APPENDIX Q

UFW CONTROL PLAN SUPPORTING DOCUMENTS

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1 GUIDELINES FOR TECHNIQUES & METHODS IN UFW CONTROL

1.1 GUIDELINES FOR LEAKAGE CAUSES AND DETECTION

Water leakage can result from structural deterioration of the pipeline, generally corrosion or pipe barrel failure, or failure of the joint sealing mechanism. Pipeline failures due to the latter two causes can be related to both deterioration of the pipeline material, and to external loading of the pipe, resulting from poor pipe laying procedures, ground movement and internal pressure surges.

Leakage levels in older pipe systems are controlled by both structural refurbishment strategies, and by local repair activities. It is necessary to carry out repairs in a way, which ensures that they do not result in future pipeline failures. New pipe systems should be constructed to the defined standards to ensure that the expected design life of the pipe is achieved without premature failure or leakage.

The range of failure mechanisms for the alternative water pipeline systems are summarised, and the loading regimes related to these failure mechanisms discussed. Knowledge of the pipeline loading regimes and associated failure mechanisms for the alternative materials is the basis of the guidance given on pipeline design and construction.

Leakage management is discussed, including the major methods of leakage assessment, Total Integral Flow, the Night Line method, and Leakage Modelling. Each of these techniques for leakage assessment has value, although the most appropriate approach for any system depends upon the available information and the use to which the information is to be put.

The use of District Meter areas is becoming the world-wide standard for leakage measurement because of its easy installation. As well as enabling comparable leakage levels to be monitored, this approach also allows data to be gathered which allows improved boundary management and system modelling.

Leakage control is driven by both product availability and by economic considerations. Potential target levels of leakage are discussed, based on technical, economic and political factors. The range of commonly available techniques for leak location and these are outlined, including the technologies upon which these techniques are based.

Pipe Failures

The major causes of pipe failures in trunk and distribution mains are related to external loading of the pipe due to poor pipe laying procedures, loads applied by ground movement, environmental deterioration of the pipe, and internal pressure surges. Combinations of these loading factors can result in failures, as can structural and joint failures due to faulty system construction. Trunk and distribution systems have been constructed, and been in operation for many years. The pipe materials used to construct the pipelines over the years have had a range of properties. This results in differing levels of failures occurring between the range of materials.

To minimise the economic penalties resulting from water leakage, it is therefore important to:

- ensure that new pipe is laid to the appropriate standards, so as to ensure that the expected design life is achieved without failure.
- ensure that repairs to pipe failures are carried out in a way that does not lead to further failures,

Pipe Materials and Failures - Trunk and Distribution Mains

The principal pipe materials and their failure mechanisms are summarised below:

FAILURE MECHANISMS OF WATER PIPELINE MATERIALS	
MATERIALS	**FAILURE MECHANISMS**
Grey Cast Iron	Joint leakage impact damage Bending failures (smaller diameters) Corrosion (graphitisation) Strain corrosion (fissuring)
Ductile Cast Iron	Joint leakage Corrosion (plug) Strain corrosion (fissuring) Lime leaching of liner cement
Steel	Mechanical joint leakage Corrosion Interference damage to pipe coatings
Medium Density Polyethylene (MDPE or PE80)	Failures can be induced by contaminated ground - detergents, solvents, oxidisers. Joint failures if proper procedures are not followed. Risk of rapid crack failures in larger pipe diameters (above 250mm)
High Performance Polyethylene (HPPE or PE100)	Failures can be induced by contaminated ground - detergents, solvents, oxidisers. Joint failures if proper procedures are not followed.
Unplasticised PVC (u-PVC)	Notch-sensitive - failures during laying, and tapping. Impact damage
m-PVC and MOPVC	Ductile failures can occur. Good pipe bedding is required in stony conditions.
Concrete (prestressed)	Leakage and fractures of joints Chemical attack by some soils and waters
Glass Reinforced Plastic (GRP)	Joint leakage Impact damage Bending failures Strain corrosion

Asbestos cement	Impact damage Bending failures Chemical attack

Pipe Failure Mechanisms

Pipeline failures must be minimised, both in the older pipe systems, or in newly laid pipe systems, for both customer service and economic reasons. Pipe laying standards and specifications are designed to minimise the number of in-service failures which occur. Working to these standards during construction of new pipework, and during the maintenance of the existing system construction will assist in reducing failures.

As an aid to understanding the relationship between pipe failures and laying standards, the major pipeline loading regimes are summarised below:

SUMMARY OF LOADING REGIMES	
LOADING REGIME	**COMMENTS**
Internal Pressure	Pipe systems are designed for a 50-year life. The maximum operating pressure specified for pipe systems must take into account both static and surge pressures.
Pipe Laying Damage	Pipe handling: Pipe must be handled and laid so as to prevent damage:- • Plastic pipe can suffer significant wall damage if impacted during laying. • The protective coating of metallic pipes can be damaged through poor handling. *Pipe bed preparation:* Required to prevent local impingement from sharp stones. Pipe laying: Damage to the wall of plastic pipes can occur when these are laid using trenchless pipelaying technology. The maximum allowable gouging damage is 10% of the pipe wall thickness. Damage which is greater than this will reduce the working life of the pipe.

External Ground Movement	External ground movement is the major loading regime on buried low pressure pipe systems, and the older and more brittle materials can fail under the loading. This loading regime can result from:- Natural ground movement: Related to seasonal moisture level and ambient temperature changes, resulting in contraction and swelling of the ground. Traffic loading: Traffic loads can be transferred to the pipe, particularly due to poor reinstatement, over- riding of heavy vehicles, and poor pipe bedding. Adjacent civil engineering works: Pipeline failures can result from ground movement or vibration due to adjacent civil engineering works. For example, deep excavation works, pile driving, tunnelling, blasting, pipe bursting and trenchless pipe and cable laying carried out close to a buried pipe system, all potentially lead to additional loading. Ground loading: Failures can result from excessive pipe burial depth, due for example to overburden being added above the pipe. Whilst it is difficult to predict failures in many of these areas, potential problems can be Minimised by regular monitoring of civil engineering operations which are being carried out close to buried mains.
Environmental Damage	Corrosion of metal pipes and the degradation of plastic pipes can lead to localised failures. These problems can be significantly influenced by the ground conditions. Following the specified laying techniques for new pipe systems will help to reduce these problems in the future.
Impact Damage	A considerable amount of damage to buried pipe occurs during utility operations. The use of mechanical excavation plant can lead to increased levels of impact damage, and the damage can be significant. Use of buried plant records and care whilst excavating can reduce the levels of impact damage.

LEAKAGE MANAGEMENT

Leakage Assessment

Leakage levels within a water supply system cannot normally be measured directly, they must be inferred by a methodology based on other measurement and assessments. Three approaches are available:

- total integral flow,
- night line method,

Each approach has value, but both rely on the installation, temporarily or permanently of bulk flow in the network and the division of the system into discrete areas. The most appropriate approach for any system, depends upon the information available and the use to which the assessment is to be put.

Total Integrated Flow

This is often referred to as the top down approach and is essentially a water balance on the system under consideration.

All known water use within a system is deducted from the water supplied to the system and the difference assumed to be leakage. Where all customer supplies are measured and the metering systems and procedures, for both customer and distribution input, are robust, a reasonably accurate assessment of losses can be made for any period of time. The assessment can be made for any area, district, supply zone, or whole undertaking if the data is available.

Where a significant proportion of customer consumption is not measured because, either an unmeasured tariff is in operation, or through illegal connections to the network, then assessment of losses by this method is inherently less accurate since a separate estimation of the unmeasured component must be made.

Another inherent disadvantage of this method is that it relies on the subtraction of large numbers to achieve the result. Any error in flow measurement, particularly in distribution input, is magnified in the resultant leakage figure. Measured customer data may not be available for smaller supply zones and districts.

The method does have the advantage of being a reasonably quick method of assessment for large areas where the data required is usually readily available, and it generally covers the total network including losses from trunk mains and service reservoirs.

WATER BALANCE

DISTRIBUTION INPUT		
MEASURED USE	UNMEASURED USE	LOSSES

Night Flow Method

This approach requires accurate flow rates to be recorded throughout the night. From the minimum night flow, typically between 2 and 4 am, allowances for customer use are subtracted and the remaining flow considered to be leakage.

The advantage of this method is that it is inherently more accurate because, although the deductions for legitimate customers are often estimates they are only a small fraction of total flow. The technique is particularly useful in District Meter Areas and small supply zones where infrastructure data and customer flow profiles can be established.

The disadvantages are that metering facilities must be available to measure night flows on a regular basis. Night use can be difficult to assess particularly over large areas or in networks with service reservoirs filling and untypical customer use.

For most distribution networks, mains pressures during the night are usually higher than those apparent during the daytime due to the lower flow rates generating smaller hydraulic losses. As the leakage flow rate from any orifice increases with pressure, leakage rates at night for any network are invariably higher than those during the day. To obtain average daily leakage from flow rates taken at night, a pressure correction factor must be used. This is often termed the "hour/day" factor.

As night flow measurements, particularly in District Meter Areas, are often taken over sample periods using data loggers, the time interval of the sample has a significant effect on the minimum flow recorded. The number of properties in the area can also have an effect on the allowances made for customer night use.

NIGHT FLOW BALANCE

NIGHT FLOW		
MEAS URED USE	UNMEAS URED USE	LOSSES

Expression of Leakage

To the layman the most appropriate expression of leakage would appear to be as a percentage of the total water supplied. However, for many years it has generally been accepted that this is a most inappropriate measure for many reasons, not least in that the percentage value is as dependent upon the level of use as it is on the level of leakage.

- Wherever possible, leakage should be expressed as simply a flow rate, that is m3 /day.
- Where a scaling factor is required then litres/prop/day or litres/km/day of mains length should be used.

District Metering

District meter areas (DMA's) are permanently isolated sections of the distribution system into which the water flow is measured, ideally using one single meter, although multiple feed and cascade meters may be used if unavoidable

Increasingly data loggers are used to record flows into, and out of, the DMA's and the readings transferred to depot based PC systems by means of hand held computers or permanently installed telemetry systems. Analysis of the data can then indicate the leakage level in each district and flag up any new bursts occurring, and the effect of any repairs. Leakage location can then be directed to investigate those districts which could be extended to give the most cost effective return.

Typical district size is between 500 and 3000 properties with the optimum size of around 1200 properties. In districts of this size, individual bursts on service pipes can usually be flagged by an increase in the minimum night flow.

District metering is rapidly becoming the world-wide industry standard for leakage management because it is relatively cheap to install and offers substantial additional benefits to the general management of the network, including:

- increased understanding of the system characteristic particularly in large urban conurbations,
- provides building blocks for boundary management,
- facilitates network analysis models to be built.

Appropriate Levels of Leakage

The benefits of reducing leakage levels can be twofold:-

- to save money,
- to save water.

If it is always worth saving money, there may be some instances where it is not worth spending too much money to save water. In reporting to either the Company Management, or the Regulator, the operator must be clear regarding what he is trying to achieve. The different contractual conditions in the various operating companies require different approaches and it is obvious that different target levels of leakage are appropriate.

- In an area where the important factor is a shortage of water, the driver for leakage management may well be maintaining supplies or meeting prescribed levels of service.

- If excessive leakage results in restrictions to supplies and a loss of income from supplies to measured customers, then the cost of lost water is at the -volumetric measured rate which, in most cases, is many times the marginal cost of production and distribution.

- It can also be that contract, statute, or regulation may require a Company to achieve and maintain some mandatory level of leakage, which has no definable economic or practical basis.

LEAKAGE DETECTION

Leak Location

The major techniques for detecting water leaking from a pressurised pipeline are based on the noise, emitted from the point of leakage. The leaking water emits sound over a range of frequencies. The amplitude and frequency of the sound emitted are related to a number of factors, including the:

- water pressure,
- size of hole,

- pipe material,
- leakage path,
- ground type.

Basic location techniques use the ability of the human ear to identify the audible noise within this frequency range. More recent instrument developments have been based on the ability of microcomputer technology to rapidly analyse the noise signals, and use this data to identify more accurately the position of the leak remotely.

Listening Sticks or Sounding Bars

These are hard wood sticks or metal rods with shaped earpiece at one end, which can be used to detect the location of water leakage. They can be quite accurate in experienced hands.

More recently, there have been a number of developments on the same principle but using systems with built in amplification, frequency filters, headphones and electronic sound intensity measurement. Use of these systems can be either direct or indirect:

The background noise occurring both on and near to the water supply system makes the use of these techniques less successful during the day than at night. Suggestions for successful night time operation are:

- noise on a stopcock should be rechecked after a short time to ensure that it was not due to the service being used,
- persistent noise indicates a burst, or water leakage on the service pipe,
- listening after closing of the stopcock should allow identification of which side of the stopcock the leak is located,

Where the sounding procedure identifies defective stopcocks, these should be included on the maintenance programme.

DIRECT AND INDIRECT LEAK LOCATION	
DIRECT	The inspector works along a section listening on valves, hydrants and stopcocks, noting indications of noise from leakage and checking nearby fittings for similar or attenuated noise. Comparing the amplitude of the noise allows the position of the noise source to be estimated.
INDIRECT	Involves the use of surface soundings to verify the point of maximum sound intensity. This technique is essential where the pipe is laid under hard surfaces and few access points to the main are available.

Leak Noise Correlators

Leak noise correlators operate on the principal that characteristic noise emissions emitting from points of leakage can be identified using sensors located at some distance from the point of leakage. In order to identify the location of a leak, sensors are positioned on either side of the suspected leak.

The sensors can be either transducers, which are attached to pipe fittings, or hydrophones, which are inserted at tapping points. The noise frequencies from the leak travel along the pipeline at constant velocity, and are therefore received at each sensor after a time delay, which depends upon the distance between the leak and the sensor.

The instrument determines the position of the leak, in relationship to the two sensors by comparing the frequency wave patterns received by each sensor, and the time for these to reach each sensor. The equipment operates most successfully on metal pipelines.

Equipment	**Comments / Application**	**Limitations**
`Basic' Listening Stick	Rudimentary sounding of SVs, FHs, MSTs etc.	Some smaller leak sounds, may go undetected (good ear required by inspector).
`Electronic' Listening Stick	General sounding of SVs, FHs, MSTs etc Few limitations, generally. useful part of the inspectors `toolkit' Better than `Basic' Stick due to sound amplification	Is sometimes used to confirm `best leak sound' position after correlation Better than `Basic' Stick, not as good as ground microphone
Electronic ground microphone	More sensitive than the electronic stick, powerful, enough to listen to leak sounds through `made roadways' generally used to confirm `best leak sound' after correlation. Can be used for general sounding with a probe screwed into microphone.	More `cumbersome' to use than listening stick. Some inspectors do not like to use microphones they prefer the electronic stick
Electronic ground microphone with sound frequency filters	As sensitive as the ground microphone with the added advantage of the inspector being able to adjust filters and remove some unwanted sounds. Generally used to confirm `best leak sound' after correlation. Powerful enough to listen to leak sounds through `made roadways'. Can be used for general sounding with a probe screwed into microphone.	More `cumbersome' to use than listening stick Some inspectors do not like to use microphones, they prefer the electronic stick

Acoustic Detection Loggers	`Stores' sounds within the distribution system usually between 02:00 and 04:00. Loggers are set up and. downloaded using a PC Leak sounds are identified by the `range' of sounds recorded by the logger Useful for areas where normal leak location activities cannot be used	Does not locate actual leak position, can give identification that leak is taking place
Step Test Unit	Mobile Advanced Step Tester (MAST) system. Used for remote monitoring of flows whilst carrying out step tests within distribution networks. Allows almost instant results leading to minimum disruption to customers . Step tests can be carried out quickly rather than waiting for. `office based' analysis using data loggers.	Valve closure required, valve closure may cause discoloration / water quality problems. Difficult to use during day as some disruption of supplies will take place(unless areas are `back fed' when valve closure takes place). Leak location activity need to be planned to gain best results of step tests
Leak Noise Correlators various	Used for general `surveying' of lengths of main for leak sounds followed by more accurate leak location. Various `models' available from easy to use menu driven machines to PC controlled FFT machines for more `difficult' jobs. Sensitive enough for quiet leak sounds, can survey long lengths of main rather than sounding individual valves.	Very accurate when all data inputs can be guaranteed. Limited to the fact that main material, length, velocities can cause errors in calculations if not accurately entered . A reasonable level of inspector training, skill and experience is required The better the information the better the site result
`Flexi Trace'	Enables non-metallic pipework to be located by the insertion of a flexible `wire'. Once inserted in the pipe a signal is induced either at the leading point of the trace wire or throughout its length. This signal can then be traced using a cable avoidance tool.	The trace wire has to be inserted into the bore of the pipe, leading to a possible contamination risk. Hygiene care needs to be taken when using the trace. Trace will not pass sharp bends or Tee's. When obstructions are met the pipe has to be excavated, the pipe cut & trace re-inserted.
Pipe & cable tools	Used for locating cables and locating / avoiding pipework	Not suitable for plastic pipes unless `flexi' trace is used.
Other pipe tracing equipment	A `vibrating' sound can be induced in the pipe to be traced via equipment attached to a hydrant. The pipe is traced by listening on the surface for sound being transmitted down the pipe	Can get complaints about noise in pipes when in use Some argument about possible damage to pipe by vibration

1.2 PIPE AND CABLE LOCATIONS

As well as the preliminary full survey of the network, it is also extremely important that ground to be excavated is surveyed prior to excavation works. There is a range of equipment available used for the location of buried pipes and cables.

Pipe and Cable Locators

These instruments can be used only for the detection of metallic pipes. They operate on the principal of injecting an electromagnetic signal into the pipe either by:-

- direct coupling with the pipe at a suitable access point, or
- remote coupling using a signal source placed on the ground surface above the pipe.

A location system is then used to sweep the ground to locate the signal emitted from the buried pipe, and hence determine its location. The signal strength received and hence accuracy of location of the pipe depends upon a number of factors:-

- the conductivity of the pipe,
- the pipe depth,
- the environmental conditions and type of ground,
- background interference from power cables,
- background interference from other responsive pipes and cables.

Whilst non-metallic pipes can not be located using these instruments, pipe marker tape can be purchased which incorporates a metallic strip, designed to be identifiable using pipe and cable location instruments. Where the signal generator can not be connected directly to this strip, the small volume of metal within the tape makes indirect coupling difficult and reduces the efficiency of the location technique.

Pulse Generators

Pulse generators operate by applying a distinctive pressure wave signal along the length of the water pipe, and then locating this signal using a seismic sensor in the receiver. The signal is amplified to provide a response on the instrument or operator's headphones. These systems are generally considered suitable for detecting plastic pipes but could be operated in metallic pipe.

The principal two types of pulse generators are.

- A design which uses a spring loaded oscillator attached to a tap or stop cock to generate the pulse and a spiked probe containing an accelerometer as the detector. It is suggested that this system has limited use except in quiet rural areas.
- An electrically driven oscillator used to induce a vibration in the pipe via a connection made directly to a hydrant or other suitable fitting. A ground microphone is used to sweep the ground, and is connected to a small receiver which is itself linked back to the oscillator by means of a radio link. The frequency of the oscillation is set to the resonant frequency of the

pipe being sought. This system is considered to be relatively expensive and power absorbing.

Electromagnetic Detectors

There are two electromagnetic detection systems which are specifically for the detection of plastic water pipes:-

- A system, which introduces electromagnetic waves into the water path using a transmitter, placed at ground level immediately above a known section of the pipe to be traced. Problems with this system are related to the potential for interference noise and induction of the signals into neighbouring plant.
- There is also an intrusive technique, which requires that the probe is inserted into the pipeline on a flexible GRP rod. This is then traced using standard locators.

1.3 GUIDELINES FOR NETWORK FAILURES, BREAKS &REPAIRS

The repair and maintenance requirements for potable water pipelines are considered in this section. It is important, when assessing repair requirements to ensure that repairs are carried out at the safest and most convenient time, whilst considering the possibility for consequential damage to other plant, the road structure, nearby buildings etc. Special circumstances related to specific customer needs or requirements, may prevent the isolation of supplies without prior consultation. Guidelines are provided on the planning of mains repairs.

The types of failures occurring in pipelines are related both to the applied loading regimes, and to the pipeline material. The major structural failure regimes are failure of the pipe joint, the pipe barrel, and of service connections. The failure mechanisms of the pipeline materials in use are discussed.

In carrying out mains repairs, it is necessary to consider the failure type, notification and safety requirements, repair operations and pipeline re-commissioning and reinstatement requirements. Guidance is provided in each of these areas.

The repair techniques and equipment used are dependent upon both the type of failure, and the material. During repair and maintenance operations, it is important for economic reasons to ensure that the size of excavations carried out is minimised. A summary of the available repair techniques and equipment, together with recommendations for maximum excavation sizes is provided.

The maintenance and repair of service pipes offers somewhat different problems in terms of customer response requirements, repair techniques and the repair or replacement decision. These factors are discussed, and guidance is provided on repair and replacement procedures, and maximum excavation sizes during service pipe repairs.

Types of Failures

The types of failures occurring in trunk and distribution mains and their causes are summarised below. The applicability of the available repair techniques is related to the type of failure and the material in which it occurs. The types of failures are summarised below:

TYPES OF FAILURES		
TYPE OF FAILURE	**FAILURE MECHANISM**	**MATERIALS AND JOINT TYPES**
Pipe Barrel	'Brittle' circumferential or longitudinal cracking resulting from pressure and ground loading	Grey cast iron, u-PVC, Asbestos cement.
	Pressure increases or surges can result in blow outs in locally weakened, brittle materials	Ductile iron, polyethylene.

	outs in locally weakened, brittle materials	
	'Ductile' tears can result from internal pressure and local pipe wall damage Manufacturing inclusions can result in local weakening. Metallic materials can weaken due to local corrosion. Local electrolytic corrosion leaks to pin holes particularly steel and ductile iron pipe	All materials.
	General deterioration of the pipe wall can occur due to environmental attack	Iron – graphitisation (corrosion) Asbestos cement – sulphur Concrete – sulphur PE and PVC – chemicals GRP - chemical (solvents)
Pipe Joint	Poor installation practices resulting in seal displacement and mating surfaces separation	Pipes with mechanical jointing arrangements.
	Stress cracking of flanges can result from the *action of externally applied loads, combined* with unequal or overtightening of range bolts, or excessive angular displacement of the pipe end in the socket	Pipes with mechanical jointing *arrangements.*
	Seal deterioration can cause leakage:- Run lead joints deteriorate as the lead hardens and the joints are moved under external loading	Run lead mechanical joints
	Compression ring seals or gasket performance relies on proper assembly Elastomeric compression seals can deteriorate with time due to breakdown or relaxation of the elastomeric material and scouring from small leaks Corrosion of joint pressure rings or bolt corrosion can lead to sealing failure	Push fit or bolted gland joints.
	Solvent welded PVC joints are difficult to assemble consistently. Joint dimensional tolerance must be accurate.	Solvent welded PVC.
	Successful butt, socket or electrofusion fusion welding of polyethylene requires:- • Compatibility of the joint materials • Correct weld surface preparation • Cleanliness in the joint surface preparation • Cleanliness in the equipment preparation • Correct heating times and current levels.	MDPE and HDPE fusion joints.
Service Connections	Common service connection failures are the pipe wall splitting at the service tapping , or stripping	Metallic mains and services.

	away of the inserted ferrule caused by:- • Corrosion problems due to the exposure of unprotected metal at the tapping point. • Shear loading on the service due to ground movement • Over stressing of brittle pipe materials during service tapping operations Where the pipe and ferrule are different materials, a local corrosion cell can be set up	
	Successful fusion welding of PE saddles requires the same preparation as outlined in "Pipe Joints".	PE mains and services.

Saddles and support straps are regularly used to reinforce service connections. Whilst these can reduce the local bending forces, large ground movements can cause shear failures. Correct fitting and protection of the saddles and straps is required to prevent bolt or wedge relaxation

Repair Procedure

Repair procedures should follow the common format, summarised below

REPAIR PROCEDURES	
ACTION	**MAJOR REQUIREMENTS**
Inspection and assessment of the failure.	Establish the severity of the failure. Record possible damage in case of dispute Identify, locate and record status of isolating valves. Check whether it is a sensitive area. Arrange notification and warning of interruption - Highway Authorities and customers. Initiate repairs.
Notification of the work (where necessary)	Notification of interruption to supply. Notification of disruption to highway
Location and excavation	Erect signs and barriers. t Locate buried mains and cables. Expose the failure sufficiently to allow safe working. Use dewatering system. Control failure using valves.
Hygiene	Maintain the work area as clean and sterile work as possible. Minimise contamination and ensure tools are clean before use. Prevent contamination of the main during working. Follow disinfection procedures. Take required samples.
Preparations for repair	Check details of existing pipe. Assess repair requirements (wet or dry). Check availability of repair fittings and required tools.
Repair operations	Follow hygiene requirements. Fit temporary electrical bond. Carry out repairs.

	Record details of the repair. Record the condition of the pipe and pipe failure.
Testing	Provide additional support to repaired section if necessary. Arrange air bleed. Slowly fill isolated section from one direction only. Visual check at working pressure. Flush through.
Recommissioning	Restore all valves to original position. Sample and test water as specified. Spot check flow to customers. Remove any temporary supplies. Arrange notification where necessary.
Reinstatement	Complete bedding and any protection. Reinstate to appropriate standard. Clear site.
Notification of completion.	Notify Highways Authority of completion.

Repair Techniques and Equipment

Repair systems suitable for localised pipe barrel failures are summarised below:

REPAIR FITTINGS FOR BARREL FAILURES		
FITTINGS	**TECHNICAL DETAILS**	**APPLICATION**
Bolted mechanical coupling	Fittings consist of a central sleeve, located between two gland rings with rubber seals Tightening of the longitudinal or circumferential bolts compresses the sealing rings between the fittings and the pipe A range of fittings are available:- • Straight couplings • Flange adaptors • Reducer couplings • Transition couplings • Available in sizes up to 3000 mm diameter.	These fittings are commonly used when it is necessary to cut out a section of pipe and connect a new section into it using two couplers Suitable for all material types.
Electrofusion fittings	Electrofusion fittings are a PE sleeve with built in heating coils. Passing electrical current through the coils heats them, melts the PE and allows fusion of the fitting and parent PE pipe. Available up to 450 mm diameter	Applicable to PE pipe only. A pipe section can be cut out and replaced using two fittings and a new pipe length Specified procedures must be followed including ensuring that the pipe and fittings are dry and clean
'0' Ring repair coupling	These fittings consist of a sleeve fitted with two Internal '0' ring seals. Both push fit and bolted mechanically locked fittings are available Available up to 400 mm diameter	Applicable to PE and PVC pipe. These fittings are commonly used when it is necessary to cut out a section of pipe and connect a new section into it using two couplings

Split Collar	Split collars are made up of two identical halve Sections, flanges on each half section allowing Bolting together. Rubber rings are compressed into position between the pipe and the half Sections to create a seal. Various seal profiles are Available. Available in sizes up to 2000mm Diameter.	Split collars can be used to joint pipes, repair leaks, impact damage and circumferential cracks.
Wrap-around Repair Clamp (Type A)	These fittings have a single body section which, is sufficiently flexible to allow it to be opened up to position it over the exposed pipe. Bolts allow the fitting to be tightened against the pipe wall, and a rubber gasket positioned between the fitting and the pipe affects the seal. Available in sizes up to dia.	Repair clamps can be used to repair circumferential cracks, pipe damage and leaking non-mechanical joints. The fitting is sufficiently flexible to allow it to be used on a range of pipe diameters, and to repair pipe that has significant ovality.
Wrap around Repair Clamp (Type B)	The damp has two half sections, hinged together to allow positioning around the pipe. Sealing is achieved by means of an elastomeric seal positioned between the pipe and the clamp. The clamp is not designed to resist end-load, but serrated rings can be installed so as to assist in providing resistance to pull out. Available in sizes up to 2000 mm diameter.	Used to repair circumferential cracks, local corrosion holes, localised damage and leaking non-mechanical joints.
End Load Resistant Coupling	This damp incorporates an integral gripping system to provide end thrust restraint. The sealing ring and grip ring are tightened into position as the longitudinal bolts are tightened. Available in sizes up to 600mm diameter.	Commonly used on plain end steel a ductile iron pipe, but can also be used on PE and PVC-U, MoPVC. Fitting procedure must be followed. Cleanliness and tightening of bolts to the specified torque is important.

Available fittings suitable for repairing leaking joints are summarised below:

REPAIR FITTINGS FOR JOINT FAILURES		
FITTINGS	**TECHNICAL DETAILS**	**APPLICATIONS**
Socket repair clamp (Type A)	The fitting consists of an anchor ring, positioned behind the pipe socket and which has an end ring bolted to it. A rubber gasket located between the pipe socket and spigot is compressed into position by the end ring as the clamp bolts are tightened, affecting a seal. Available in sizes up to 1500 mm.	The fittings are used to seal leaking joints. Applicable to mechanically jointed iron, ductile iron, steel and asbestos pipe.

Socket repair clamp (Type B)	This fitting is designed in two halves to allow it to be positioned around the socket joint. Once positioned the two halves are bolted together. Sealing is affected by means of longitudinal seals sealing the fitting, and rubber rings backed by compression rings sealing between the pipe and fitting. Available in sizes up to 3000 mm.	The fittings are used to seal leaking joints. Applicable to mechanically jointed iron, ductile iron, steel and asbestos pipe.

Standard fittings can also be used to effect repairs.
Repair requirements, which are specific to the materials used, are summarised below:

REPAIR REQUIREMENTS SPECIFIC TO MATERIALS	
MATERIAL	**REPAIR REQUIREMENTS**
Ductile iron	Severe corrosion in ductile iron pipe can be localised, and due to adverse ground conditions. In these circumstances the implementation of a cathodic protection system could be considered. Repair options range from the fitting of leak repair damps, through replacement of pipe lengths to complete lining of the system. Care should be taken when operating on ductile iron pipe, to ensure that the pipeline integrity of the pipeline is not impaired in terms of thrust restraint.
Polyethylene	The full extent of the damage to the pipe should be ascertained. Emergency repairs can be made using a split collar. A permanent repair should be carried out by cutting out and replacing the full defective length of PE with a pipe of the same pressure rating. Electrofusion fittings or suitable mechanical couplers can be used to join the new and old pipe sections. Metallic fittings should be suitably protected from environmental attack. Small leaks can be repaired using a fusion saddle, once the main has been drained. Care should be taken to ensure that the surrounding ground or highway structure is correctly filled, compacted and repaired. The danger of pull out should be considered when carrying out the repair of pressurised pipe systems.
PVC-U	The full extent of the damage to the pipe should be ascertained. Care should be taken to ensure that the pipeline does not spring apart once cut. A permanent repair should be carried out by cutting out and replacing the defective length of pipe with new pipe. If the old pipe is imperial, then the nearest equivalent metric pipe should be used. Suitable metallic couplers or repair fittings can be used to join the new and old pipe. Care should be taken to ensure that the surrounding ground or highway structure is correctly filled, compacted and repaired.

Steel	Generally, on-going corrosion prevention measures are taken with steel pipelines, for example corrosion prevention using cathodic protection and the application of pipe coatings. It could therefore be expected that deterioration should be localised. Repair techniques range from localised welding of patches to replacement of pipe lengths. In the worst case system lining may be required. Care should be taken to ensure that repairs do not adversely affect corrosion protection measures.
Asbestos cement	Due to the hazardous nature of asbestos materials, particular care must be taken with these pipe systems.

COMMON MAINS PIPELINE REPAIR TECHNIQUES			
PIPE MATERIAL	**FAILURE**	**REPAIR METHOD**	**FITTINGS**
Grey Cast Iron	Joint failure	Enclose joint Remove joint	Joint clamp Two couplers and new section
	Brittle failure	Enclose failure Remove section	Repair collar or clamp Two couplers and new section
	Corrosion	Remove section Enclose failure Pipeline rehabilitation	Two couplers and new section Repair collar or clamp Lining
Ductile Iron	Joint failure	Enclose joint Remove joint	Joint damp Two couplers and a new section
	Localised corrosion	Enclose leakage	Repair collar or clamp
	Extensive corrosion	Remove section Pipeline rehabilitation	Two couplers and new section Lining
	Ductile failure	Enclose leakage Remove section	Repair collar and clamp Two couplers and new section.
Steel	Joint failure	Remove joint Enclose joint	Two couplers and new section Special joint damp
	Localised corrosion	Enclose leakage	Patch and weld Repair collar or damp
	Extensive corrosion	Remove section Pipeline rehabilitation	Two couplers and new section Lining
Asbestos Cement	Joint failure	Enclose joint	Joint damp
	Longitudinal cracking Surface softening	Remove complete pipe length	New pipe section and fittings
	Circumferential failure	Endow burst Remove crt0ete pipe length	Repair collar a damp New pipe section and fittings
Concrete	Joint failure	Endow joint Remove complete pipe length	Special joint damp Two coolers and new pipe section
	Cracking Surface softening	Remove complete pipe length	Two couplers and new pipe section

PE and PVC	Joint failure	Cut out joint	Two couplers and new pipe section
	Brittle failure	Enclose burst Remove damaged section	Repair collar or damp Two couplers and new section
	Fast crack propagation	Remove damaged section	Two couplers and new section
GRP	Joint failure	Endow joint Replace joint	Joint clamp Repair collar or clamp
	Delamination, Fracture or damage	Remove section Enclose failure	Two couplers and new section Repair collar or clamp

Repair & Replacement Procedures

Mains Repair Procedures

MAINS REPAIR PROCEDURES		
METHOD	**PROCEDURE**	**EXCAVATION SIZES**
Collar or Clamp Repair	Cut-chase surface material where required. Remove surface and immediate foundation materials. Excavate to pipe. Clean and disinfect pipe and fittings. Dismantle collar or clamp. Position collar or clamp around pipe. Fit and tighten nuts and bolts. Denso joint if required. Reinstate.	Up to 150 mm dia (1.071 x 0.91w) 175/250 mm dia (2.291 x 1.07w)
Cut Out Using 2 V.J. Type Couplings	Cut/chase surface material where required. Remove surface and immediate foundation materials. Excavate. Clean, measure and mark pipe. Set up abrasive wheel cutters or pipe crackers. Cut and break out pipe, remove broken pieces. Disinfect pipe ends and fittings. Position pipe and fittings into trench. Position couplings, fit and tighten nuts and bolts. Denso joint if required. Reinstate.	Up to 150 mm dia (1.831 x 0.91w) 175/250 mm dia (2.291 x 1.22w)

Cut and Cap Main (Using F.J. and Blank Plate)	Cut/chase surface material where required. Remove surface layer and immediate foundation material. Excavate using a breaker if required. Clean, measure and mark pipe. Set up abrasive wheel cutters or pipe crackers. Cut and break out pipe, remove broken pieces. Clean and disinfect pipe ends and fittings. Position pipe and fittings. Position coupling, fit and tighten nuts and bolts. Denso joint if required. Construct thrust block. Reinstate.	Up to 150 mm dia (1.071 x 0.91w) 175/250 mm dia (1.371 x 1.22w)
Repack Valve	Cut/chase surface material where required. Remove surface and immediate foundation materials. Excavate. Demolish or dismantle access chamber. Operate valve to closed position. Remove valve cap and false spindle. Dismantle gland and remove defective packing. Cut new packing, refit and re-assemble gland. Position new valve cap and false spindle. Operate valve to bed in packing. Finefill around pipework. Install access chamber including the frame and lid. Reinstate.	Up to 250 mm dia (0.911 x 0.91w)
Install Valve	Cut/chase surface material where required. Remove surface and immediate foundation materials. Excavate. Clean, measure and mark pipe. Set up abrasive wheel cutters or pipe crackers. Cut pipe, break out and remove broken pieces. Clean and disinfect pipe ends and fittings. Position valve and fittings into trench. Prepare flanges and position gaskets. Position valve and bolt up flanges. Denso joints if required. Finefill around pipework. Install access chamber including the frame and lid. Reinstate.	Up to 150 mm dia (1.071 x 0.91w) 200/250 mm dia (2.291 x 107w)

Renew Valve	Cut/chase surface material where required. Remove surface and immediate foundation materials. Excavate. Demolish or dismantle access chamber. Clean, measure and mark pipe. *Set up abrasive wheel cutters or pipe crackers.* Cut pipe, break out and remove defective valve and broken pieces. Clean and disinfect pipe ends and fittings. Position valve, spigot and flanges. Denso joints if required. Finefill around pipework. Install access chamber, inducting the frame and lid. Reinstate.	Up to 150 mm dia (1.831 x 0.91w) 200/250 mm dia (2.291 x 1.07w)
Install or Renew F.H./W.O. Including Tee Piece, Duckfoot, Extender or Change Piece	Cut/chase surface material where required. Remove surface and immediate foundation materials. Excavate. Demolish or dismantle access chamber. Clean, measure and mark pipe. Set up abrasive wheel cutters or pipe crackers. Cut pipe, break out existing branch pipe and remove defective F.H./W.O. spigot and broken pieces. Clean and disinfect pipe ends and fittings. Prepare tee piece or duckfoot and fittings assembly. Prepare flanges and position gaskets. Position F.H./W.O. assembly and bolt up flanges. Operate F.H./W.O. Denso joints if required. Finefill around pipework. Install access chamber, including the frame and lid. Reinstate.	Up to 150 mm dia (1.371 x 0.91w)
Remove F.H./W.O. *and Pipe Through*	Cut/chase surface material where required. *Remove surface and immediate foundation materials.* Excavate. Demolish or dismantle access chamber. Clean, measure and mark pipe. Set up abrasive wheel cutters or pipe crackers. Cut pipe, break out existing branch pipe and remove F.H./W.O. and pieces. Clean and disinfect: pipe ends and fittings. Pick up and position pipe and fittings into trench. Position couplings, fit and tighten nuts and bolts. Denso joint if required. Reinstate.	Up to 150 mm dia (1.371 x 0.91w)

Replace Corroded Bolts on Flanged Fitting	Cut/chase surface material where required. Remove surface and immediate foundation materials. Excavate. Clean joints and remove nuts and bolts. Knock out bolts from fittings. Clean and disinfect: joints and fittings. Dismantle, refit and tighten new bolts to fittings. Denso joints if required. Reinstate.	Up to 150 mm dia (1.071 x 0.91w) 200/250 mm dia (1.371 x 1.22w)
Tracking	Cut/chase surface material where required. Remove surface and immediate foundation materials. Excavate. Reinstate.	Up to 150 mm dia based on 0.61w and full trench depth. 175/250 mm dia based on 0.76w and full trench depth.
Operate Valve	Check plans. Position road cones where necessary. Remove cover and dean chamber Use key to dose or open valve. Remove key, replace cover, remove cones. Inform control.	

SERVICE PIPES

Over the years a number of different materials have been used for the construction of the service pipes to customers' premises. The replacement and repair methods for failures of these pipe systems are very similar. It may be necessary to cut through the pipe at the leaking section to allow fitting of repair fittings and liners. This also allows a general assessment of the condition of the pipe. However, replacement decisions are generally taken strategically and based on economic factors and the known performance of the alternative service pipe materials.

The commonly used repair techniques for each material are summarised below

COMMON SERVICE PIPE REPAIR TECHNIQUES		
SERVICE PIPE MATERIAL	**SMALL AREAS OF DAMAGE**	**LARGE AREAS OF DAMAGE**
All materials		Services should be renewed where possible.
Lead	Wrap around collar, with inserts if necessary.	Replace with length of PE jointed using mechanical couplers, with inserts if necessary.
Copper	Metallic or plastic compression couplers with inserts.	Replace with protected copper or PE, jointed using Compression fittings or transitional couplers.
Galvanised steel	Wrap around repair clamp.	Replace with length of PE jointed using transitional couplers or wraparound clamps.
Polyethylene	Electrofusion saddle, repair collar or mechanical repair clamp	Replace with equivalent pressure rated PE, jointed using electrofusion or mechanical endload resistant couplers.

Early plastics	Wraparound repair clamp, split collar with inserts.	Replace with equivalent pressure rated PE, jointed using mechanical couplers. End load resistance may be required.

The customer is responsible for leakage from their section of the supply pipe, though eventually remedial action may be taken by the Company to prevent the water wastage. Wastage from customers' taps can be significant and for this reason procedures allow rewashering of taps in some circumstances. Similarly leakage through float operated valves can be prevented by maintenance of the valve, which may be carried out by the Company in some circumstances.

Service Laying and Repairs - Excavation Sizes and Methods

Excavation Sizes

The sizes of excavations for service laying should be minimised wherever possible. The excavation sizes below are provided as a guide:

SERVICE EXCAVATION SIZES - LAY AND RENEW SERVICES			
SERVICE TYPE	**LENGTH**	**WIDTH**	**DEPTH**
Lay & Renew	1.83	0.61	0.76
Service repair	1.22	0.61	0.76
Thickening	1.0	0.46	0.76

Operating Procedures - Service Laying and Repairs

PROCEDURES FOR THE LAYING AND REPAIR OF SERVICE PIPE	
OPERATION	**PROCEDURE**
Lay Communication Pipe – Single	Remove any surface layer. Excavate to allow connection to main. Excavate tracking (if required) to enable the connection to the customers supply pipe. Clean main and fit service UPC or saddle (Metal, PVC, AC or PE main). Install meter and position chamber. Connect CP from the UPC to the meter chamber, threading pipe through duct (if required), using elbows as required. Connect SP to the meter chamber and open UPC. Flush meter and test at premise. Fit meter chamber cover. Backfill to compaction standards. Carry out permanent or temporary surface reinstatement.

Lay Communication Pipe – Double	Remove any surface layer. Excavate to enable connections to the main. Excavate tracking (if required) to enable connection to the customers supply pipe. Clean main and fit service UPC or saddle (Metal PVC AC or PE main). Install meters and position chambers. Connect CP from the UPC to the meter chambers threading pipe through duct (if required) using a tee-piece and elbows as required. Conned SP's to the meter chambers and open UPC. Flush meter and test all premise. Fit meter chamber covers. Backfill to compaction standards. Carry out permanent or temporary surface reinstatement.
Renew Communication Pipe- Single	Remove any surface layer. Excavate to enable connection to main. Excavate tracking (if required) to enable the connection to the customers supply pipe. Remove ferrule connection from the main and fit a UPC if PVC AC or PE main, replace saddle. Connect CP from the UPC to the stopcock. Conned SP to the stopcock and open UPC. Test service pipe and supply at premise. Install access chamber including base and cover. Backfill to compaction standards. Carry out permanent or temporary surface reinstatement.
Renew Communication Pipe – Double	Remove any surface layer. Excavate to enable connection to main. Excavate tracking (if required) to enable the connection to the customers supply pipe Remove ferrule connection and if required re-tap to increase the mains tapping, fit UPC or enlarge mains tapping and fit pre-drilled collar. Clean and disinfect pipe and fittings. Connect CP from UPC to the stopcocks using a tee-piece and elbows as required. Connect SP's to stopcocks and open UPC. Test service pipe and supply at premise. Install access chamber including base and cover. Backfill to compaction standards. Carry out permanent or temporary surface reinstatement.

Communication Pipe Repairs	Remove any surface layer. Excavate to enable connection to main. Sound for leakage. Close stopcock or freeze/clamp CP. Fit and remove earthing clips. Cut service pipes and make repair. Thaw pipe (if required) or open stopcock. Sound for leakage and test at premise. Backfill to compaction standards. Carry out permanent or temporary surface reinstatement.
Transfer Communication Pipe or Renew CP using Pre-drilled Split Collar	Remove any surface layer. Excavate to enable connection to main. Cut communication pipe. Remove existing ferrule and fit UPC plug or saddle. Re-tap main/or enlarge mains tapping and fit pre-drilled collar. Clean and disinfect pipe and fittings. Clean new main drill and tap (metal, PVC AC or PE). Re-connect communication pipe and open UPC. Sound for leakage and test supply at premise. Backfill to compaction standards. Carry out permanent or temporary surface reinstatement.
Renew Stopcock	Remove any surface layer. Excavate to enable connection to main. Freeze/clamp service. Fit arid remove earthing clips (if required). Cut service pipe and remove stopcock. Install new meter chamber and reconnect service. Thaw pipe/or remove clamp. Remove meter, if required. Install new meter. Open stopcocks. Test meter and supply at premise.
Change Meter Interior	Clean/bail/pump out meter access chamber. Close off supply. Remove meter mechanism. Install new meter mechanism. Open supply. Test meter and supply at premise.
Tracking	Excavate. Lay duct in trench. Thread pipe through duct if required. Backfill and compact. Reinstate as required.

CP Communication Pipe (the part of the Service line that is the responsibility of the Water Company

UPC Under-Pressure Connection

SP Supply Pipe (the part of the service line that is the responsibility of the customer)

1.4 GUIDELINES FOR SPECIFIC LEAK DETECTION TECHNIQUES

Method of Locating Leaks by Sounding

The location of leaks by sounding demands considerable experience, which can be acquired by good training in which the various problems are carefully demonstrated. It is, of course, far easier to detect leaks by direct contact with a main valve or service connections than through the ground. Some basic points on sounding techniques are covered in the following paragraphs.

An ordinary metal rod or a valve key will transmit the sound of a leak, but extraneous noises make this simple sounding difficult. An improvement has been developed by fitting double earpieces containing diaphragms which amplify the sound. The sound can be detected by a microphone and amplified electronically. When this technique is used, leak sounds can be indicated visually and heard at greater distances. Traffic noises are deadened by rubber seals around the earpieces facilitating the detection of sound patterns that indicate types of leakage. Unfortunately, extraneous sounds other than traffic may also be amplified. All this equipment is valuable, but good training is essential for its proper use and above all for care in handling to avoid breakage. Batteries must be checked and well maintained, and all contacts must be cleaned to avoid corrosion.

Differences in the type of sound will indicate to an experienced operator whether he is listening to a leak or to water being drawn off for consumption. If the leak is near by, the sound is normally of a higher frequency. Listening on a valve is often useful, provided the pipe material is not asbestos cement or plastic. Leaks are easier to detect in metal pipes than in asbestos cement and most difficult of all in plastic and rubber pipes. Leaks are more easily detected in dry soils than when the pipes are below the water table. If there are air pockets in the pipe, sound is not transmitted beyond them. But the sound of a slight leak from a gland on a valve will drown out the sound of a larger leak at a distance. The sound heard from hydrants or service pipes is much more faint, unless the leak is associated with the particular branch.

It is extremely difficult to locate a leak by reference to the intensity of sound at different points. Usually final location is best achieved by indirect sounding on the ground or by listening on a pin driven down to contact with the pipe.

For indirect sounding on the ground, it is usually best to use geophones with dual hollow tubes connected to ground plates or to pointed probes containing diaphragms. This equipment is also available with microphones and amplifiers. The plates or probes need to be vertically above the pipe, thus it is usually best to begin by using magnetic pipe locators to determine the pipe location accurately. The sounds heard by indirect sounding are of a very low pitch and not easy to differentiate from traffic noises. Only by changing the position of the probe/plate in relation to the leak may differences be detected. Sounds emitted from metal pipes tend to be concentrated along the line of the pipe whereas those emitted from plastic pipes are spread uniformly in all directions. False indications can be obtained through transmission by foundation walls in contact with the pipe.

Depending on labor conditions, simple sounding -- without any means of concentrating effort by district metering or otherwise -- aimed at covering the whole area of. supply twice a year could entail the employment of one three-man team for every 20,000 properties.

Step-Testing in Metered Districts

Before carrying out step-tests on a waste district, it is essential to go through a checklist to ensure that:

(a) a map of this district has been prepared and is correct

(b) a program of the procedure has been prepared, complete with timing instructions for valve operation;

(c) each valve shown on the plan can be found, is operable, is correctly set, and can be closed "drop-tight";

(d) all large meter locations are known and, where necessary, consumers have been notified of shut-down;

(e) the police and fire service have been notified;

(f) all supplies for hospitals and essential services are maintained;

(g) all employees have the necessary maps, instructions and equipment including flashlights, watches, valve keys, cover keys, pressure gauges, fluorescent jackets, and two-way radios;

(h) the waste meter clock is correct and all watches are timechecked.

Incidental equipment for normal repair operations should be available on the spot.

It is essential that any new program be well rehearsed in daylight before proceeding with a night test. Security of personnel should be given special attention.

There are various types of step-tests, such as the three noted below:

(a) Christmas Tree - This is the standard method extended to give a reverse opening sequence. This extension may not be practical in situations where low night flows are of very short duration.

(b) Open and Close - This is a method where each section is turned off and on again for a brief period so that the supply is interrupted for only a short time. The results are much more difficult to analyze but the procedure may be necessary to better maintain supplies for essential services.

(c) Double Locking - For this test, as the metered supply is cut off to a section an alternative supply is made available from outside the district. This is ideal where it can be arranged but requires more labor and an assurance that all valves, not only the boundary valves, close drop-tight.

When conducting such tests it may be desirable to have in mind that: it is impracticable to find and repair all leaks; it may be uneconomical to repair large numbers of small leaks. Figures for acceptable leakage vary but generally in old districts in the United Kingdom flows of up to four liters per property per hour are acceptable, whereas in newer districts lower figures apply.

In many old urban areas, when beginning to practice active leak detection in this way, it will probably be difficult to achieve minimum net night flows less than 10 liters per property per day unless the average pressure is relatively low. If operating pressures are too low, step-testing will probably not be a practical method of leak control. Experience shows that in many districts where waste water meter districts have been established it is more cost effective to treat the meters in the same way as district meters; that is, to monitor the 24-hour flows frequently, evaluate changes that occur, and concentrate leak detection accordingly. Further concentration of activities to single streets is often not justified especially where labor is plentiful and not expensive.

Instructions for Step Tests

Objective

To identify and analyse the flows into different parts of a test section of the Water supply zone. When carried out at period of low demand (min night flow) the objective is to identify the sub-sections with the highest flows; these being likely to have the highest rate of leakage

General Description

- A section of the water supply zone is identified
- PZT is carried out before step testing to check that there are no unknown or forgotten cross-connections
- All valves connecting the test section to the rest of the system are closed, except the key valve at the inlet
- The flow into the section is recorded for a short period of a few minutes

- The most distant valve from the inlet to the section is closed and the system allowed to settle down
- The flow into the section is again recorded for a short period of a few minutes
- The next most distant valve from the inlet to the section is closed and the system allowed to settle down
- The flow into the section is again recorded for a short period of a few minutes
- This sequence of "steps continues until the inlet valve is reached and the test is complete
- The difference between each flow measurement is calculated to give an indication of the flows (and demand) in each part of the section.

Note: The figures for flow will not be exact because the demand will vary over the period of the test, as customers turn taps on and off

Setup & Preparation

- Prepare map or schematic of the section to be tested
- Study map to check the location of all valves necessary to isolate the section to be tested.
- Identify the "key" valve to be used to perform the pressure zero test
- Ensure that a suitable point is available for fitting the flowmeter to be used
- Identify and record the sequence of valves to be closed along the line for "step " testing
- Setup & Prepare flowmeters, loggers, hoses etc for the test (Use 1 minute logging interval)
- Prepare a Step test form with all preliminary information completed

Step Test

- Fit flow measuring equipment to the test point
- Isolate all boundary valves identified
- Complete the Step test form with all information as the test proceeds
- Wait 10 minutes for pressure & flow to stabilise
- Record the flow over 5 minutes for an average rate
- Close First valve in the sequence (furthest from the inlet)
- Wait 10 minutes for pressure & flow to stabilise
- Record the flow over 5 minutes for an average rate
- Close next valve in the sequence
- Repeat the above series of actions until the sequence is complete
- SLOWLY reopen key valve and recharge the system
- Reopen all other isolated step sequence and section boundary valves
- Collect in all equipment used for test
- Return the completed test forms to the Network Chief

Results

The flow into each sub-section is calculated by calculating the difference between the flow recorded into the section before that sub-section is isolated (A) and the flow after it is isolated (B)

Flow in sub-section = A - B

Instructions for Pressure Zero Tests

Objective

To prove that the section under test is « tight » and has no cross-connections with other sections that allow flow in or out of the test section.

General Description

- A section of the water supply zone is identified
- PZT is carried out to prove that there are no unknown or forgotten cross-connections
- All valves connecting the test section to the rest of the system are closed, except the key valve
- The key valve is left open so that all flow into the section passes through this single point. This is the most upstream valve, closest to the supply source, that acts as the single inflow point for the test
- Pressures are recorded at 3 points, using either loggers or pressure gauge readings:
  - Inlet (at key valve)
  - High Point the highest elevation in the section where pressure can be measured
  - Far point the most distant point of the network with the smallest pipe diameter in the section where the pressure can be measured
- The key valve is closed so that no water should be entering the section. Any water in the section will flow out as a result of leaks and/or customer demand
- The pressure in the section should fall rapidly to zero (or much lower value than before) as water flows out.
- After a short period (e.g. 10 mins) the pressures at the three points are again recorded to verfiy the drop in pressure
- The section is then opened back up
- First the key valve is opened slowly to enable the system to be recharged without pressure surges
- The other valves that were closed to isolate the section are reopened
- The results of the test are recorded
- If the PZT failed, investigation is carried out to find out why and after remedial action the PZT is repeated

Setup & Preparation

- Prepare map or schematic of the section to be tested
- Study map to check the location of all valves necessary to isolate the section to be tested.
- Identify the "key" valve to be used to perform the pressure zero test
- Identify suitable sites where connections can be made to measure pressure at the 3 points
- Setup & Prepare pressure gauges, loggers, hoses etc for the test (Use 1 minute logging interval)
- Prepare a PZT test form with all preliminary information completed

Pressure Zero Test

- Fit pressure measuring equipment to the test points
- Isolate all boundary valves identified
- Complete a PZT test form with all information as the test proceeds
- Wait 10 minutes for pressure & flow to stabilise
- Record pressure
- Close key valve
- Monitor pressure and note characteristics/ record pressure after 10 minutes
- SLOWLY reopen key valve and recharge the system
- Reopen all other isolated boundary valves
- Collect in all equipment used for test
- Return all completed forms to the Network Chief

Results

- If pressure drops to zero or close, then PZT has passed: otherwise refer to Network Chief for decision

1.4 GUIDELINES FOR METER SELECTION & INSTALLATION

Metering requirements can be divided essentially between those for domestic supplies, that is services with a diameter of 25 mm or less, and for non-domestic, those larger than 25 mm diameter.

On this basis, small commercial and industrial enterprises are normally to be considered as domestic category for tariff purposes, unless there is a record of continued high consumption or other special circumstances.

Charging on the basis of a metered supply is now taken to be the standard and the related effects on rebates and control of supply pipe leakage must also be considered.

Performance

The UK specification relating to performance of all meters, ISO 4064, is a much used international standard and it or an equal equivalent shall be used for all meters to be installed. ISO 4064 defines a stepped operating envelope and the errors allowed within this envelope, giving the permitted accuracy over a range of flows.

Domestic And Non-Domestic Meters

The long term performance of meters is critical to revenue income and meter defects must be recognised and actioned. The selection of a meter is influenced by a number of key considerations, namely:

- size and performance - to meet anticipated flow rate,
- class - to meet the accuracy specified,
- type - to meet operational constraints,
- installation - reading errors related to method of plumbing.

Performance of Domestic Meters

The performance requirements relating to Class type are shown below and define the operating regimes available.

PERFORMANCE REQUIREMENTS OF DOMESTIC METERS				
METER CLASS	DESIGN FLOW RATE L/HR			
FLOW M3/HR	Qmin	Qt	Qn	Qmax
Class D: Qn 1.0	7.5	11.5	1000	2000
Class D: Qn 1.5	11.25	17.25	1500	3000
Class C: Qn 1.0	10	15	1000	2000
Class C: Qn 1.5	15	22.5	1500	3000

Qn	Nominal flow rate	Qt	Transition flow rate
Qmin	Minimum flow rate	Qmax	Maximum flow rate

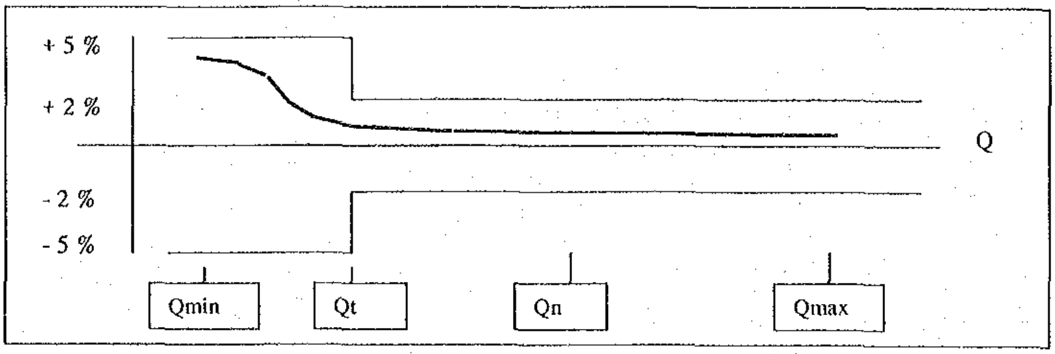

Diagram of Typical Operating Envelope for ISO 4064 Meter

Meter Errors - Domestic Meter

Meter registration error is defined as the sum of all errors at each flow rate over a given period, which is calculated by multiplying the % error and % total flow at each flow rate. This data is derived from the meter error curve and the proportionate flow rate across the range.

From this information, estimates of under-reading and hence lost revenue can be determined. Details of replacement meters should also be recorded to ascertain both the cause of failure and the cost incurred.

Meter registration is affected by the type of plumbing installation:

Selection of Non-Domestic Meters

Typical applications of non domestic meters of >=50 mm nominal diameter are:

Non-Domestic Customers

- industrial customers,
- commercial customers,

Network Bulk Meters

- supply meters,
- trunk mains,
- transfer between zones (areas),
- district meter zones (areas).

The most common flowmeters currently in use for non-domestic applications are Woltmann turbine meters, rotary piston meters, and Jet (multi-jet) meters.

There are an increasing number of electromagnetic devices whilst ultrasonic devices have not yet become established as an option. Differential pressure types tend to have been installed in older premises. The operating principle, performance and experience of each type are now considered.

Meter Types

There are a number of alternative types of meter. Their advantages and disadvantages are detailed below.

METER TYPES			
***METER* TYPE**	***DESCRIPTION***	**ADVANTAGES**	**DISADVANTAGES**
Woltmann Meter	Referred to as a helix or impeller meter. It comprises a helical rotor, coupled to an external register through gears and/or magnetic drives.	Range from 40 mm - 300 mm nominal dia. Minimum turndown of 10:1 with ±2% accuracy; 400:1 is claimed for some models but with reduced low flow accuracy. Relatively low cost. No external power source; ideal for remote sites. Ease of maintenance; rotor and register can generally be removed from housing in-situ. Pulse output for data logging can generally be fitted.	Affected by poor flow conditions, i.e. swirl. Best performance requires minimum of 10 diameters of upstream pipe or more where geometry may disturb flow conditions. Pressure loss is lower than rotary piston meters – higher than non-intrusive types. Cavitation can occur when head is low or velocity high, affecting readings and likely to damage rotor and bearings.
Rotary Piston Meters	This type of meter is widely used for domestic metering.	Range up to 100 mm diameter. Wide turndown, up to 200:1 No external power source. Output devices may be fitted to modem versions connected to data logging systems but require power. Inlet conditions not critical: simple installation, low costs.	Main pressure loss is relatively high. Sensitive to particulate matter; may jam or damage meter.
Jet Meters	Jet meter performance and operating characteristics are fully described in the future metering manual.	1% full scale accuracy. Cheap and generally reliable. Available up to 100 mm diameter.	Higher head loss than a conventional turbine meter.

Insertion Meters	A small single sensor, typically turbine or electromagnetic type, inserted into the pipe, measures point velocity. The sensor can be moved within the pipe to record the velocity profile and hence, flowrate. Alternatively, a number of sensors may be used.	Great care needed; local point accuracy can be less than 2% reading but full velocity profile may only be 10% accurate. Multi-point measurement: Differential pressure probes (averaging pilot tubes) accurate to 2% reading. Electromagnetic probes new in UK, suited for large pipes with 1 % accuracy claimed	insertion probe causes restriction; insignificant on large pipes but significant on small pipes.
Electro-magnetic Flowmeters	in these devices the water acts as a conductor with electromagnetic coils mounted on the pipe. Water flow generates an induced voltage from which the flow rate is calculated. These are very commonly used instruments, especially above 100 mm diameter.	Size range of 1 mm up to 2.5 m nominal diameter. Minimal flow intrusion minimising head loss. Less than 1% full scale accuracy. Minimum turndown of 10:1, newer models claim up to 1000:1. Low maintenance and good reliability. Different lining materials can be used to suit circumstances. Relatively unaffected by turbulence. Potential use with microprocessor.	Function only with conductive fluids above 10 u S/cm; water is usually well above this figure. Large units are expensive. External power source required; battery powered versions available. Minimum of 10D upstream straights recommended.
Differential Pressure Methods	The several versions of differential pressure meters all work on the same principle. A primary device constricts the flow, causing a local pressure drop which is measured by the secondary device. Primary devices include orifice plate, Venturi tube, nozzle, and Dall tube. Secondary devices typically comprise of a differential pressure cell connected to each side of the primary constriction. The reading can be mechanical, manometric or electronic.	Well established performance. Good primary reliability device. Maintenance/replacement of Secondary device independent of primary.	Performance probably inferior to electro-magnetic instrument. Power is required `or secondary device. Secondary device sensitive to blockage in connections. Wear can occur on the primary device over time. Low turndown of only 3:1 typically.

Ultrasonic Flowmeters Transit Time	Best suited to clean fluids Uses pairs of transducers pointing upstream and downstream. Transducers transmit and receive ultrasonic signals. Downstream signals will travel faster than upstream signals. Flow velocity and hence flowrate can therefore be calculated.	Accuracy of less than 2% reading in good conditions; accuracy to less than 1% is claimed where more pairs of transducers are fitted.	Negligible head loss. Susceptible to disturbance; need to minimum of 5D up to 40D upstream straight section. Relatively expensive.

Combination Meters

The combination meter overcomes the problems associated with low flows; a sensitive second meter being incorporated in a by-pass. A pre-set valve opens such that low flow passes through the secondary meter. Typically, a Woltmann meter acts as the primary and a rotary piston as the secondary meter. These devices are particularly well suited where there is a wide range of flowrates and effectively extends the range of a standard unit.

METER LOCATION

The choice of meter location essentially depends upon both the customer's views and water company's requirements. There are five permissible locations, namely:

- at the point of entry inside the property (internal),
- at the property boundary (public), typically in boundary box,
- at the property boundary (private),
- wall-mounted on the building,
- at the building boundary, but underground.

Each option has particular advantages and disadvantages as broadly described below:

ALTERNATIVE METER LOCATIONS		
LOCATION	**ADVANTAGES**	**DISADVANTAGES**
Internal	Cheapest on new or retrospective. Easy customer access to read. Individual properties in flats may be metered.	Need to agree with customer. Could be expensive. Needs protection from condensation and freezing. Access needed for installation, maintenance and reading. More opportunity for tampering and fraud. Supply pipe ownership needs consideration.

External Property Boundary	Easy access for installation, etc. Minimum disruption to customer. Minimises supply pipe ownership problems.	Excavation in street disruptive and expensive. Water ingress protection Customer reading difficult. Individual metering for shared supply not possible
External Wall Mounted/ Building Boundary	Easier for installation, etc. but requires some property access- Customer reading practical. Individual readings of shared supply may be possible. Ideal option for new property.	Reduced excavation Supply pipe ownership needs consideration. Buried boundary box may become 'hidden'.

For multi-occupancy buildings it is accepted practice to meter individual supplies within the building.

Meter Installation Design

General requirements for meter installations are as follows:-.

- A separate supply and stopcock is required for each separately rated property.
- For buildings with several ingoing supplies, manifold pipes can be used to mount stopcocks and individual meters.
- The meter should be protected from heat, damage and misuse.
- The installation should allow easy maintenance or replacement.

Domestic Meters - Internal

- Internal meters should be sited as close as possible to the statutory stopcock.
- It is usual to include an additional service valve and drain facility on internal meters.
- The meter dial should not be more than 1.5 m above ground level.
- A meter, installed in a cupboard, should be within 300 mm of the front of the cupboard.

Domestic Meters - External

- External meters should be housed in meter boxes or chambers for protection.
- Boundary boxes should be installed at a convenient and preferably traffic-free location.

Industrial Meters

Some industrial meter installations may be of a size that individual chambers must be constructed.

- The chamber should be large enough to allow easy installation and subsequent maintenance.
- Safe access using rungs or ladders should be provided.

Installation Procedures

Once an area is to be metered, a co-ordinated metering scheme needs to be implemented which takes into account the relevant legislation, the customer's requirements and operational constraints.

The interested parties need to be managed effectively either by the Water company or its agent, and the following key matters must be addressed:

- customer relations,
- selection and purchase of equipment,
- preferred meter location,
- planning - timescales and installation rates,
- requests for tendering,
- the approach to the survey,
- safety Issues,
- quality control procedure,
- change to meter charging.

Other items that merit some consideration are:
- extent and allowable cost of splitting shared supplies,
- other work that could be undertaken at same time, i.e. communications pipe renewal.

Planning
The overall plan must address all stages and aspects of the entire installation programme from which a clear strategy can be developed. The logistics of progressing on a street by street basis needs to be studied in order to:

- • optimise the order or of installation,
- • consider the rate of completion,
- • minimise local disruption,
- • address sensitive areas,
- • avoid deviation from planned activities.

Survey
Surveys carried out as part of the planning process, are essential in order to allow operational needs and costs to be assessed. The detail and number of individual surveys will depend typically upon whether the installation is external or internal and the type and age of the property. Surveying every property would be cost prohibitive and reference to any appropriate records will minimise the number of surveys. Old properties may have joint supplies and/or joint usage, and a full survey may be best advised.

The minimum data required to allow planning of an external installation must include:-
- the location of the stop cock and does it need to be moved,
- is there a joint supply and should it be split,
- are there any common facilities.
- the reinstatement requirements,

The minimum data for an internal installation, after access has been arranged must include:-
- supply pipe entry point and position of stopcock,

- preferred meter location for ease of installation and reading,
- type of meter required,
- are there any tappings before supply pipe enters property,

Installation Requirements

Water meters must be treated as delicate precision instruments and they must be handled carefully. Particular attention should be paid to:-

- handling - do not drop, handle roughly or impact,
- fit end caps to retain some water in the meter, to prevent drying out, and to protect against contamination,
- storage and transport - use original packing,
- protection from extreme temperatures, especially freezing.

Other checks should consider:-
- the acceptability of proposed orientation of the meter,
- the number of fittings used, and hence potential pressure drop,
- provisions for ease of access for meter readings and maintenance.

The following table provides guidance on the procedures for both internal and external installations.

PROCEDURES FOR INSTALLATION OF INTERNAL AND EXTERNAL METERS	
INSTALLATION	**PROCEDURE**
Internal/External	After cutting pipework, remove all swarf and any water. Install non return valve to prevent backflow & contamination Flush pipework thoroughly before installing meter. Check meter seals and faces are clean; check lead security seals are provided. Lubricate threads sparingly if appropriate. Open the stopcock slowly to displace air in the pipework and meter whilst dosing the main's valve intermittently. Check meter registers when all air has been displaced by opening the main's valve. Check for leaks.
Internal	Do not solder or otherwise heat pipework after meter installation.
External	Check boundary box is installed, if appropriate For below ground, ensure all debris is removed from the chamber. Check for leaks in the service pipe; close internal stop cock and check meter

Removal and re-installation of meters must be carried out with the same care and procedures described in this section. In addition, prior to removal, all debris must be removed to avoid contamination.

1.6 GUIDELINES FOR MEASUREMENT CAMPAIGN WORK

It is necessary not only to carry out leak detection surveys, but above all to establish a monitoring sequence and a method of rapid intervention to deal with the water losses.

This is staged in three phases :

- ALERT
- LOCATION
- DETERMINATION

This method, which is based on minimum flow measurements and gradual subdivisions of networks, is in no way exceptional as far as the main principle is concerned, but it requires in practice perfect control of the measured sectors. This is why the initial works of checking the information and network maps on the 1/2000 scale of the distribution system is vital.

ALERT & IDENTIFICATION
The aim of this operation is to set up a monitoring sequence by means of minimum flow measurements covering sectors of approximately thirty kilometres, after dividing up the entire network. This first stage of works establishes a priority of intervention.

Two fundamental principles are currently applied to determine whether one particular sector has more leakages than another one :

- the output, district by district, with a statistical estimation of the water sales,
- analysis of minimum night-time minimum flow, with a breakdown of the main users.

Implementation - division of the network
The entire network is divided into sectors ranging from 10 to 40 kilometres (30 km on average). The distribution study also determines the strategic points where flowmeters with recording devices will be inserted in the pipe through under-pressure tappings to take temporary measurements. It is sometimes possible to take these measurements partly on existing meters.

A plan of the division of the network, for the alert stage, is drawn up. It mainly shows the main water users, the boundaries of each sector, the gates to be operated when the analyses are performed, the time stages of minimum night time flows and the different measurement points.

Monitoring sequence
When the monitoring sequence is set in operation, a basic operating flow is attributed to each sector. It covers the water losses from the network and the minimum volumes used by the

consumers. It can therefore in no way be compared with the rating of linear water losses. This is termed the Estimated Reference flow.

Gradually, in the process of operation, the basic flow will be rectified in relation to the minimum discharges measured, after repair of the leaks. This provides reference values for the flows.

It must be pointed out that the minimum value measured at night, with a breakdown of the main users, can vary from 0.1 l/s to 0.7 l/s per kilometre, this variation mainly relating to the density of populations, the state of wear of the pipe and the pressure of distribution.

The frequency of each measurement in the monitoring sequence is determined in relation to the frequency of recurrence of leak in certain sectors.

LOCATION

The aim of this operation is to locate the leakages by means of flow measurements over limited distances in gradual subdivisions, by operating valves.

This detection phase, performed in one night over a unit covering roughly 30 kilometres, enables the location, by discharge analysis, of the leaking sections (100 to 1000 m on average in urban networks).

The leaking area is gradually supplied from the point of measurement, one portion of network after the other, by manipulating the valves. Each additional portion is indicated on the flowmeter by an increase in instantaneous flow. Each value, progressively measured over approximately 2000 m, will possibly be subdivided into sections of 100 to 1000 m if this value is higher than a reference value, and therefore characteristic of a leaking section. If this operation is carried out on a grid system, a return supply is ensured.

Implementation

1/2000 scale plans are drawn up, showing :

- the number of valves to be operated, the locations of measured sectors, the main users, ...

These enable the mobile vehicles to come into action rapidly following an operating order from the control point.

The time required to set up this operation at the initial stage depends on the operational characteristics of each service department.

- the state of the gate valves (files),

- mapping (simplified diagram of the method of operation and watermen's records).

Checking of water stoppages, which are necessary to prepare the flow measurements in each division, entails inspection of gates and may lead to the detection of gates to be raised or repaired. Air valves have to be checked and repaired if necessary.

DETERMINATION OF LEAKS

Once the value of the leakage rate is known leak detection is done using conventional means, but over a limited area, having been directed to areas of known high leakage. The method and the type of apparatus used are determined according to the nature of the soil and the characteristics of the distribution system.

LEAKAGE INVESTIGATION BY MEANS OF MINIMUM NIGHT-TIME DISCHARGE MEASUREMENT

- PRINCIPLE -