values of up to 2.5. In distribution systems with a mix of pipe materials and low leakage, N1 factors may be of the order of 1–1.15. Therefore, a linear relationship can be assumed initially until N1 Step Tests are carried out to derive a more accurate N1 factor. Recent developments have shown that when the FAVAD principles are applied then N1 is a function of pressure, but that this does not become significant until pressures are below 25 m.

N1 Step Test

The N1 step test, sometimes referred to as a pressure step test, is used to determine the N1 value for areas of the distribution network. Net flow to the area, e.g. a zone or a DMA, and pressure at the Average Zone Point are recorded. During the test, pressure in the area is reduced in a series of steps by changing the settings on a PRV. This pressure reduction, together with the corresponding net inflow reduction, form the basis for the calculation of N1.

N2 Factor

The N2 factor was introduced when it was believed that the relation between burst frequency and pressure could be expressed as:

$$BF_1 = BF_0 \times (P_1/P_0)^{\mathrm{N2}}$$

where BF is the burst frequency in no/yr and P is the pressure. It has now been found to be slightly more complicated, having an offset for non-pressure dependant bursts. So, the relationship is now considered to be:

$$BF_1 = (BF_0 - BF_{\mathrm{npd}}) \times (P_1/P_0)^{\mathrm{N2}} + BF_{\mathrm{npd}}$$

where BF_{npd} is the burst frequency of non-pressure dependent leaks. The formula has to be applied separately for mains burst frequency and _Service_Pipe_Burst_1 service pipe burst frequency. N2 is of the order of 3.

N3 Factor

The N3 factor is used to describe the pressure/consumption relationship:

$$C_1 = C_0 \times (P_1/P_0)^{\mathrm{N3}}$$

where C is the consumption. There is a different N3 factor for internal use, e.g. toilet cistern, or external use, e.g. hosepipe watering. Typical values of N3 are 0–0.2 for internal use and 0.5–0.75 for external use.

MAINS AND SERVICE PIPE REHABILITATION

Rehabilitation is the generic term covering any form of renovation or replacement of pipes to restore or upgrade its performance. Mains and service pipe rehabilitation can therefore be carried out to assist leakage management. Rehabilitation is undertaken to reduce repetitive detection and repair (find and fix) activity and should therefore be targeted at high burst frequency mains and/or service pipes.

Mains Relining

Mains relining is a technique for pipe refurbishment and may be also be carried out to improve water quality. Typical relining materials are cement, epoxy or polyurethane. While many of these linings do not have any structural capability and will not stop or reduce burst frequency, some newer semi-structural linings now exist which will cover small holes. There is, however, evidence that pipe burst frequencies increase following relining because of the stress that the pipes are subjected to in the cleaning process. There can also be severe problems with damage to tapping points due to scraping, which is usually used as part of the cleaning process. Therefore, relining should not be considered for refurbishment of pipes for leakage control reasons.

Open Cut Replacement

Open cut replacement is where a full-length trench is excavated down to the pipe, the old pipe removed and a new one installed. This process causes maximum disruption to the general public in the locality.

Pipe Bursting

Pipe bursting is a technique for mains replacement using what is referred to as a trenchless technique in order to minimise the level of disruption to the public. In this case, an entry and exit pit are excavated at about 100 m intervals, usually coinciding with existing valves or hydrants. A pneumatic percussive “torpedo” is then pulled through, breaking (bursting) the existing main and pushing the fragments into the surrounding ground. The torpedo pulls through a sacrificial duct made from PE or PVC at the same time. There is also the pipe cutting or splitting method where the existing main is sliced and levered open. A new PE main is then slip-lined through the duct. Excavations must be made in order to replace each service connections. The technique is also referred to as the pipeline insertion method (PIM).

Slip Lining

In slip lining, a new PE main is inserted through the existing main. It therefore has a smaller diameter than the original main. The diameter needed should be validated using hydraulic modelling. Significant reductions in leakage contribute to allowing smaller diameter mains to be used.

Roll Down

Roll down is a similar technique to die drawing. The PE pipe is folded or passed through rollers to reduce its diameter, rather than put under tension, prior to insertion.

Die Drawing

Die drawing is where a PE pipe is drawn through a die to reduce its diameter. While the pipe is still under tension it is pulled through the existing main, after it has been cleaned. When the tension is released the pipe attempts to return to its original diameter until it creates an interference fit with the existing pipe. In this case the new PE pipe can create a leak-proof lining which may or may not be structural. The technique is also referred to as swage lining.

Service Pipe Rehabilitation

It is generally more economic to relay a new service pipe along a new line rather than refurbish the existing service pipe. This can be carried out by digging a new trench or by using a mole to install a new pipe without the need to dig a new trench. This is sometimes referred to as directional drilling.

There are several techniques for in-situ service pipe refurbishment. One technique called pipe pulling involves pulling the existing pipe through the ground while pulling a new pipe in behind it. Another technique is to line the service pipe with a plastic liner (usually made from PET) which can be inserted and then subsequently inflated inside the pipe.

Pipe Condition Surveying

Pipe condition surveying is the process of establishing the general condition of a water main. In the case of metallic pipes, this can involve the estimation of the residual life of a water main taking into account both internal and external corrosion. It can also include the investigation of any build-up of deposits within the main. Any examination of the internal condition is carried out in a similar fashion to intrusive leak detection and will require access into the main through hydrants, tapings or pigging chambers.

Pigging Chamber

A pigging chamber is a specific piece of furniture which allows access to a water main for the insertion of a swab (pig) for the purpose of mains cleaning or flushing, see Figure 43. There will also be a pigging chamber for receiving and recovering the swab. They will generally be used on larger diameter mains when a hydrant cannot be used.

Mains Flushing

Mains flushing is a process for cleaning a distribution network to remove deposits and encrustations with the intention of reducing the risk of customers experiencing discoloured water. There are several techniques of mains flushing including air scouring, swabbing and ice pigging. Most techniques can be adjusted to give different levels of aggression depending on the extent and types of deposits within the mains. Customers must be warned prior to any cleaning exercise. Hydraulic modelling can be used to check whether the velocities required in order to re-suspend deposits in the mains can be achieved. Existing hydrants can be used by most techniques but some may need the construction of bespoke entrance and exit apparatus (e.g. pigging chambers) which adds significantly to the cost.

LEAKAGE MODELLING

Leakage modelling is the generic term for the process of computer simulation and analysis of leakage using the relationship of leakage to the pressure, bursts and run times, that have now been established and understood.

Demand Calibration

Demand calibration is a methodology to analyse 24-hour net flow and pressure data of a hydraulically discreet part of the distribution system, e.g. a zone or a DMA, using the N1 pressure-leakage relationship principles and results of the N1 Step

Figure 43 Typical pigging chamber (Source: K Atkinson).

Test. Using this technique the net flow can be split into consumption and leakage, which can be further split into background leakage and leakage from bursts, both reported and unreported.

Component Loss Model (CLM)

A component loss model (CLM) can be constructed to estimate each of type of leakage (background, reported bursts and unreported bursts) on each of the various components of the network, such as mains, service connections, private service pipes and even trunk mains and plumbing systems. By including the relationship of leakage to the extent of the assets, the burst frequencies, the pressure and the awareness, location and repair times, and calibrating this to the existing leakage, it is possible to use the CLM to forecast possible options to reduce leakage. Also known as the burst and background estimation (BABE) model or Real Loss Component Analysis.

Hydraulic Modelling

A hydraulic model is a computer representation of a distribution system which models the flows and pressures within the network. The model uses standard head-flow equations, such as Hazen–Williams or Colebrook–Wight, to relate head loss through a pipe as a function of the flow. Standard pipe roughness values based on material and age are used. Calibration is the process of adjusting the pipe roughness so that the difference between predicted pressures and actual recorded pressures are minimised. Leakage, established by a simple water balance for the period being modelled, is usually distributed evenly across all nodes within the model. Techniques have been developed which attempt to predict where leaks are on the system by changing the distribution of leakage to further improve the calibration. There are several well-developed modelling packages.

Economic Level of Leakage (ELL)

The ELL is the level of leakage at which the cost of undertaking additional leakage control activity is equal to the cost of producing the water that would be saved by this additional leakage control, i.e. the total cost of leakage control and production cost of leakage is at a minimum, see Figure 44.

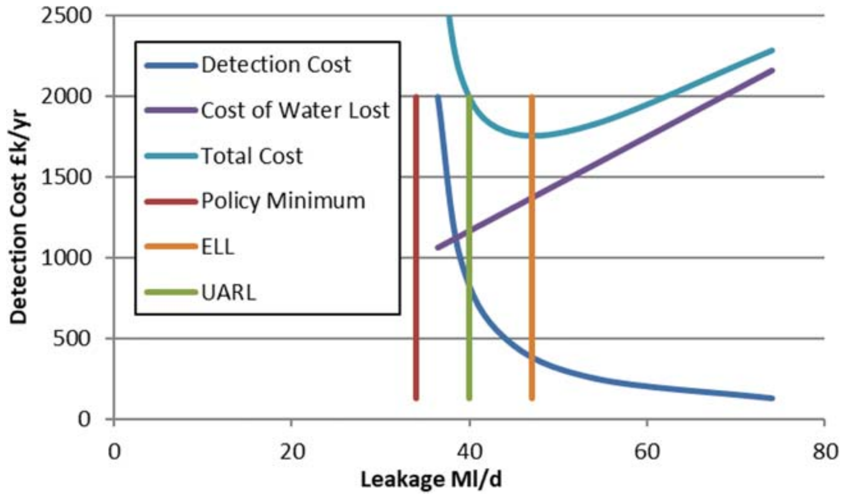

Figure 44 Figure to illustrate the concept of ELL (Source: D Pearson).

In the illustration shown in Figure 44, only the level of active leakage control is varied in order to find the optimum economic balance. This is the only true operational cost that can impact on the level of leakage. This is referred to as the short-run economic level. However, there are capital interventions, such as pressure management and mains rehabilitation, that can be undertaken to reduce leakage. The economic level of pressure management and rehabilitation can and should be assessed. In this case, because capital costs are being investigated, this is referred to as the long-run economic level of leakage.

Should there be no constraints on water available for supply then the cost of water lost is assessed using the marginal cost of water production, namely power, chemicals and sludge disposal. However, if water supply is constrained, then it may be more economic to undertake further leakage control rather than develop a new water resource. In this case, the marginal cost of water is increased to include the discounted cost of developing the next resource. This is referred to as the marginal value of water. Where any water that is saved from leakage reduction can be resold, then the marginal cost of revenue should be used.

APPARENT LOSS MANAGEMENT

Apparent loss management encompasses activities designed to manage, control and reduce all aspects of apparent losses. The areas of apparent losses can be grouped into four different and distinct areas. These are illustrated in Figure 45.

Typical activities designed to control apparent losses in each of the four areas are listed below:

Customer metering inaccuracies

- Programme to replace meters on a regular cycle
- Correct sizing verification of average flow volume against meter size
- Programme to replace meters with those of a higher class
- Physical surveys to check for installation arrangements
- Physical site check of meters with zero and/or low consumption registered in the billing system

Data handling and billing errors

- Checks of the customer billing register against other databases, such as postal or police address files
- Regular changing of meter reader routes
- Billing database checks for flagged premises
- Physical survey of premises indicated as demolished

Underestimation of unmeasured consumption

- Ensure metering of communal and other supplies even if the customer is not charged on meter readings
- Increase statistical size and socio-economic groupings of consumption monitors used to estimate unmeasured domestic consumption
- Consider a programme to extend metering of non-household premises

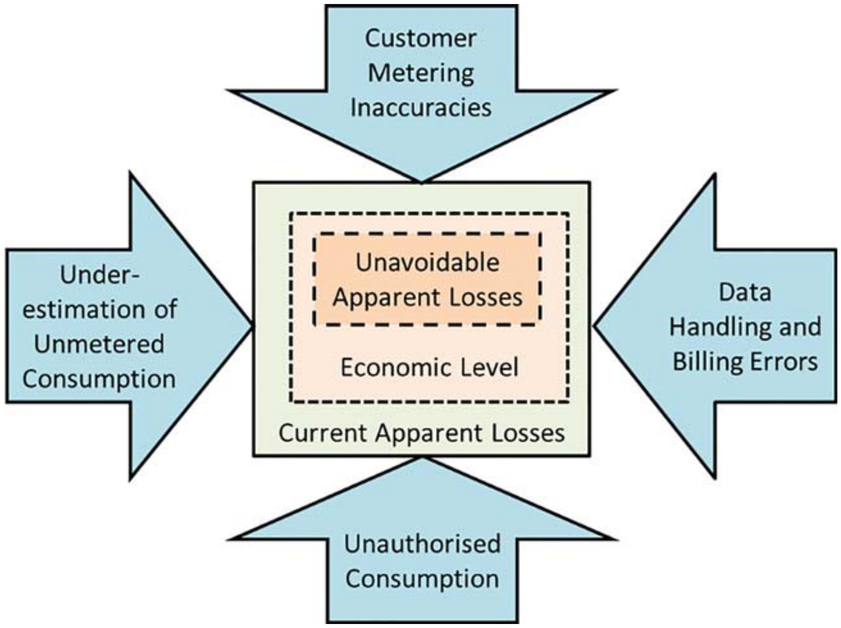

Figure 45 The four areas of apparent losses (Source: D Pearson).

Unauthorised consumption

- Physical surveys to identify illegal connections
- Install lead seals on meter screws/nuts
- Physical survey of unmeasured fire supplies to check for abusive consumption
- Random excavation based on billing consumption records

Meter Under-Registration (MUR)

Meter under-registration (MUR) is the amount that any flow meter under-records or over-records the true volume of water that passes through the meter.

MUR is defined, in ISO 4064, as:

$$MUR = (Volume_{Actual} - Volume_{Measured})/Volume_{Actual}$$

Thus, MUR is between –100 and +100% and the actual volume that should be recorded is:

$$Volume_{Actual} = Volume_{Measured}/(1 - MUR)$$

Economic Level of Apparent Losses (ELAL)

The ELAL is the level of apparent losses where the marginal cost of carry out further measures to reduce apparent losses is equal to the marginal cost of revenue that would be gained by reducing apparent losses. The concept of ELAL is exactly the same as the concept of the economic level of leakage (ELL). Figure 46 illustrates the example of where the level of unauthorised consumption is managed by carrying out surveys to identify illegal connections and theft. The cost of carrying out the surveys increases as the frequency of the surveys is increased. Unauthorised consumption, and hence revenue lost, will be lower with more frequent surveys. There will be an economic balance where the increase in survey costs will outweigh the increase in revenue. This will then be the economic level of apparent losses. The same process has to be repeated for all the different activities that could be carried out to control apparent losses. Each activity has to be carried out at the frequency when the marginal cost of carrying out the work to reduce losses is equal to the marginal cost of revenue.

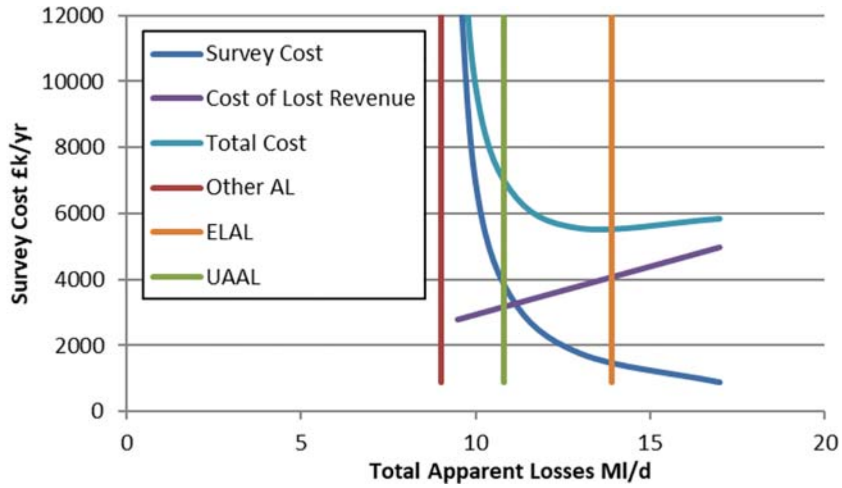

Figure 46 Figure to illustrate the concept of ELAL (Source: D Pearson).

PERFORMANCE INDICATORS (PIS)

A performance indicator is a measurable value that demonstrates how effectively a utility is achieving key objectives. Organisations use performance indicators at multiple levels to evaluate their success at reaching targets. They can also be used to compare performance and set targets between zones within a large utility. In addition, they can also be used to compare performance between different utilities, although care must be taken in their interpretation, particularly if different utilities have differing external factors, costs and constraints.

No single performance indicator will be fit-for-all-purposes or wholly indicative of water system efficiency. Performance indicators have, therefore, to be selected carefully and chosen to be fit-for-purpose for a given situation.

Performance Indicators for Non-Revenue Water

It is difficult to find a suitable PI for NRW as NRW is a mixture of both apparent losses and real losses and the PIs for these components individually are quite different. It is common to express NRW as a percentage of system input volume and performance targets set using this measure. However, the IWA WLSG recommends that this measure **should not** be used as it is totally inappropriate.

If a single PI for NRW is required, then this should be in the form of NRW per connection i.e.:

$$NRW/Connection = NRW_{wsp} \times (24/ST)/Number\ of\ Connections$$

Alternatively, it is recommended that NRW is split into the two main components of real losses and apparent losses, even if this split is estimated, with PIs then being set and tracked for the two components i.e. PI for real losses and PI for apparent losses.

Performance Indicator for Apparent Losses

The most suitable PI for apparent losses is to express these in relation to the volume which should have been measured as the authorised consumption if there were no apparent losses. Thus:

$$PI_{AL} = AL/(AC + AL)\%$$

Thus, PI_{AL} can be between 0 and 100%. This is equivalent to the definition of meter under-registration (MUR).

Performance Indicators for Real Losses

Real losses (or physical losses) cannot be totally eliminated. It is therefore inappropriate to use a measure that implies that real losses can be reduced to zero. In order to address this the concept of the unavoidable level of losses has been developed. The recommended PI for real losses is then derived by expressing current losses as ratio of unavoidable level of losses. This is referred to as the infrastructure leakage index.

Current Annual Real Losses (CARL)

CARL is the current best estimate of the average real losses over a year evaluated using the IWA Standard Water Balance. It can be in the form of volume per year or volume per day. In the case of a system with intermittent water supply, CARL should be evaluated when the system is pressurised.

Infrastructure Leakage Index (ILI)

The ILI is a measure of how well a distribution network is managed, maintained, repaired and rehabilitated as regards control of real (physical) losses, at the current operating pressure. It is the ratio of current annual volume of real losses (CARL) to unavoidable annual volume of real losses (UARL).

$$ILI = CARL/UARL$$

In the case of a system with intermittent water supply the calculation of ILI must take into account the supply time. The calculation is therefore:

$$ILI = CARL_{wsp} \times (24/ST)/UARL$$

CARL and UARL must be evaluated in the same units, typically m^3/d, m^3/yr, Ml/d, Ml/yr, gal/d/, gal/yr. As a ratio, the ILI has no units and thus facilitates comparisons between countries that use different measurement units, namely metric, U.S. or imperial.

Since the UARL takes pressure into account, ILI is only a measure of leakage detection and repair performance. Average operating pressure should be stated along with the ILI so a view can be taken as to whether an opportunity exists to undertake pressure management.

Losses per Connection (when system pressurised)

As a faster and simpler performance index, to be used for target setting and tracking progress in an individual system, unit losses per connection can be used, usually expressed in the form of l/conn/d or gal/conn/d. It is therefore not necessary to know the length of mains or the pressure. The slight downside is that it tends to disadvantage systems with a very low connection density, and it is therefore not recommended for use on systems with a connection density less than 20 connections/km. If the number of connections is not known, a sensible estimate should be made based on a knowledge of likely connection ratio to billed premises.

For a system with continuous supply, the calculation is:

$$Losses/Connection = Leakage/Number\ of\ connections$$

In the case of a system with intermittent water supply the calculation of losses per connection must take into account the supply time. The calculation is therefore:

$$Losses/Connection = Leakage_{wsp} \times (24/ST)/Number\ of\ connections$$

Systems which are metered at the property boundary will have lower losses per connection than comparable systems which are metered internally or unmetered as leakage in these latter systems will include leakage on private service pipes. Losses per connection are usually expressed as l/conn/d or g/conn/d.

Losses per Unit Length of Main (when system pressurised)

Unit losses per length of main, usually expressed in the form of m^3/km/d, is more appropriate for systems with a connection density of less than 20 connections/km.

For a system with continuous supply, the calculation is:

$$Losses/Unit\ length\ of\ Main = Leakage/Length\ of\ Mains$$

In the case of a system with intermittent water supply the calculation of losses per connection must take into account the supply time. The calculation is therefore:

$$Losses/Unit\ length\ ofMain = Leakage_{wsp} \times (24/ST)/Length\ of\ Mains$$

Systems which are metered at the property boundary will have lower losses per unit length of main than comparable systems which are metered internally or unmetered as leakage in these latter systems will include leakage on private service pipes. Losses per length of main are usually expressed as m^3/km/d or g/mile/d.

Pressure Management Index (PMI)

The PMI has been suggested as a way of measuring network performance in respect to pressure management. In this case, the average zone pressure is expressed as a ratio of the Standard of Service on pressure, be that statutory, regulatory or simply a guidance level.

Normalised Mains Burst Frequency

In order to compare mains burst frequencies between areas it is necessary to express burst frequencies per unit length of mains. This is referred to as the normalised mains burst frequency. It is common to express the normalised mains burst frequency as no/100 km/yr. Alternatively, no/100 ml/yr can be used.

Normalised Service Pipe Burst Frequency

In order to compare service pipe burst frequencies between areas it is necessary to express burst frequencies per unit number of connections. This is referred to as the normalised service pipe burst frequency. It is common to express the normalised service pipe burst frequency as no/1000 conns/yr. However, expressing this as a ratio of the number of connections can be misleading depending on the connection ratio. It is, therefore, more sensible to split the frequency of bursts between those occurring on service connections and those occurring on private service pipes. See normalised service connection burst frequency and normalised private service pipe burst frequency.

Normalised Service Connection Burst Frequency

In order to compare service connection burst frequencies between areas it is necessary to express burst frequencies per unit number of connections. This is referred to as the normalised service connection burst frequency. It is common to express the normalised service connection burst frequency as no/1000 conns/yr.

Normalised Private Service Pipe Burst Frequency

In order to compare private service pipe burst frequencies between areas it is necessary to express burst frequencies per unit number of properties. This is referred to as the normalised private service pipe burst frequency. It is common to express the normalised mains burst frequency as no/1000 props/yr.

FINANCIAL

Marginal Cost of Water (MCW)

The marginal cost of water is defined as the additional cost of producing or purchasing and distributing an addition unit of water, such as 1Ml. In the case of a water source, it is the marginal cost of power used in the abstraction, treatment works and distribution pumping, the marginal cost of chemicals and the marginal cost of sludge disposal from the treatment works. It does not include any capital items, such as treatment works, or revenue items, such as manpower or maintenance costs, which would not be readily saved by reducing output by 1 Ml/d. The marginal cost is often derived by adding the annual costs of the items mentioned and dividing by the annual output. This is the ***unit*** cost of water. It is not necessarily the same as the marginal cost when the cost-vs-output relationship is not constant. In the case of water imported from another utility, it is the volumetric charge rate paid to the supplier of the water.

The marginal cost of water is used when evaluating the short run economic level of leakage (ELL). The ELL should be evaluated at WRZ level. In theory the maximum marginal cost of water of any sources or supply feeding a WRZ should be used in the calculation of the ELL on the basis that it would be sensible to pass on leakage reductions by reducing production or purchase at the most expensive source or supply of water. However, the average marginal cost of all sources in or supplies to a WRZ is often used instead of the maximum. The marginal cost of water for the WRZ is either the maximum or average marginal cost of water of the sources feeding the zone plus the marginal cost of distribution pumping.

$$\text{The units of MCW are typically } €/m^3, £/Ml, \$/Ml, p/m^3, \text{ c/gal.}$$

Marginal Value of Water (MVW)

Where the headroom in a WRZ is very low, it may be necessary to evaluate whether it is more cost efficient to carry out additional leakage control activity rather than develop a new resource. In this case, the additional cost of constructing the water resource and associated treatment works (including annual maintenance) has to be added to the marginal cost of water of the WRZ. This total is referred to as the marginal **value** rather than **cost** of water. This is then used in the ELL assessment to evaluate the level of additional leakage measures, such as additional active leakage control and additional pressure management. The units of the marginal value of water are the same as those for the marginal cost of water.

Marginal Cost of Revenue (MCR)

The marginal cost of revenue is the loss in income when a unit of water is not charged/recovered. It is therefore the volumetric charge on the tariff. The cost of revenue is used to judge the value of carrying out activities to reduce apparent losses. At the economic level of apparent losses, the marginal cost of additional apparent loss control will equal the marginal cost of revenue. The units of the marginal cost of revenue are the same as those for the marginal cost of water.

Capital Expenditure (CAPEX)

Capital expenditure or CAPEX is the cost of developing or providing non-consumable parts for the product or system. Capital expenditures is the cost to purchase major physical goods or services that will be used for more than one year. For example, a utility may have capital expenditure to increase or improve its fixed assets. Examples of capital expenditure associated with leakage control and water loss management would include the purchase of PRVs, DMA meters, pressure loggers, flow loggers, correlators and acoustic sensors. It is the asset depreciation, based on its financial life, rather than the expenditure on capital items themselves that impacts on the “bottom line” of a utility. In the case of municipal utilities, capital expenditure will be controlled, and hence possibly limited, by central or local government. In the case of corporate or private utilities capital expenditure will be controlled by internal budgetary control and the ability to raise money on the financial markets.

Operational Expenditure (OPEX)

Operational expenditure or OPEX is the ongoing cost for running a product, business or system. It may also be referred to as revenue expenditure. Examples of operational expenditure associated with leakage control and water loss management would include staff salaries, rent, administration, travel and cost of outsourced leakage detection resources.

Discounted Cash Flow (DCF)

Often it is necessary to combine the effect of both operating and capital costs. This process is referred to as discounted cash flow (DCF) analysis if the capital cost is discounted into an equivalent revenue stream or net present value (NPV) analysis if the revenue stream is converted into an equivalent lump sum. In either case, a discount rate must be used to carry out the conversion and is usually provided by national, federal or local government.

INFORMATION TECHNOLOGY

Geographical Information System (GIS)

A geographic information system (GIS) is designed to capture, store, manipulate, analyse, manage and present spatial or geographic data, for example, providing information on the location and attributes of water mains or DMAs.

Work Management System (WMS)

A computer system used to record physical work undertaken on assets and track the progress of work. Also sometimes referred to as an asset management system or maintenance management system. It is common to have separate systems for “point” assets such as pumps, treatment works, for example, and “linear” assets such as water mains or sewers. A linear asset management system is useful in leakage management as it is the primary source for information on the number of leaks on the various assets and the time that leaks run prior to repair. It is feasible, but not common, to include non-revenue meters, PRVs and, say, air valves on a point asset management system so that warranty issues and regular maintenance schedules on these assets can be managed. A point asset work management system can be designed to record and manage activity on leak detection surveys or this may be held on a separate system or possibly the leakage management system.

Leakage Management System (LMS)

A computer system for managing all aspects of leakage management. It will have access to all flow and pressure monitoring data on the network. It can be separate from or integrated with the GIS, work management and customer billing system so that relevant information on DMA boundaries, property counts, lengths of main, leakage detection surveys, leaks found and repaired, can be viewed and compared against the flows and pressures on the system. The leakage management system will have details of the network hierarchy so that leakage can be reported at multiple levels within the utility.

Customer Contact System

A computer system that records and tracks all customer contacts with a utility. This will include all contacts including no water, poor pressure, visible leak and water quality concerns, among other issues. The system is relevant to leakage management as it records when customers report a visible leak and tracks progress and results of subsequent inspections.

Customer Billing System

A computer system that has information on consumers and their consumption. This is critical for leakage management. The customer billing system will usually also include all information on the revenue meters including type, manufacturer, model, class, date purchased and date installed for example, in order to assist with all aspects of managing the meter stock.

Waste Notice System

A computer system used to manage the process of issuing and monitoring waste notices issued to owners of premises for the repair of leaks on private service pipes or repair of plumbing losses. Also sometimes referred to as leak notice systems or defective fittings notice systems.

Index

Standard Definitions for Water Losses

A compendium of terms and acronyms and their associated definition in common use in the field of water loss management

iwapublishing.com

@IWAPublishing

ISBN: 9781789060874 (paperback)

ISBN: 9781789060881 (eBook)

ISBN 978-1-78906-087-4