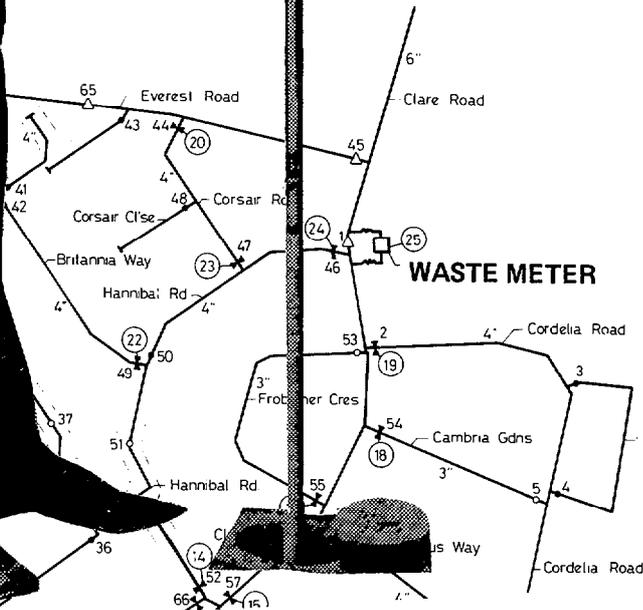


Technical Working Group
on Waste of Water

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Leakage Control Policy and Practice



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Technical Working Group
on Waste of Water

Leakage
Control
Policy
and
Practice

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Chairman's Foreword

A major programme of field experiments, believed to be the largest ever undertaken within the water industry in the United Kingdom, has provided a solid foundation upon which the Group has developed a procedure which can be used to determine the most appropriate method of leakage control for any system, and also the appropriate degree of effort required.

This is a major development, which provides a standard procedure with a firm economic and factual foundation, upon which leakage control policies can be based.

The benefits of following a systematic procedure to achieve the best balance between the costs of leakage and of leakage control are substantial but they will not be acquired unless the necessary resources are committed to programmes of implementation.

Having satisfied the terms of reference as far as practicable, and made recommendations on future coordination and monitoring, it is proposed that the Group should cease to exist three months after the publication of this report.

I wish to record my thanks to all members of the Group, to the liaison officers of the water industry and to the Water Research Centre for the work they all have done, frequently after a normal day's work, and for the care with which the proposals have been formulated.

I commend the report to the Council and to the Department.

W. F. RIDLEY
Chairman,
Technical Working Group on Waste of Water.

Format of the report

This report is published in three self-contained parts.

Part 1 is intended for senior management and policy makers and outlines the background of the report and states the Group's terms of reference and membership. A brief summary of the investigations that have been carried out is given and a procedure recommended for determining an appropriate leakage control policy.

Part 2 is a manual for determining a leakage control policy and is principally intended for operational staff concerned with the planning and implementation of such a policy. The field investigations and their implications are described in more detail and the procedure outlined in Part 1 is discussed fully. It also details the economic calculations necessary and gives advice on the implementation and review of procedures in changing circumstances.

Part 3 is a manual of leakage control practice. It rehearses and updates current technology, practices and techniques and replaces Water Research Association publication TP 109, *Waste control*, and should be referred to by staff concerned with the operational aspects of leakage control policy.

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Technical Working Group on Waste of Water

FINAL REPORT

PART ONE

Leakage control policy and practice

A summary of the work carried out together
with conclusions and recommendations

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1. SUMMARY

1.01 A lack of reliable information on the extent of leakage and the need to account for all water put into supply led to the formation of a Working Group in 1973. (Ref 3.03 and 4.05).

1.02 A First Report was published in 1976 and an Interim Report in 1977. Thereafter information consisting of subjective views based on widely distributed questionnaires and, more particularly, hard facts derived from a large programme of field experiments, has enabled the Group to produce this Final Report. (Ref 3.04, 3.05 and Chapter 5).

1.03 The experimental programme provided, for the first time on a country-wide scale, sufficient factual information upon which to base an ordered and logical procedure for the determination of a leakage control policy. (Ref 6.05). This practical procedure is recommended for use when it is proposed to:

- (a) determine a leakage control policy where none exists;
- (b) review an existing policy;
- (c) determine the operational resources appropriate to those policies.

1.04 No single leakage control method is economic or practical for all situations and so it is recommended that the most appropriate methods are determined by following the standard procedure outlined in Chapter 6.

1.05 For each system, the procedure enables an economic comparison to be made of the several methods of leakage control that are available. Clearly the immediate financing and resource requirements necessary to advance the long term benefits have to be carefully considered in some circumstances. (Ref 6.03).

1.06 Prior to the implementation of an active leakage control method it may be necessary, in some areas, for expenditure to be incurred on work necessary to remedy the inheritance of systems that have not been recorded on plans nor possess adequate numbers of operable valves to enable preparatory investigations to be undertaken. (Ref 6.12).

1.07 Part 1 of this report outlines the background, states the Group's terms of reference and membership, gives a brief summary of the investigations that have been carried out and recommends a procedure for determining an appropriate leakage control policy.

1.08 Part 2 is a manual for determining a leakage control policy; it discusses the field investigations in more detail, the conclusions derived therefrom and details the procedure outlined in Part 1. It describes the economic calculations necessary and gives advice on the implementation and review of procedures in changing circumstances.

1.09 Part 3 is a manual of leakage control practice; it rehearses and updates current technology, practices and techniques.

2. INTRODUCTION

2.01 The term 'waste' is often interpreted in different ways. However so that the reader clearly understands its use within this report the meanings of the terms 'waste' and 'leakage' are defined here.

2.02 Waste is that water which, having been obtained from a source and put into a supply and distribution system and into consumers' installations, leaks or is allowed to escape or is taken therefrom for no useful purpose.

2.03 Leakage is that part of waste which leaks or escapes other than by a deliberate or controllable action.

2.04 It is leakage from reservoirs, mains, communication pipes and consumers' supply pipes which is the major concern of this report although leakage control methods can serve to identify leakage from other apparatus belonging to the consumer.

2.05 The terms 'waste meter' and 'waste district' are used in a particular method of leakage control and these widely accepted terms are therefore used within the report.

2.06 A glossary of terms appears as Appendix A.

3. BACKGROUND

3.01 Although many local investigations have been carried out and close regard has been paid in some areas to the detection and prevention of leakage, there has been a serious lack of adequate published data concerning the benefits of leakage control. Consequently it has in the past been difficult to quantify the appropriate allocation of resources on economic grounds.

3.02 The following factors were relevant in motivating a thorough investigation of the topic.

- (a) The lack of adequate quantifiable data on the extent of the problem;
- (b) A need to account for all water put into supply;
- (c) The increasing cost of supplying water;
- (d) Doubts about the watertightness of many reservoirs, trunk mains and distribution mains networks, many of which were constructed before the turn of the century.

3.03 A Working Group on Waste of Water was established by the Department of the Environment in 1973. Following the reorganisation of the water industry in England and Wales in 1974, the Group was reconstituted under a chairman appointed by the National Water Council. Its terms of reference and membership are given in Appendices B and C.

3.04 A First Report was published in September 1976. It concluded that there was an urgent need to investigate the many aspects of the problem and its recommendations included that each water undertaking should,

- (a) nominate a liaison officer to be the contact point for the group;
- (b) review its current leakage control policy;
- (c) establish close contact with the Water Research Centre in undertaking any field experiments;
- (d) assess the volume of unaccounted for water.

3.05 An Interim Report was published as supplement 83 of the National Water Council *Bulletin* in December 1977. This reported on progress since the publication of the First Report and outlined the future work programme.

4. THE PROBLEM

4.01 It is clearly uneconomic to ensure that pipelines and reservoirs will never leak. It is also clear that there is an economic limit to the loss of water that should be tolerated through leakage.

4.02 Current leakage control practice within the United Kingdom varies from the one extreme of repairing only those leaks that become self-evident to the other extreme of detecting leaks by maintaining a high degree of monitoring and inspection.

4.03 Those undertakings expending the minimum effort are not necessarily doing too little nor those expending a large effort too much. The appropriate leakage control policy will vary from system to system and will depend on such things as the availability and cost of supplying water, the magnitude of leakage within the system and any practical or financial constraints which may exist.

4.04 The benefits of leakage control are mainly economic, brought about by reduced leakage, although many engineers consider some degree of control of leakage as part of the proper management of their systems, irrespective of the economic benefits.

4.05 In the past, due to a lack of adequate reliable information, the adoption of leakage control policies has been based on subjective assessments of the benefits and one of the factors that has prevented the universal adoption of positive leakage control measures has been the absence of an acceptable method of assessing the benefits and weighing them against the costs. This has resulted (in some areas) in one or more of the following:

- (a) the implementation of a leakage control method, other than the most appropriate;
- (b) an incorrect level of effort being applied to the leakage control method adopted;
- (c) no positive leakage control measures being adopted where it would be economic to do so.

5. INVESTIGATIONS

Introduction

5.01 The collection of adequate information upon which to base recommendations has been pursued by the issue of questionnaires throughout the industry and by a large programme of field experiments.

5.02 In its First Report the Group had recommended that each authority and company should nominate a liaison officer who would be the contact point with the Group. Regular meetings have been held with the appointed liaison officers to coordinate the experimental programme and the accumulation of information: much credit for the success of the programme is due to their keenness and support. A schedule of liaison officers is given in Appendix D.

Questionnaires

5.03 An early questionnaire circulated to 37 selected water undertakings led to conclusions and recommendations contained in the First Report.

5.04 In 1977 questionnaires were circulated to all undertakings throughout the United Kingdom to obtain information and opinions on:

- (a) the extent of water unaccounted for;
- (b) the relative importance of common and most frequent points of leakage;
- (c) current methods of leak location and leakage control.

5.05 The response to this request for information was excellent (98 per cent return) and the results, which were mainly subjective, were distributed to liaison officers and chief officers of water undertakings in November 1977.

5.06 Reports of unaccounted for water ranged from 10 to over 50 per cent of total water supplied and the average was of the order of 24 per cent. Whilst little confidence can be placed in the individual figures for each system owing to the inherent inaccuracies of the method used, the average figure may represent the general scale of the problem in the country as a whole.

5.07 The causes and relative importance of points of leakage are areas where many presumptions have been made with little supporting evidence. Although the mechanisms are complex and the factors well known, it is difficult to quantify them for a single system let alone set down guidance for general application throughout the industry. A careful analysis of the questionnaires confirmed that little reliable information on this subject was available and that the subjective opinions showed little consistency. The Group subsequently formed the view that it would not be worthwhile to undertake investigations on these topics at the present time.

5.08 The questionnaires also provided information on the leakage control practices currently adopted and on the numbers and types of leak detectors and pipe locators in use. Subjective opinions were also obtained on their effectiveness.

5.09 Information on the numbers and types of installed meters and subjective views on their accuracy were also obtained. This confirmed expectations that the majority of meters installed are rarely inspected or calibrated once they have been installed.

Field experiments

5.10 Having exhausted the collection of useful information by questionnaire, it was considered that a programme of field experiments was necessary and this was drawn up, in conjunction with the Water Research Centre, to obtain specified data. The programme included over 500 individual experiments, probably the largest series of coordinated field trials ever undertaken by the water industry in the United Kingdom.

5.11 The main objectives of the experimental programme were as follows:

- (a) To quantify the range of leakage occurring in the several parts of a water supply and distribution system.
- (b) To provide factual evidence upon which to determine a logical procedure for establishing the economic methods of leakage control.
- (c) To gather together a more comprehensive knowledge of the whole subject than had been available previously in order to provide a wide and firm base upon which to found rules of general application.

5.12 Details and results of the field trials are discussed in Part 2 and more complete information can be found in WRC Technical Report *Results of the experimental programme on leakage and leakage control*. Some of the main findings are given below.

5.13 *Service reservoirs*. Leakage from most service reservoirs is relatively minor, being frequently less than 0.5 per cent of their total capacity each day, but occasionally a reservoir may be found to have excessive leakage. For example, in a few cases, daily leakage of almost 30 per cent of a reservoir's capacity had gone undetected for long periods.

5.14 *Trunk mains*. Leakage on 81 per cent of the trunk mains tested was found to be low (less than 1,000 litres per kilometre per hour). Only 3 per cent of the mains had leakage above 3,000 litres per kilometre per hour: the maximum value recorded was 6,000 litres per kilometre per hour. Leakage was found to be independent of diameter.

5.15 *Distribution systems*. The majority of all leakage was found to occur within the distribution system. The mean values of net night flows (which provide the best estimate of leakage) in areas subject to no active leakage control was 18.6 litres per property per hour although there was considerable variation about this figure. In areas subject to waste metering, a mean value of 6.1 litres per property per hour was obtained.

5.16 *Pressure*. Reductions in pressure were shown to cause proportionately greater reductions in leakage. Although the scope for pressure reduction may be limited by a number of physical factors, reductions in pressure are likely to be worthwhile where it is appropriate to effect them.

5.17 The results of the experimental programme were presented at a series of twelve regional meetings organised by the Water Research Centre. The meetings were well attended and valuable first hand feedback from the industry was obtained.

6. THE RECOMMENDED PROCEDURE

Introduction

6.01 The field trials provided adequate reliable information to enable an assessment of the benefits of the various leakage control methods to be made.

6.02 However the trials also demonstrated large variations in the magnitude of leakage and in the costs of performing the various control methods. Consequently the approach adopted was to develop a procedure for evaluating the appropriate policy for any system (irrespective of its current policy) taking account of local conditions and using local costs.

6.03 The procedure developed is based upon an economic comparison of the total costs of each of the leakage control methods available. The availability of financial or manpower resources will obviously control the speed at which the procedure can be implemented. These constraints are

likely to be most important in those areas where systems that have been neglected in the past require the input of significant resources to bring them to a standard necessary for the development of a leakage control policy that requires the provision of waste meters. It is important to preplan and budget carefully in these circumstances and the selection of a sample area will normally assist in ensuring the greatest cost effectiveness and the achievement of a proper overall economic comparison.

6.04 A further conclusion from the field trials was that the greatest potential savings would occur in distribution systems. Therefore, whilst the recommended procedure is applicable to all parts of water supply systems including trunk mains and service reservoirs, its application to a distribution mains system is detailed below.

The procedure

6.05 The recommended procedure can be used to,

- (i) determine a leakage control policy where none exists;
- (ii) review an existing policy;
- (iii) determine the operational resources appropriate to any leakage control policy.

It consists of the following principal steps:

- (a) An initial measurement of the magnitude of leakage within the system;
- (b) Determination of the benefits of reducing leakage (by calculation of the unit cost of leakage);
- (c) Estimation of the costs and potential savings of pressure control;
- (d) Calculation of,
 - (i) the cost of operating each of the methods of leakage control;
 - (ii) the cost of leakage appropriate to each method of leakage control;
- (e) Comparison of the sum of the costs in (d) (i) and (ii) for each method to determine which methods are economically acceptable;
- (f) Consideration of local factors;
- (g) Decision on the leakage control method to be adopted;
- (h) Determination of the operational resources required;
- (j) Implementation of appropriate action;
- (k) Monitoring of performance at regular intervals.

Fundamentals of the procedure

6.06 The procedure which is fully described in Part 2 is in two sequential stages. The first is the choice of the appropriate method of control, which is a long-term decision, and the second is the determination of the operational resources required in applying that method effectively.

6.07 It is always necessary to measure the initial magnitude of leakage within any system. Typical costs are given in Part 2 and techniques are described in Part 3. For trunk mains and service reservoirs direct measurement of leakage is normally required.

6.08 The unit cost of leakage is derived from the change in costs brought about by changing the amount of leakage within the system. It consists of changes (normally reductions) in,

- (a) the annual operating costs;
- (b) the deferment of those capital schemes or those parts of capital schemes that are required to satisfy increases in demand.

The method of calculation of the unit cost of leakage is described in detail in Part 2.

6.09 Where pressure reduction is feasible then this needs to be investigated and the benefits estimated as described in Part 2.

6.10 Costs, which varied over a wide range, were collected for the implementation and operation of the five principal methods of leakage control that involve leak detection and location. These are,

- (a) passive;
- (b) regular sounding;
- (c) district metering;
- (d) waste metering;
- (e) combined district and waste metering;

These five methods of leakage control are described in detail in Part 3. A sixth method (ie pressure control) is separately described in Part 3; it can be applied together with each of the above methods.

6.11 Each undertaking is recommended to determine local costs since the variation throughout the industry is considerable. The costs given in Part 2, Table 2, are given as a guide for initial consideration.

6.12 A wide disparity exists across regions in the records and condition of distribution systems that were inherited upon reorganisation of the industry. Whereas in some undertakings, records of the positions and sizes of mains, valves and other fittings have been accurately recorded and kept up-to-date, there are some areas where this has not been done. Similarly, while some systems include adequate well maintained valves, some do not possess sufficient operable valves to enable investigations to be carried out prior to the formation of zones for leakage control purposes.

6.13 The costs involved in bringing records and valves up to a useful operational standard have not been included in Part 2 of the report because they are so variable. Nevertheless in these areas it will be necessary to understand that costs will be incurred before systematic leakage control can start. Whether these costs are charged to leakage control or to general operations (where it is suggested that they belong) is a matter for the water undertaking.

6.14 The costs of leakage appropriate to each method of leakage control are obtained by multiplying the unit cost of leakage by the magnitude of leakage appropriate to each method of control. A method of determining the likely net night flows appropriate to the five methods of leakage control specified above is given in Part 2.

6.15 To obtain the rankings for the local situation the annual cost of each leakage control method is added to the cost of the leakage appropriate to each method of control; the totals are then compared to determine the most economic methods.

6.16 Local factors that should be considered include:

- (a) manpower availability and suitability;
- (b) level of experience within the workforce;
- (c) physical constraints.

Outbreak of leaks

6.17 A change from one leakage control method to a more intensive one will create a short-term increase in the number of leaks requiring repair. However, once the more intensive leakage control method has become established the long-term rate of repair of leaks, which approximates to the rate of occurrence of leaks, will remain substantially unchanged because none of the factors affecting the outbreak of leakage has been changed. A more detailed explanation of this 'steady state' theory of the occurrence of leaks is given in Part 2.

6.18 Therefore, although a change from one leakage control method to another will create a requirement for an initial increase in repair effort, the long-term average annual cost of repairs will remain unchanged and can be ignored in comparative economic assessments.

6.19 The responsibility for the costs associated with the initial repair effort will fall on both the undertaking (repairs to mains, communication pipes and their fittings) and on consumers

(repairs to supply pipes and fittings). The implications of these latter costs may need careful consideration by individual undertakings as will the timing of the initial financial burden which may arise.

7. APPLICATION OF THE RECOMMENDED PROCEDURE

7.01 Application of the procedure to hypothetical systems which encompass the likely range of leakage, unit costs of leakage and costs of leakage control have enabled the following general conclusions to be drawn:

- (a) It is worthwhile to adopt active leakage control methods in all areas where the unit cost of leakage is greater than 1p per cubic metre. This will apply to all but a few systems.
- (b) District metering is a sensible first stage in all but a few areas.
- (c) Waste metering (either in isolation or in combination with district metering) is normally economic in areas where the unit cost of leakage is greater than 3p per cubic metre and can be worthwhile at lower values.
- (d) Because pressure reduction is relatively cheap and can be quickly effected, it should always be investigated.

7.02 However it is not possible to forecast accurately appropriate leakage control methods for any system until the recommended procedure for determining them has been followed. Only then will it be possible to,

- (a) forecast any necessary increase in the resources required; and
- (b) estimate the net benefits

7.03 The costs of determining the appropriate leakage control methods and appropriate operational resources will vary according to the size and nature of the undertaking. Based on a small number of exercises the range is expected to lie within £0.01 and £0.1 per property; the lower figure is appropriate to well documented large urban undertakings and the higher figure to those areas with scant records, scattered properties and long lengths of mains.

7.04 The benefits consist of,

- (a) reductions in running costs; and
- (b) deferment of expenditure on capital works

The benefits arising from reductions in running costs will take place when a more intensive leakage control method becomes established. On the other hand the benefits arising from the deferment of capital expenditure may not be immediate; they will begin to apply when the first capital scheme, however small, is able to be deferred or reduced in capacity because of the introduction of a more intensive leakage control method.

7.05 Because of variations in both past standards of operation of systems and current leakage control methods, there will be variations in the resources required to implement the procedure to individual systems. Therefore whereas only a relatively short time should be required to implement the procedure in those areas where district or waste metering is currently practised, a considerable time may be required before the remaining areas are subjected to appropriate leakage control methods.

8. GOOD OPERATIONAL PRACTICE

8.01 Previously many of the aspects of leakage control eg sounding or waste metering have been justified as good operational practice; these need to be separated into cost effective measures and general good practice. The recommended procedure described in this report enables the appropriate policy to be justified economically and subjective assessments can therefore be avoided.

8.02 Nevertheless, the benefits of good operational practice will often complement the requirements for effective leakage control. Examples include:

- (a) the ability to isolate service reservoirs for structural examination, cleaning and leakage testing. The likely reduction in leakage will not normally by itself justify the regular inspection of all reservoirs.
- (b) the ability to measure trunk main leakage. Again the likely reduction in leakage will not normally justify regular testing of all mains.
- (c) the ability to measure quantities supplied, particularly levels of leakage, with sufficient accuracy.
- (d) the definition of the limits of supply of each source and the area monitored by each meter.

8.03 Installation of valves, level measuring devices and tappings required to perform these measurements are normal requirements of a properly managed system. If they are not already available, it is suggested that their provision should not be costed against leakage control. Individual undertakings are able, of course, to include these costs in the economic assessment if they wish, but since it is necessary to incur some expenditure on calculation of the unit cost of leakage and measurement of the magnitude of leakage before any conclusion can be drawn, careful pre-planning and tentative implementation is recommended.

8.04 It is relatively inexpensive for the necessary leakage control features, in particular the means of measuring leakage or net night flow, to be incorporated in all new water supply works, including distribution mains extensions.

9. EQUIPMENT AND METHODS

9.01 Leakage detection methods are described in Part 3 which also gives guidance in relation to sizes of areas, types of meters and their operation and maintenance. Reference is made to other publications, particularly to technical reports of the Water Research Centre.

9.02 Information is also given on the main types of equipment currently available for the detection and location of leaks and for the location of underground apparatus.

10. EXPRESSIONS FOR LEAKAGE

10.01 There are numerous ways in which leakage can be expressed but expressions of percentages without qualification can be very misleading, especially when comparisons between undertakings, areas, or districts are involved.

10.02 Leakage from a service reservoir may be usefully expressed as a percentage of its capacity per day. Direct measurements of leakage from trunk mains are best expressed in litres per kilometre of main per hour.

10.03 Leakage from the complete systems of an undertaking, including leakage within the premises of the majority of consumers, can only be satisfactorily expressed in terms of minimum night flow. For whole undertakings, or for urban systems, the most meaningful and useful measure is net night flow rate per separately-charged property but for most rural distribution systems net night flow rate per kilometre of main is more appropriate.

11. TRAINING

11.01 The continuation of updated courses currently run by the Training Division of the National Water Council should adequately meet any future demands for training or re-training in the methods and techniques of leakage control.

12. FUTURE COORDINATION

12.01 The Group considers that it has now fulfilled its terms of reference, so far as is reasonably practicable, and it has therefore completed its work. For the future, a need to monitor achievement is seen, together with a need to disseminate quickly throughout the industry, new developments in procedures, methods and techniques.

12.02 In performing its current functions, the existence of a liaison officer in each water undertaking has greatly facilitated the practical work of the group and it is considered that meetings of liaison officers would provide the ideal forum for disseminating new information and collecting data. Because of its associations with each of the relevant sectors of the industry, the Water Research Centre affords an ideal organisation for coordinating the future work of liaison officers.

12.03 Continuation of research into leakage control techniques is likely to be cost-effective, particularly where technological innovations can aid practitioners.

13. CONCLUSIONS AND RECOMMENDATIONS

Use of the standard procedure

13.01 No single leakage control method is economic for all situations and it is important that the most appropriate method or methods are determined by following the recommended procedure.

13.02 The procedure outlined in Chapter 6 and detailed in Part 2 affords for the first time a soundly-based and practical method for,

- (a) determining a leakage control policy where none exists; (6.05 (i))
- (b) reviewing an existing policy; (6.05) (ii))
- (c) determining the operational resources appropriate to a particular policy; (6.05 (iii))

Recommendation 1a

The recommended procedure should be used to determine:

- (i) the leakage control methods and operational resources appropriate to each system.**
- (ii) the anticipated net benefits arising from the application of the recommended procedure.**

Recommendation 1b

Where the most appropriate methods have already been adopted the appropriate operational resources should be determined.

Recommendation 1c

The recommended procedure should be used to review, at appropriate intervals, the method or methods adopted, the resources employed and the estimated net benefits.

13.03 An active leakage control policy is likely to be economically justified in all but a few distribution systems. (7.01 (a)).

13.04 District metering is a sensible first stage in all but a few areas. (7.01 (b)).

13.05 Waste metering (or combined district and waste metering) is worthwhile where the unit cost of leakage is greater than 3 pence a cubic metre and can be worthwhile at lower values. (7.01 (c)).

13.06 Pressure control is relatively cheap to carry out and, although the opportunities for reduction of pressure may be limited, its investigation is worthwhile. (7.01 (d)).

Good operational practice

13.07 Undertakings need to be able to account for quantities of water supplied (particularly the leakage from each part of the system) and the proper maintenance of assets, irrespective of which positive leakage control measures are adopted. Given this ability to account for water, the recommended procedures will eliminate most of the subjectivity from decisions on leakage control.

Recommendation 2a

Water undertakings should provide facilities to enable,

- (i) the water supplied to be accounted for;**
- (ii) their assets to be properly maintained.**

13.08 It is relatively inexpensive for the necessary leakage control features, in particular the means of measuring leakage or net night flow, to be incorporated in all new water supply works including service reservoirs, trunk mains and distribution mains extensions or reinforcements. (8.04).

Recommendation 2b

New works should include the necessary features to enable appropriate leakage control measures to be carried out.

Expressions for leakage

13.09 The use of percentages of water supplied, as a means of comparing the magnitude of leakage in differing undertakings and areas is misleading. (10.01). Net night flows expressed per property or per unit length of main are more meaningful for distribution systems. (10.03).

Recommendation 3a

The use of percentages of quantities supplied for making comparisons of leakage levels should be abandoned.

Recommendation 3b

Leakage within distribution mains should be expressed in terms of net night flow rate in

- (i) litres per property per hour for urban areas and for whole systems; or**
- (ii) litres per kilometre of main per hour for rural areas.**

The mechanism of leakage

13.10 Investigations did not reveal a correlation between magnitudes, probability of occurrence or frequency of leakage and any feature of design, construction or arrangement of a distribution system or its constituents. Any further investigations will necessitate the expenditure of large sums with little hope of definite conclusions. (5.07).

Recommendation 4

No further work should be carried out at the present time in investigating the mechanism of leakage and its points of occurrence.

Future coordination

13.11 There will be a continuing need to update and review the information given in Parts 2 and 3 of this report and bodies will be required for this function and to monitor progress in the reduction of leakage (12.01).

Recommendation 5a

The Water Research Centre should be given the task of periodically updating Parts 2 and 3 of this report on the basis of research and development in equipment and methods of leakage control and on updated information obtained from the industry.

Recommendation 5b

The committees of liaison officers already in existence should be used to facilitate the central coordination of information, achievements and progress.

13.12 Continuation of research, albeit at a modest level, into leakage control methods is likely to be cost-effective. (12.03).

Recommendation 5c

The Water Research Centre should continue to research leakage control methodology, and to assist, as appropriate, in the evaluation of equipment and methods that may be developed for, or are made available to, the water industry.

APPENDIX A

GLOSSARY OF TERMS

area: a part or subdivision of a supply and distribution system of unspecified size or characteristic.

communication pipe: that part of a service pipe which runs from a main to, and including, a stop-cock at or as close as is reasonably practicable to the boundary of the street in which the main is laid.

consumer: a person supplied, or about to be supplied, with water by a water supply undertaking.

consumption: a volume of water taken from a water supply main into a consumer's installation.

demand: the volume of water which has to be put into a supply and distribution system to satisfy the requirements of consumers plus leakage and other waste which may be incurred in the process.

distribution main: a pipe laid by the water supply undertaking for the purpose of giving a general supply of water, as distinct from a supply to individual consumers, and including any apparatus used in connection with such a pipe.

district: an area of a supply and distribution system (but usually of a distribution system) which is or can be specifically defined, eg by the closure of valves, and in which the quantities of water entering and leaving the area are metered.

district meter: see meter – district.

inspection: physical investigation to locate leaks by sounding and metering methods eg step tests.

leak detection: the process of detecting and locating leaks.

leakage: that part of waste which leaks or escapes or is lost other than by a deliberate or controllable action.

meter - combination: a meter installation consisting of two or more devices, usually of different types used preferentially such that the best characteristic of each device is used at that flow range at which it is most accurate.

meter – district: a device for measuring the quantity of water passing into or leaving a district.

meter - source: a device for measuring the quantity of water entering a supply and distribution system from source works.

meter waste: a device capable of measuring and recording the range of rates of flow passing into a waste district overnight.

metered consumption: quantity of water registered on consumers' meters.

Note: this quantity will include waste and/or leakage occurring on the consumers' premises and meter error.

minimum night flow: the minimum rate of supply of water into any area during the night.

net night flow: the difference between minimum night flow and metered consumption.

night line: see minimum night flow.

pipe locator: portable electrical or electronic instrument specifically designed for use in the field to assist in locating buried pipes.

pressure control: the reduction of hydraulic pressure to, or the maintenance of pressure at, a predetermined desired range of pressures within defined zones.

property: building premises or structure occupied by a consumer as separately identified for billing purposes.

section: a subdivision or 'step' in a waste district.

service pipe: so much of any pipe for supplying water from a main to any premises as is subject to water pressure from that main, or would be so subject but for the closing of some tap.

service reservoir: a water-retaining structure hydraulically linked into a supply and distribution system to provide storage capacity to meet diurnal variations in demand and to provide reserve supplies of water for emergency purposes.

sounding - direct: a method of searching for leaks in which trained inspectors listen with a stethoscope or electronic leak detector applied directly on to a main, valve or stopcock for the characteristic noise of escaping water. It may be carried out at night when both ambient noise and consumption are at a minimum.

sounding - indirect: a method of searching for leaks, similar to direct sounding but with the stethoscope or electronic leak detector in contact with the ground surface. The method is dependent upon sound being transmitted through soils, backfill, road material etc.

sounding - stop tap, stop cock: see sounding – direct. Particularly used to detect leakage from a consumer's installations.

sounding - surface: see sounding – indirect.

sounding - valve and hydrant: a form of direct sounding applied initially to the undertaking's valves and hydrants.

step tests: a method of enhancing the effectiveness of waste metering whereby successive valve closures are made to reduce the size of the waste district temporarily whilst simultaneous measures of rate of flow are being made.

supply: amount of water made available to satisfy demand.

supply and distribution system: an arrangement of apparatus, installations and works operated by a water supply undertaking between the point of abstraction from a source and the consumer's installation.

supply pipe: so much of any service pipe as is not a communication pipe.

system: an arrangement of apparatus, installations and works operated by the water supply undertaking.

trunk main: a main with few branches constructed for conveying relatively large volumes of water.

undertaking: see water supply undertaking.

unmetered consumption: volume of water taken by consumers other than through metered connections.

valve inspections: see step tests.

waste: that water which, having been obtained from a source and put into a water supply and distribution system and consumers' installations, leaks or is allowed to escape or is taken therefrom for no useful purpose.

waste district: a qualified form of district, the inflow to which is or is capable of being measured through a waste meter and in which tests can be carried out such that leakage can be traced to relatively small sections.

waste inspector: an employee or other person skilled in the practical work involved in identifying causes of waste and, in particular, locating leakage.

waste meter: see meter — waste.

water unaccounted for: that water which is the difference between the total put into a supply and distribution system and the water accounted for.

water supply undertaking: a statutory organisation with the responsibility of providing a public water supply.

zone: an area of a supply and distribution system which is or can be specifically defined by the closure of valves or other physical constraint within which the hydraulic pressure of the public water supply is reduced to, maintained at or increased to a preferred limited operational range.

APPENDIX B

TERMS OF REFERENCE

The Group's terms of reference are:

- (a) To produce a list of definitions in connection with waste (loss) of water;
- (b) To identify and evaluate the relative importance of common and most frequent points of leakage and to investigate the extent of present waste (loss) of water;
- (c) To examine, compare and evaluate present methods of leak location, waste detection and prevention;
- (d) To identify what research, if any, needs to be carried out;
- (e) To consider and advise on appropriate methods whereby water authorities and water companies may decide the amount that should be expended on waste detection and prevention;
- (f) To make reports.

APPENDIX C

MEMBERSHIP OF THE WORKING GROUP

W. F. Ridley	Northumbrian Water Authority (Chairman)
J. Baird	National Water Council
C. W. Bolt	Department of the Environment
G. A. Booker	Welsh Water Authority
T.R. Ellson	Southern Water Authority
R. Fellows	Central Regional Council
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J. A. Millar	DoE, Northern Ireland
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J. Reid	North West Water Authority
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D. B. Field and S. J. Goodwin of the Water Research Centre have attended many of the meetings of the Group and of liaison officers and have played a significant part in the production of this report.

APPENDIX D

LIAISON OFFICERS

Regular coordination of collection of information and of field work has been carried out via liaison officers in water authorities and water companies in England and Wales and in regional councils in Scotland.

In water authorities in England and Wales, liaison officers coordinated the activities of divisional liaison officers whilst in Scotland the work of the regional council liaison officers was centrally coordinated by the Scottish representatives on the main group (messrs Crombie, Fellows and Semple). R. A. Pepper acted generally in coordinating the activities of the 28 water company liaison officers who worked individually and, where appropriate, in collaboration with regional working parties.

Water authority liaison officers were messrs Bowden (Welsh), Cornfoot (Yorkshire), Edkins (North West), Ellson (Southern), Gordon (South West), Howarth (Wessex), Parks and Cook (Anglian), Pocock (Thames), Smith (Northumbrian) and Thompson (Severn Trent).

Technical Working Group on Waste of Water

FINAL REPORT

PART TWO

Leakage control policy

A manual for the determination or review
of leakage control policy

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1. INTRODUCTION

1.01 Current leakage control practice within the United Kingdom varies from the one extreme of maintaining a high level of routine monitoring and inspection to the other of repairing only those leaks which become self evident, such as by water appearing on the surface or from complaints of poor pressure. Although this wide diversity in leakage control effort exists, it does not necessarily follow that those expending the minimum effort are doing too little nor those expending a large effort too much. This is because the most appropriate method of leakage control will vary from one system to another depending upon such things as the availability and costs of supplying water, the leakage levels within the system and any local factors or system constraints which may exist.

1.02 In this report a procedure is proposed which will enable the management of a water undertaking to determine, firstly, the method of leakage control appropriate to each system and, secondly, the operational resources required for its effective operation. The complete procedure can be used not only to determine a first time leakage control policy but also to review an existing policy by determining whether a change of method or a modification of operational resources would be beneficial.

1.03 A further benefit, which will apply to all undertakings, can be gained by ensuring that any method is performed in an effective manner. Guidelines for this are given in Part 3.

1.04 Previous work on this subject has recognised the need for an economic appraisal of leakage control activity but none has proposed a practical method by which this may be evaluated. The procedure set out in this report provides a comprehensive method of determining a leakage control policy which has been demonstrated, by case studies, to be logical and practical.

2. BACKGROUND AND APPROACH

Terminology and units

2.01 Throughout this report reference is made to many terms and expressions which are currently in common, but in many cases inconsistent, use throughout the industry. A list of these terms is given in the Glossary in Appendix A.

2.02 The term 'waste' is one that has a wide interpretation throughout the water industry. However so that the reader clearly understands its use within this report the meanings of the terms 'waste' and 'leakage' are defined here.

2.03 Waste is that water which, having been obtained from a source and put into a supply and distribution system and into consumers' installations, leaks or is allowed to escape or is taken therefrom for no useful purpose.

2.04 Leakage is that part of waste which leaks or escapes other than by a deliberate or controllable action.

2.05 It is leakage from reservoirs, mains, communication pipes and consumers service pipes which is the main concern of this report although leakage control methods can also serve to identify leakage from other apparatus belonging to the consumer.

2.06 The terms 'waste meter,' and 'waste district' are used in a particular method of leakage control and these widely accepted terms are therefore used within the report.

2.07 Leakage from trunk mains and service reservoirs can often be measured directly, but this is not the case within the distribution system. For practical purposes the best measure of leakage is obtained from the minimum night flow (night line) modified by subtracting metered consumption. This is referred to in this report as the net night flow. There will be minor legitimate unmetered consumption of water but for leakage control purposes changes in net night flow for a given area can be taken to represent changes in leakage.

2.08 Fundamental to discussions of leakage and leakage levels is a method of expressing them which will allow comparison between different areas or districts. Several methods are currently in use within the industry, the most common of which is to express the minimum night flow rate as a percentage of average supply rate sometimes including and sometimes excluding metered consumption.

2.09 Because there are several ways in which a percentage can be derived, it is recommended that leakage levels should be expressed either as a flow rate eg litres per hour (l/hr) or, if comparison is necessary, as a flow rate per property, eg litres per property per hour (l/prop/hr). This is described more fully in Part 3.

2.10 In rural areas with long lengths of main and relatively few properties, a better comparative index is to express the night flow in terms of the mains length eg litres per kilometre per hour (l/km/hr).

2.11 Leakage levels from trunk mains should also be expressed as a rate per unit length whilst service reservoir leakage is meaningful when expressed either as a quantity per day or as a percentage of capacity leaking away per day.

Methods of leakage control

2.12 There are two main problems faced by the management of a water undertaking in determining or reviewing its leakage control policy for a particular area. These are the determination of,

- (a) the most appropriate method of leakage control for that area,
- (b) the effort or expenditure to be incurred on that method.

2.13 The six methods of leakage control available are described fully in Part 3. They are:

Pressure control

Although the adoption of pressure control does not directly involve leakage detection, reductions in pressures may reduce the rate of escape through each leak and may also affect the rate of out-break of leaks.

The remaining methods all involve the detection and location of leaks.

Passive leakage control

In this method only those leaks which become self-evident are located and repaired. A leak may be self-evident because water shows on the surface or may become so upon 'ad hoc' investigation following consumer complaints.

Regular sounding

This method involves teams of inspectors seeking to locate leaks by systematic direct sounding on all stop-cocks, hydrants and valves throughout the distribution system and listening for the characteristic noise of leaking water.

District metering

Separately defined areas typically containing 2,000 to 5,000 properties are metered continuously and the total quantity of water entering the district is recorded. The meters are read regularly and if the total supply is inexplicably high, inspectors are sent into that district to locate leaks.

Waste metering

The distribution system is subdivided into areas containing 500 to 3,000 properties. These areas are isolated and fed through a single meter capable of measuring and recording the low rates of flow that occur during the early hours of the morning. The flows are recorded at regular intervals eg quarterly, so that the inspectors are directed to the districts with most leakage.

Combined district and waste metering

This method consists of both district metering and waste metering. When increases in supply are indicated on the district meter the waste meters downstream of it are read in order to subdivide the district into more manageable units and therefore guide the inspectors to the areas containing most leaks.

2.14 Pressure control can be applied in conjunction with each of the other methods of leakage control.

Choice of method

2.15 The choice of leakage control method appropriate to a given system should be made with due regard to economic and engineering factors, although financial or political constraints may also need to be considered. The major elements to be considered are,

- (a) the magnitude of leakage from the system,
- (b) the benefit of reducing leakage,
- (c) the costs of implementing each of the possible methods of leakage control.

2.16 Whilst the cost of each method of control may be similar from system to system, the benefit of reducing leakage may vary considerably. The benefit depends on the costs of pumping and treating a unit quantity of water and on the amount of water saved. It also depends on the modification in the programme of capital investment consequent upon a change in future water supply requirements. Because of variations between different systems, each of the available methods could be the most appropriate in any particular case.

The recommended procedure

2.17 This report sets out a procedure which will enable the management of a water undertaking to determine, in a logical manner, the leakage control policy appropriate to any system. The procedure can be used for,

- (a) determining a leakage control policy where none currently exists,
- (b) reviewing an existing policy.

The procedure is shown diagrammatically in Figure 1.

Assumptions and implications

2.18 The procedure adopted is in two successive stages. The first stage is the choice of the appropriate method of control and the second stage is the determination of the operational resources required in applying that method effectively. Obviously, these two stages are interdependent but their separation is made possible by the differing nature of the two decisions. The second may be a short or medium term decision and as circumstances (such as costs) change, the operational resources may be varied. The choice of method, however, must be a long term decision as it is impractical to change the method adopted every few years in view of the investment made in meters and in training personnel. Thus the costs considered must include those to be incurred for many years into the future and short-term variations can be ignored.

2.19 A change from one leakage control method to a more intensive one will create a short-term increase in the number of leaks requiring repair. However once the more intensive leakage control method has become established the long-term rate of repair of leaks, which approximates to the rate of occurrence of leaks, will remain substantially unchanged because none of the factors affecting the outbreak of leakage has been changed.

2.20 This can be likened to a queue of customers in a shop where the rate of joining the queue and rate of being served are analagous to the rate of outbreak and rate of repair of leaks. Provided these are in balance the length of the queue (the level of leakage) is not affected. This is true whatever the length of the queue (the level of leakage). Any change in the rate of joining or of being served (the rate of outbreak or of repair of leaks) has no long-term effect on the length of the queue (the level of leakage).

2.21 Short-term variations may occur; for example, if a customer with an exceptionally large order joins the queue, but in the long-term the average number and size of orders must reach a steady state otherwise the queue would carry on lengthening or reducing indefinitely. The analogy says that short-term variations in the magnitude of leakage may occur if a large leak breaks out but it is clearly not possible for larger leaks to continue to break out at an increasing rate, otherwise either the pipe would become riddled with holes or the workload of the repair gang would continue to increase. This is clearly not possible nor is it confirmed by experience.

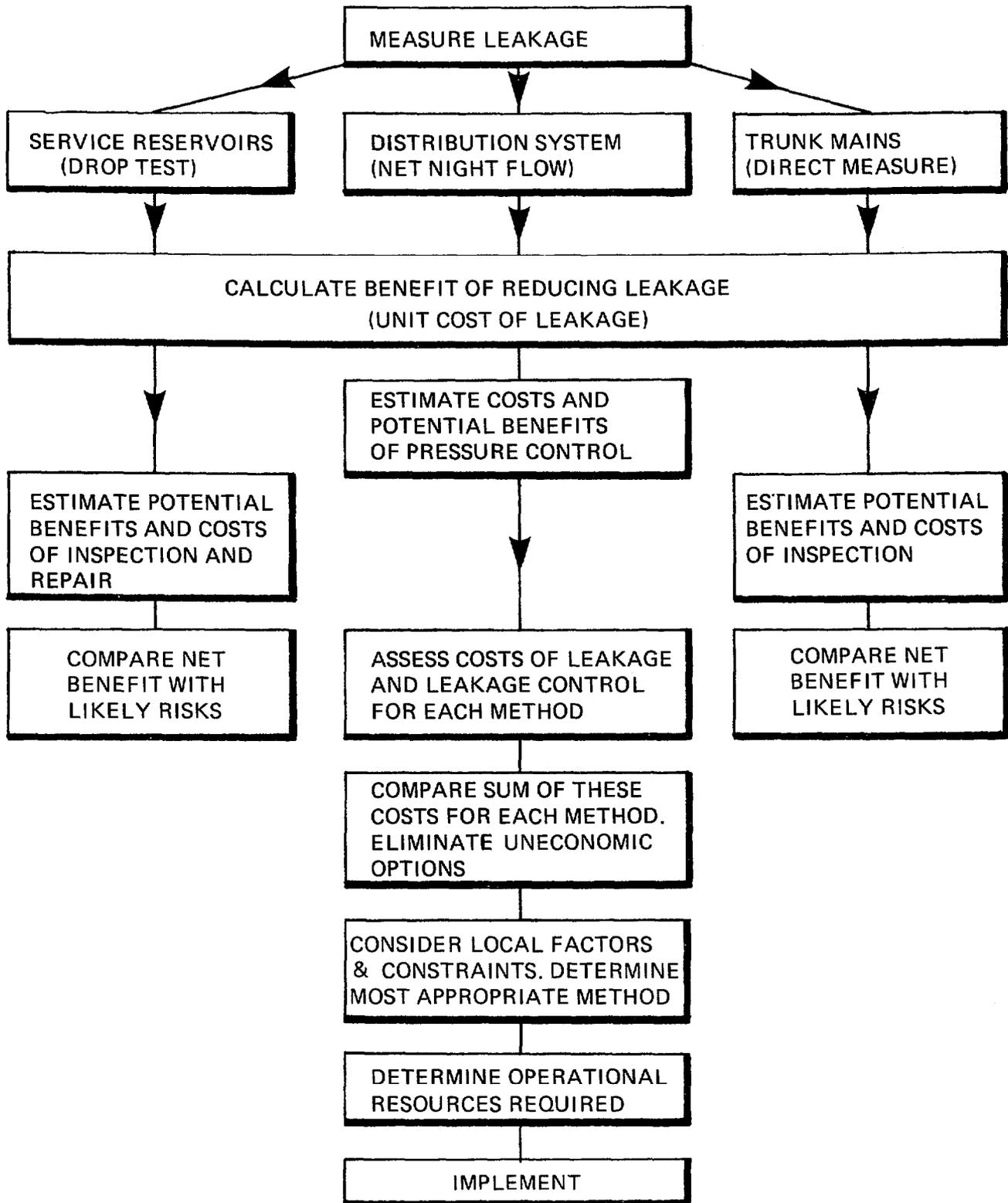


Fig. 1. Flow diagram of the procedure for the determination of leakage control policy

2.22 The process of adopting a more intensive method of leakage control, which reduces average leakage levels, will result in a temporary backlog of extra repairs. This can be likened to decreasing the average length of the queue of customers by a short term increase in the rate of serving them. The shop assistant will require assistance for a short period to reduce the length of the queue; thereafter his efforts alone are sufficient to maintain this reduced queue at a constant length.

2.23 Therefore, although a change from one leakage control method to another will create an instantaneous backlog of repairs, the long term average cost of repairs will remain unchanged and can be ignored in comparative assessments.

3. THE EXPERIMENTAL PROGRAMME

Introduction

3.01 It became apparent early in the work of the Group that despite the large amount of information recorded by parts of the industry in performing their chosen methods of leakage control, there was insufficient reliable data available upon which to base a detailed standard procedure for the determination of a leakage control policy. Therefore the Group, in conjunction with the Water Research Centre, proposed a series of ten different field experiments and data collection exercises to provide factual information of both leakage levels and leakage control costs and effectiveness. The subsequent programme of over 500 individual field trials, which was carried out during the spring and summer of 1978, is believed to be the largest ever undertaken by the United Kingdom water industry.

3.02 A brief summary of the results and conclusions is given in this chapter and full details and results of these trials can be found in WRC Technical Report *Results of the experimental programme on leakage and leakage control*.

Leakage levels

3.03 Four of the experiments were designed to measure the levels of leakage in the different parts of a system, namely service reservoirs, trunk mains and the distribution mains.

Service reservoirs

The results showed that 216 (86 per cent) of the 250 service reservoirs tested had less than 0.5 per cent of their capacity leaking away per day (see Figure 2). Most of the remaining reservoirs had leakage levels under 4 per cent of capacity per day. However, seven reservoirs (3 per cent) had leakage of between 12 and 30 per cent of capacity per day. Reservoir capacities varied from 50 to 20,000 cubic metres; most were of the order of 5,000 cubic metres and were thus typical of the majority of service reservoirs throughout the country. There was evidence that the older reservoirs had higher leakage than the newer ones; it should be noted that the older reservoirs were constructed of brick or stone and clay compared with the mass and reinforced concrete of more recent structures.

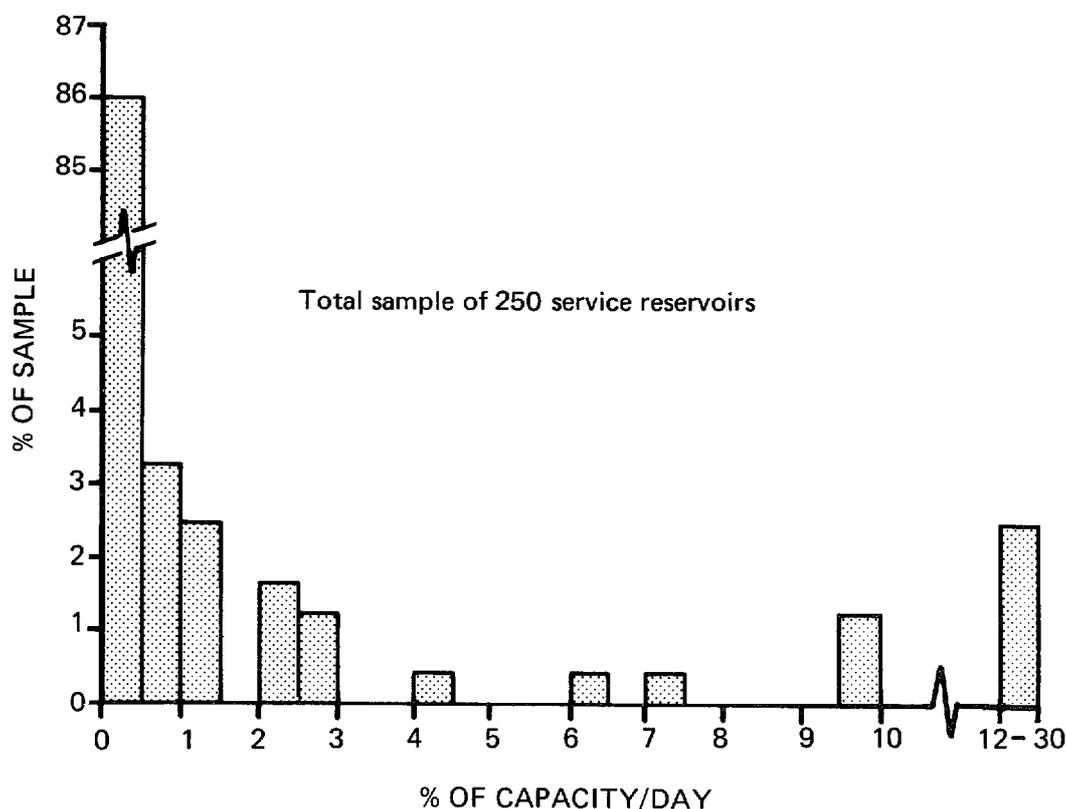


Fig. 2. Histogram of results of reservoir leakage tests

Trunk mains

Measurements of leakage from trunk mains revealed that 91 (81 per cent) of the 113 mains tested had leakage of less than 1,000 litres per kilometre per hour. Of the remainder, only 4 per cent had leakage greater than 3,000 l/km/hr up to the maximum leakage measured of 6,500 l/km/hr (see Figure 3). It was found that the older mains had the higher leakage; the effect may be related to pipe laying practice, jointing techniques or pipe materials. No relationship was found between leakage, expressed as a flow rate, and the diameter of the main.

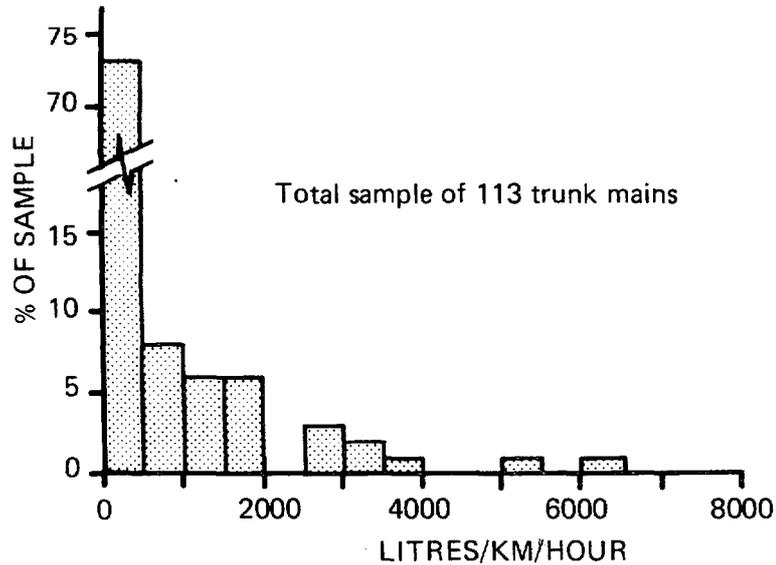


Fig. 3. Histogram of results of trunk main leakage tests

Distribution systems

Leakage from a distribution system cannot be measured directly. The best method of its estimation is by measuring the night rate of flow (the flow during the early hours of the morning). Data taken from the records of water undertakings throughout the United Kingdom showed that nearly all urban districts subject to waste metering had net night flows of between 2 and 12 litres per property per hour with a mean of 6.1 l/prop/hr. Of similar districts without positive leakage control only 34 per cent lay within this range; the remainder had leakage of up to 50 l/prop/hr with a mean value of 18.6 l/prop/hr (see Figures 4 and 5).

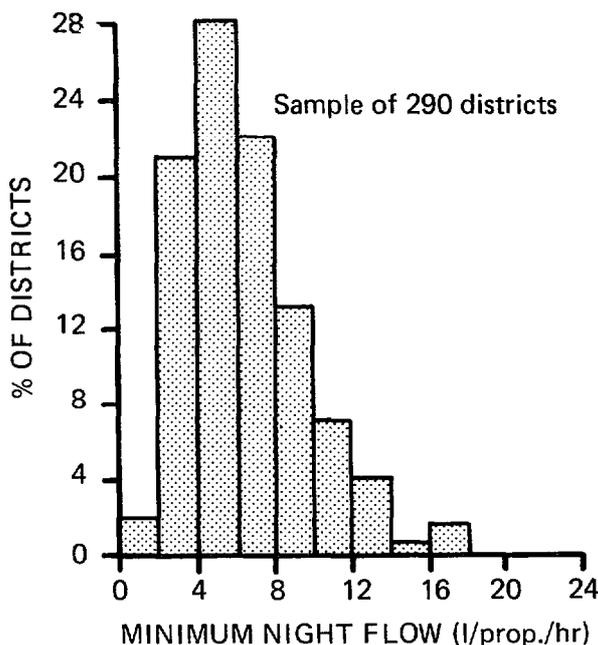


Fig. 4. Histogram of night flows in districts with effective waste metering

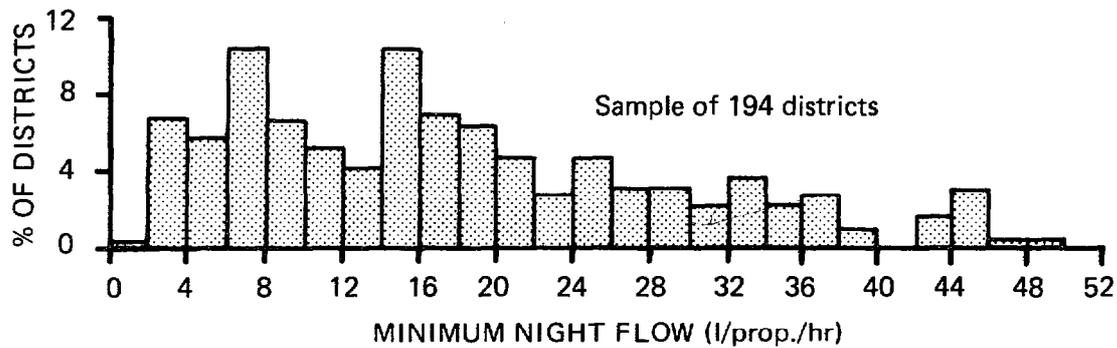


Fig. 5. Histogram of night flows in districts with passive leakage control

Not all of these night flows can be considered to be leakage; some may be due to metered consumption or other legitimate use such as filling storage cisterns. The results of trials to measure the component parts of night flows showed that,

- (a) in some districts, metered consumption may represent a significant proportion of the minimum night flow, and
- (b) unmetered, but legitimate, consumption is generally relatively small when compared with the range of minimum night flows. The average figure is below 2 l/prop/hr.

The effectiveness of leakage control methods

3.04 Several trials were designed to provide objective measurements of the effectiveness of the various methods of leakage control and leak detection techniques currently in use in the industry. These are:

- (a) Leakage reduction by pressure control
- (b) Leakage detection by:
 - Passive leakage control.
 - Regular sounding.
 - District metering.
 - Waste metering.
 - Combined district and waste metering.
- (c) Leak location by:
 - Valve and hydrant sounding
 - Stop cock sounding
 - Step tests combined with sounding

Leakage reduction by pressure control

3.05 The results of trials to measure the reduction in leakage brought about by various decreases in pressure showed that the rate of reduction was greater at higher pressures. The relationship obtained is shown by the solid line in Figure 6. It is the converse of the theoretical square root relationship between the flow through an orifice and the pressure (shown dotted) which was previously thought to apply to overall leakage levels. Thus, quite small reductions in high pressures will cause a correspondingly greater reduction in leakage.

3.06 In the long term, however, lower pressures may also increase the leak population by making them less detectable, and this may possibly diminish the shorter term savings. This effect is currently under investigation.

Leakage detection methods

3.07 The effectiveness of the methods of leakage detection were determined from a large number of data collection exercises. Some of this information, which was referred to in 3.03, shows the levels of night flows encountered in urban domestic districts of around 500 to 1,000 houses both with passive leakage control and with effective waste metering. The mean values were found to be 18.6 l/prop/hr and 6.1 l/prop/hr but, particularly in districts subject to passive leakage control, there was considerable variation about these values.

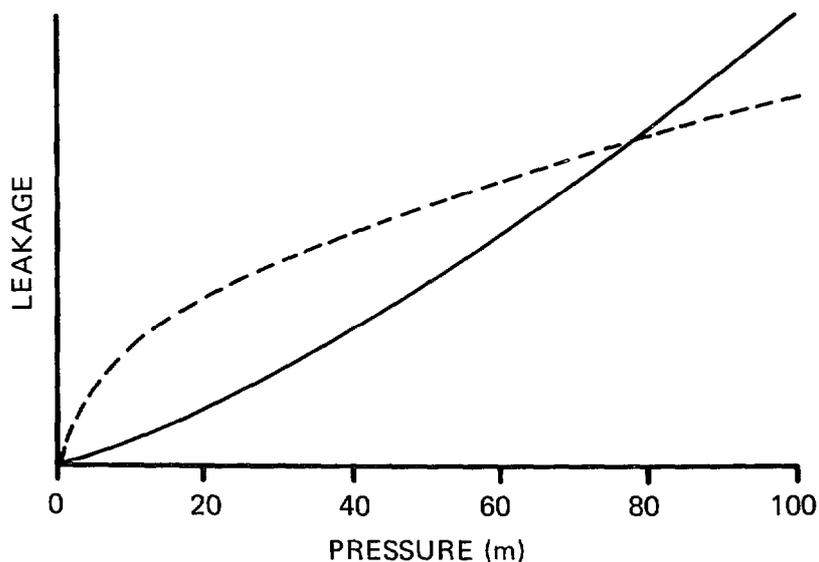


Fig. 6. The effect of pressure on leakage levels

3.08 For large areas consisting of many districts, the range of net night flows is unlikely to be so great, and typical values for areas with low, medium and high leakage levels are shown in Table 1. This table has been extended to include likely night flows in areas subject to other methods of control; it is important to note that these additional figures are based on the limited amount of data available and also on interpolation. The effectiveness of combined district and waste metering has proved difficult to estimate; however, net night flows are likely to be similar to those in areas with waste metering.

Table 1. Levels of net night flows in large urban areas

<i>Leakage control method</i>	<i>Areas where leakage is typically</i>		
	<i>Low (l/prop/hr)</i>	<i>Medium (l/prop/hr)</i>	<i>High (l/prop/hr)</i>
Passive leakage control	15	18	25
Regular sounding	8	10	14
District metering	6.5	8	11
Waste metering	5	6	8
Combined district and waste metering	5	6	8

Leak location methods

3.09 The trials to determine the overall effectiveness of the methods of leak location revealed that, in general, direct sounding at all access points was more worthwhile than valve and hydrant sounding alone. In areas with waste meters, step testing and sounding was more effective than sounding only, as both inspection costs and the possibility of leakage being missed, were reduced. Waste meter districts of up to 1,000 properties were satisfactorily reduced to 10 sections (steps) whilst 20 or more sections were required in larger waste districts. It was also found that, in districts consisting of 2,000 properties, sounding was required on average in 65 per cent of the sections compared to 45 per cent in districts of 1,000 properties.

The costs of leakage control methods

3.10 The remaining data collection exercises provided information on the costs involved in setting up and operating the various methods of leakage control. These showed that, for example, the costs of installing a waste meter and setting up a waste district varied typically between £1,000 and £2,000. The time taken to obtain a night line, where it was possible to set up a waste meter during the day, could be as little as four man hours, but where night work was involved, this extended to 12 man hours. Stop-cock sounding costs were also variable; the typical rate for urban areas was between 10 and 30 stopcocks sounded per man hour. A summary of this data, converted into costs at mid 1979 levels, is given in Table 2.

Table 2. Costs of components of leakage control methods (at mid 1979 levels)

<i>Operation</i>	<i>Mean cost</i> £	<i>Typical range</i> <i>of costs</i> £
Install a waste meter and set up district	1,650	1,000–2,000
Record a night line (day/night work)	36	18– 54
Record a night line (night work only)	52	26– 78
Perform a step test	85	60– 110
Sound 1,000 houses	150	100– 300
Read 100 district meters	80	60– 100
Repair backlog of leaks found when introducing active leakage control (per 1,000 properties)	300	200– 500
Locate reported leaks when operating passive leakage control (per 1,000 properties)	60	0– 300
Install PRV and set up pressure zone	1,750	500–3,000
Annual PRV maintenance	25	10– 50
Sound a trunk main (per km)	6	2– 12
Install a tapping and chamber	150	100– 500
Perform leakage measurement using a heat pulse meter or bypass meter	35	15– 70
Locate leakage by SF ₆ gas tracing (per km) in soft ground	60	
Perform reservoir drop test	35	15– 70
Locate leakage using leak noise correlator (per 200m)	15	10– 20

4. THE UNIT COST OF LEAKAGE

Introduction

4.01 A fundamental component of the procedure is a derivation of the economic benefit to an undertaking of changing leakage levels. This figure is relevant not only to all parts of the system but also has implications for subjects other than leakage control. It is therefore discussed in this chapter as a separate topic.

4.02 The benefit to the undertaking is the effect, upon the expected costs of supplying water, of the change in demand brought about by a change in leakage. Past expenditure can in no way be affected by a future change in demand and is therefore irrelevant. This change in costs, which can be considered to be a saving brought about by a reduction in leakage, consists of two distinct elements:

- (a) a reduction in annual operating costs, and
- (b) a deferment of demand-related schemes effecting a reduction in the programmed capital investment.

4.03 The approach adopted incorporates total costs but, because each method of control will achieve a different leakage level within the same system, it is more convenient to express these cost reductions as a unit amount eg pence per cubic metre (p/m³). This figure is referred to as the unit cost of leakage.

Theory

4.04 The reduction in the relevant annual operating costs incurred by an undertaking in supplying water will consist of a reduction in energy charges for pumping or boosting, a reduction in the quantities of chemicals used for treatment and in some cases a reduction in costs incurred for the bulk purchase of water. There may also be small (and probably insignificant) reductions in maintenance and labour costs. These cost reductions may be expressed directly as a unit operating cost in pence per cubic metre.

4.05 The second element of the unit cost of leakage is the value of deferring certain capital schemes. A reduction in leakage will produce a similar reduction in supply requirements for all subsequent years which will enable demand-related schemes to be deferred. The period of deferment will be the same for all of these schemes and will depend upon the reduction in leakage (and a consistent rate of growth of demand). This is indicated in Figure 7.

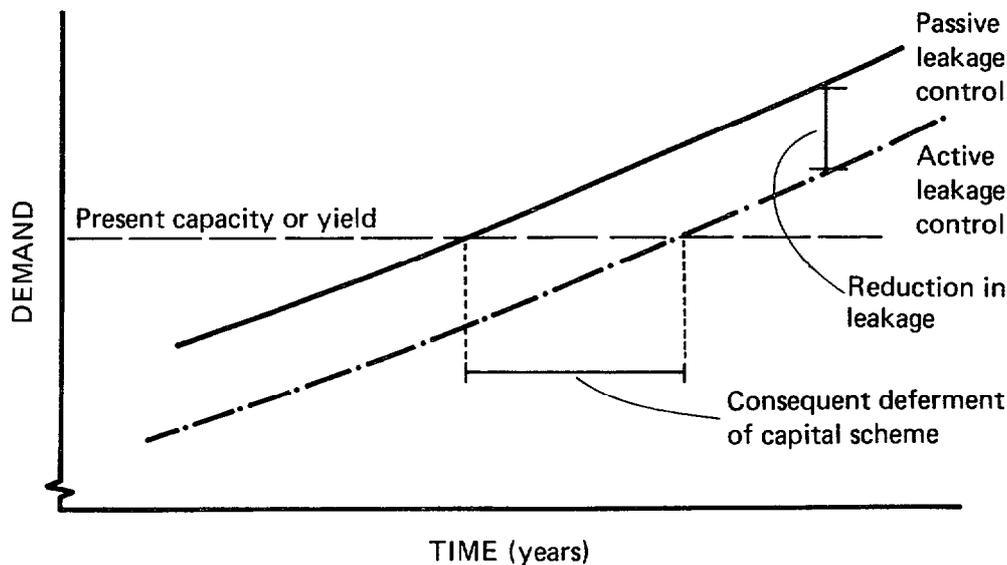


Fig. 7. Diagrammatic representation of the deferment of capital expenditure

4.06 For a given level of leakage there is an associated programme of capital investment; the greater the reduction in leakage the more the relevant schemes are deferred within this programme.

4.07 The values of each of these differing programmes of capital investment can be calculated by discounting the series of costs at the recommended test discount rate (currently 5 per cent). This procedure assigns lower values to costs occurring further in the future and therefore those investment programmes corresponding to lower leakage levels will have a lower total discounted capital cost. In order to avoid setting out and discounting complete capital programmes for several levels of leakage, a unit capital cost is calculated from which a total cost can be calculated for any level of leakage.

Inflation

4.08 In times of inflation, deferring a capital scheme will mean that its cost, in money terms, will be increased. However this is really the effect of a steady decrease in the value of money and in real terms ie excluding inflation, the costs will be very similar. Therefore in the recommended procedure, which is essentially an economic analysis, inflation need not be considered. All costs are in real terms and are the costs which would be incurred at today's prices, not future inflated costs.

4.09 This is not satisfactory if certain costs are inflating at a different rate to the general fall in the value of money, but over the last decade this has not been the case. Nevertheless it is now considered likely that energy costs may inflate at a higher rate than other costs, in which case allowance should be made as discussed in Appendix B.

4.10 In a financial analysis, in which account is taken of the funding of capital schemes, inflation cannot be treated so simply.

Summary of calculations

4.11 The remaining part of this chapter consists of a summary of the method proposed for the calculation of the unit cost of leakage. Full details of the method, together with the tables and figures referred to in the text can be found in Appendix B. This method has been successfully applied to supply systems of three different water undertakings and the results of these case studies can be found in Appendix C.

4.12 The calculations are detailed below.

Calculation of the unit operating cost

1. Determine the source or sources of water where output would be reduced if demand decreased. This may be achieved either at existing sources or from decreases in bulk purchases or a combination of these two.

2. For each relevant pumping station determine those pumps the output of which would be decreased as demand decreased; determine the water output and power input of those pumps and the costs of that power. For electricity, this is the cost of the last unit of power used, (averaged if there are daily or seasonal variations), and can be estimated from previous bills. Calculate the unit pumping cost from the formula,

$$\text{unit pumping cost} = \frac{\text{power input per hour} \times \text{cost per unit of energy}}{\text{water output per hour}}$$

Multiply this figure by the inflation multiplier, if appropriate. (See Appendix B).

3. For each of the relevant sources calculate the unit treatment cost from either the sum of the unit treatment costs for each chemical used where,

$$\text{unit treatment cost} = \text{dosage rate of chemical} \times \text{unit quantity cost of chemical}$$

or from the formula

$$\text{unit treatment cost} = \frac{\text{annual chemical costs}}{\text{annual quantity of water supplied}}$$

4. For bulk purchase of water calculate the unit purchase cost from the formula:

$$\text{unit purchase cost} = \text{unit charge} + \left\{ \frac{\text{annual fixed charge}}{\text{annual quantity purchased}} \right\}$$

The annual fixed charge should only be included if it increases as the quantity requested each year increases.

5. Calculate the unit operating cost by:

(a) adding the unit treatment costs to the unit pumping costs and unit purchase costs (as applicable) for each of the sources identified in 1.

(b) determining the average of these source costs which should be weighted according to the likely magnitudes of the reductions in supply at each source.

Calculation of the unit capital cost

6. Determine the relevant future capital costs from the five year plan and fill in the appropriate costs in the upper part of each space in the Capital Cost Table (See Appendix B, Figure B1).

Relevant schemes are those which would be affected by changes in the demand trend.

Annual costs should only be entered in the first year.

If these planned schemes do not include at least one of each of the main elements of a supply and distribution system ie source works, treatment works, storage works or trunk main, estimate when the missing ones will be required and their approximate costs and insert them in the spaces at the bottom of the table.

7. For each scheme determine the fixed annual operating cost eg labour, maximum demand charges etc; multiply by 21 to convert to a capital sum and insert in the year in which the works

become operable. For discount rates other than 5 per cent, this factor should be changed to $(1 + r) \div r$.

8. Determine the proportion of each scheme which would be affected by changes in demand (the demand multiplier) and insert in the appropriate spaces in Figure B1.

9. Determine the capacity multipliers from Figure B2 and insert them in the appropriate spaces in Figure B1. These depend on the time before further works of the same type will be required and can be obtained by division of the capacity or yield of that scheme by the annual increase in the peak week's demand. The capacity multiplier for annual costs is 21 for a discount rate of 5 per cent.

10. Multiply each capital cost by the demand and capacity multipliers and insert this figure, the modified capital cost, in the space beneath the actual cost in Figure B1.

11. Sum the modified costs obtained year by year and enter them in the total modified cost column (xii).

12. Multiply each modified capital cost by the appropriate discount factor shown in column (xiii) for 5 per cent, insert these discounted capital costs in column (xiv) and sum to arrive at the total discounted capital cost (TDCC).

13. Calculate the unit capital cost of leakage from the following formula

$$\text{unit capital cost} = (\text{TDCC} \times r^2) \div [(1 + r) \times 3.65 \times d]$$

where r is the discount rate

and d is the annual change in demand (m^3/day)

Calculation of unit cost of leakage

14. unit cost of leakage = unit operating cost + unit capital cost

5. THE RECOMMENDED PROCEDURE

Introduction

5.01 In this chapter the results of the experimental programme are used to enable the management of a water undertaking to either:

- (a) determine the method of leakage control most suitable for areas with no existing policy, or
- (b) review the suitability of existing methods of leakage control.

5.02 The second stage of the procedure, to determine the correct level of operational resources to be expended on the chosen method, is discussed in Chapter 6.

5.03 The most appropriate method of leakage control for an area will depend upon several factors such as the unit cost of leakage, the level of leakage or the type of area. Owing to the large variation of these factors no single method will be satisfactory for all areas. The procedure therefore involves determining these factors by measurement and calculation and then interpreting them to decide on the appropriate method of leakage control.

5.04 The recommended procedure consists of the following principal steps:

- (a) An initial measurement of the magnitude of leakage within the system;
- (b) Determination of the unit cost of leakage;
- (c) Estimation of the costs and potential savings of pressure control;
- (d) Calculation of:
 - (i) the cost of leakage appropriate to each method of leakage control;
 - (ii) the cost of operating each of the methods of leakage control.

- (e) Comparison of the sum of the costs in (d) (i) and (ii) for each method to determine which methods are economically acceptable;
- (f) Consideration of local factors, unquantifiable benefits and constraints;
- (g) Decision on the leakage control method to be adopted;
- (h) Determination of the operational resources required;
- (j) Implementation of appropriate action;
- (k) Monitoring of performance at regular intervals.

5.05 The results of the experimental programme have shown that the greatest potential savings are likely to be within the distribution system. The application of the procedure to the distribution system is now described. A similar but simpler procedure for trunk mains and service reservoirs is discussed later in this chapter.

5.06 Examples of applying the recommended procedure are given in Appendix E.

Measurement of leakage within the distribution system

5.07 The first step in the procedure is to measure leakage within the distribution system. Although full details of the techniques available are given in Part 3 of this report, the aims of the measurement are discussed below.

5.08 The leakage level obtained from the measurement is to be used in economic calculations involving large sums of money, the results of which will affect operations for many years into the future. Consequently it is imperative that the results of the measurement are as accurate as possible.

5.09 It has been found that estimation of leakage from daily quantities is unlikely to give sufficiently accurate results.

5.10 It is recommended therefore that the leakage in the distribution system is obtained from measurements of night flows and night consumption and it is this method which is discussed in Part 3, Appendix D. The method can be used to obtain a measure of the absolute level of leakage but to do this it would be necessary to make a deduction for unmetered night consumption. However, because unmetered night consumption is materially unaffected by changes in the leakage control method and within the recommended procedure all leakage levels are used comparatively, this requirement can, in practice, be ignored in the recommended procedure.

5.11 The figures used throughout the recommended procedure are net night flows, ie minimum night flow less metered night consumption.

5.12 As mentioned earlier, the choice of leakage control method depends upon the potential reduction in leakage, the unit cost of that leakage and the type of area. Thus the night flow measurement and the procedure should be applied separately to areas which are, or are expected to be, dissimilar in these components. For example, the measurements and subsequent calculations will need to be performed separately for urban and rural areas within a single system, even though the unit cost of leakage will be the same. This will also be the case if part of a system has higher leakage levels than another part. Otherwise, it is possible that a method of leakage control will be chosen which is ideally suited to neither part of the system.

5.13 The measurement of net night flow may be carried out as a single measurement for the whole of the study area or as a series of measurements on subdivisions within the study area which can be summed. The latter approach provides more information of the range of leakage levels and will be appropriate in areas in which some metering exists.

5.14 If it is not possible to isolate the whole of the area, sample measurements can be taken and the total net night flow calculated pro rata. Provided that at least 80 per cent of the area is measured, and that the omitted part is typical of the whole area, an estimate of sufficient accuracy will be obtained for confident selection of the appropriate leakage control method.

Determination of the unit cost of leakage

5.15 The second step in the procedure is to calculate the unit cost of leakage. An introduction to and a summary of the proposed method is given in Chapter 4 and full details of the method are given in Appendix B. Three case studies, which may be used as examples, are given in Appendix C.

Estimation of the costs and potential savings of pressure control

5.16 Although pressure reduction can affect the subsequent choice of leakage control method, it is possible that only a part of the system will be capable of having its pressures reduced significantly. Nevertheless as this method can be implemented and hence savings made relatively quickly, it is recommended that its adoption should always be considered.

5.17 If pressure reduction is possible the effect of that reduction can be predicted using results from the experimental programme, which are reported in Figure 6. The procedure is as follows:

First obtain the present average zone night pressure (AZNP) which is the average pressure throughout the zone recorded at night. Taking into account the low hydraulic losses overnight this will usually be an average of maximum and minimum pressures recorded in the zone at night.

In areas with large differences in ground levels, the average zone night pressure is given by:

$$AZNP = S \times \text{maximum night pressure} + (1-S) \times \text{minimum night pressure}$$

where S is the proportion of the system with pressures greater than the average of the minimum and maximum night pressures.

An examination of the pressures at the point within the zone which experiences the lowest daily pressure ie at the highest point or at the far end of the zone, the potential reduction in pressures can be estimated. The minimum acceptable pressure at this point will vary between undertakings. However in many areas minimum mains pressures of 10 to 15 metres head will maintain satisfactory supplies.

Reference to the graph in Figure 8 will then yield the leakage indices for the original and reduced average zone night pressures (see Appendix E.17) and the expected reduced net night flow can be obtained from the equation:

$$\frac{\text{reduced net night flow}}{\text{original net night flow}} = \frac{\text{leakage index at reduced pressure}}{\text{leakage index at original pressure}}$$

The likely reduction in net night flow can then be obtained by subtraction and can be converted into a daily quantity. Where appropriate, Figure 8 can also be used to make allowance for pressure variations over the day. The details of this method are also given in Part 3, Chapter 5. However for most districts it has been found that multiplying night flow rates by 20 hours gives a satisfactory estimate of the daily leakage.

Thus the annual cost saving is given by:

$$\text{annual cost saving (£)} = \frac{\text{reduction in net night flow}}{\text{net night flow}} \times 20 \times 365 \times C \div 100$$

where the net night flow is in cubic metres per hour and C is the unit cost of leakage (p/m^3) as calculated for this area by the method in Chapter 4.

The relevant leakage control costs are for the installation and maintenance of the pressure reduction equipment. These will depend to a great extent on the type of equipment, the size and number of PRVs required and the number of valves required to isolate the zone. However, as a guide to these costs, examples of the likely range are given in Table 2.

Due to the limit of current knowledge concerning the duration of these reductions in leakage, the installation cost should be discounted only over a few years (the payback period). A payback period of 5 years is suggested.

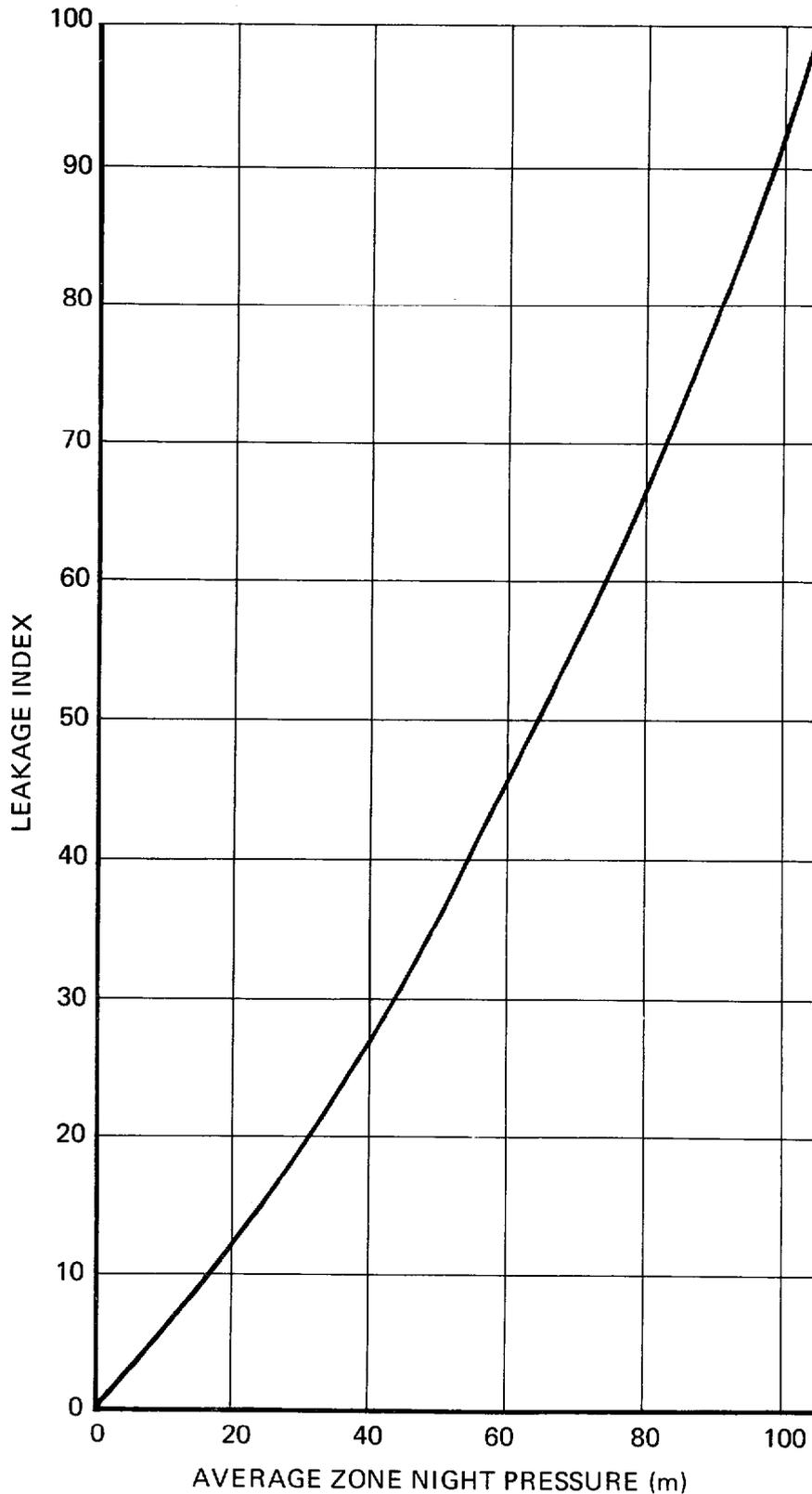


Fig. 8. Relationship between leakage (net night flow) and pressure

Thus:

$$\text{Annual cost of pressure control} = \left\{ \frac{\text{installation cost}}{\text{payback period}} \right\} + \text{annual maintenance cost}$$

A comparison of the annual cost saving with the annual cost of pressure control to achieve that saving will enable the preferred course of action to be identified. It is not possible to give any guidelines as to the size of the net benefits ie savings less costs before pressure control becomes worthwhile. This will depend upon such factors as the size of area and the cost of achieving the saving.

Calculation of the costs of leakage and of leakage control methods

5.18 Each of the methods of leakage control will be associated with a level of leakage from the system. Generally the more expensive methods will result in lower levels of leakage. The procedure combines cost of leakage with the cost of the leakage control method so that the most economically attractive methods are readily apparent. This method is logistically simpler than the calculation of the benefit for each method of control.

5.19 Consequently, it is necessary to estimate the likely net night flows, which are used here as an indicator of leakage for each method of control, and to determine the costs of incurring them.

Estimation of the net night flows associated with each method of leakage control.

5.20 The levels of net night flow likely in large urban areas associated with the different methods of leakage control have been derived from the results of the experimental programme and are shown in Table 1.

5.21 No single value applies to all areas but, depending upon the individual characteristics of a system and the current leakage control method, the overall net night flow is expected to lie somewhere within the range shown. Whilst levels in small individual areas may lie outside the range of these figures, it is unlikely that the net night flow for large areas would do so.

5.22 In order to estimate the likely net night flow for the methods of leakage control other than the one currently practised, it is necessary to determine whether the area under consideration has intrinsically low, medium or high leakage levels. This is done simply by comparing the initial measurement of the net night flow, expressed in litres per property per hour, with the figures in Table 1 for the existing method of leakage control.

5.23 Alternatively, as it is likely that the initial measurement lies between the tabulated values, Figure 9 can be used. A horizontal line should be drawn at the existing net night flow and, at the point where it crosses the sloping 'method line' representing the current practice, a vertical line should be drawn, crossing the remaining sloping 'method line' at points corresponding to the likely net night flows. (See Appendix E.02).

5.24 In areas where the introduction of pressure control has been shown to be worthwhile, the net night flow related to the lower pressure should be used. Further, if these calculations are being performed in an area already subject to an active leakage control policy, it is important that consideration is given to the level of operational resources currently applied to that method (See Chapter 6). Otherwise it is possible that the alternative levels of net night flow may be over-estimated. For instance, an area currently subject to an infrequent programme of district metering will have higher leakage levels than at a more appropriate level of application. Consequently an allowance should be made for this difference as the figures quoted in Table 1 apply to effective leakage control based on the recommendations in Chapter 6.

5.25 In rural areas, higher levels per property can be expected due to lower housing densities. The large range of housing densities precludes the construction of a similar graph to Figure 9. It is suggested that an approximation to the likely leakage levels in rural areas can be obtained from Figure 9 by artificially increasing the number of properties to a value considered typical for an urban network with comparable length of mains.

Calculation of the annual cost of leakage

5.26 The annual cost incurred per property in supplying the net night flow is calculated as follows,

$$\begin{array}{l} \text{annual cost} \\ \text{of leakage,} \\ \text{(\pounds per prop)} \end{array} = \begin{array}{l} \text{net} \\ \text{night} \\ \text{flow} \end{array} \times 20 \times 365 \times C \div 100,000$$

where the net night flow is in litres per property per hour and C is the unit cost of leakage (p/m^3) as calculated in Chapter 4.

Note: The factor of 20 is used (rather than 24) to convert the net night flow rate into an equivalent daily quantity as discussed in 5.17.

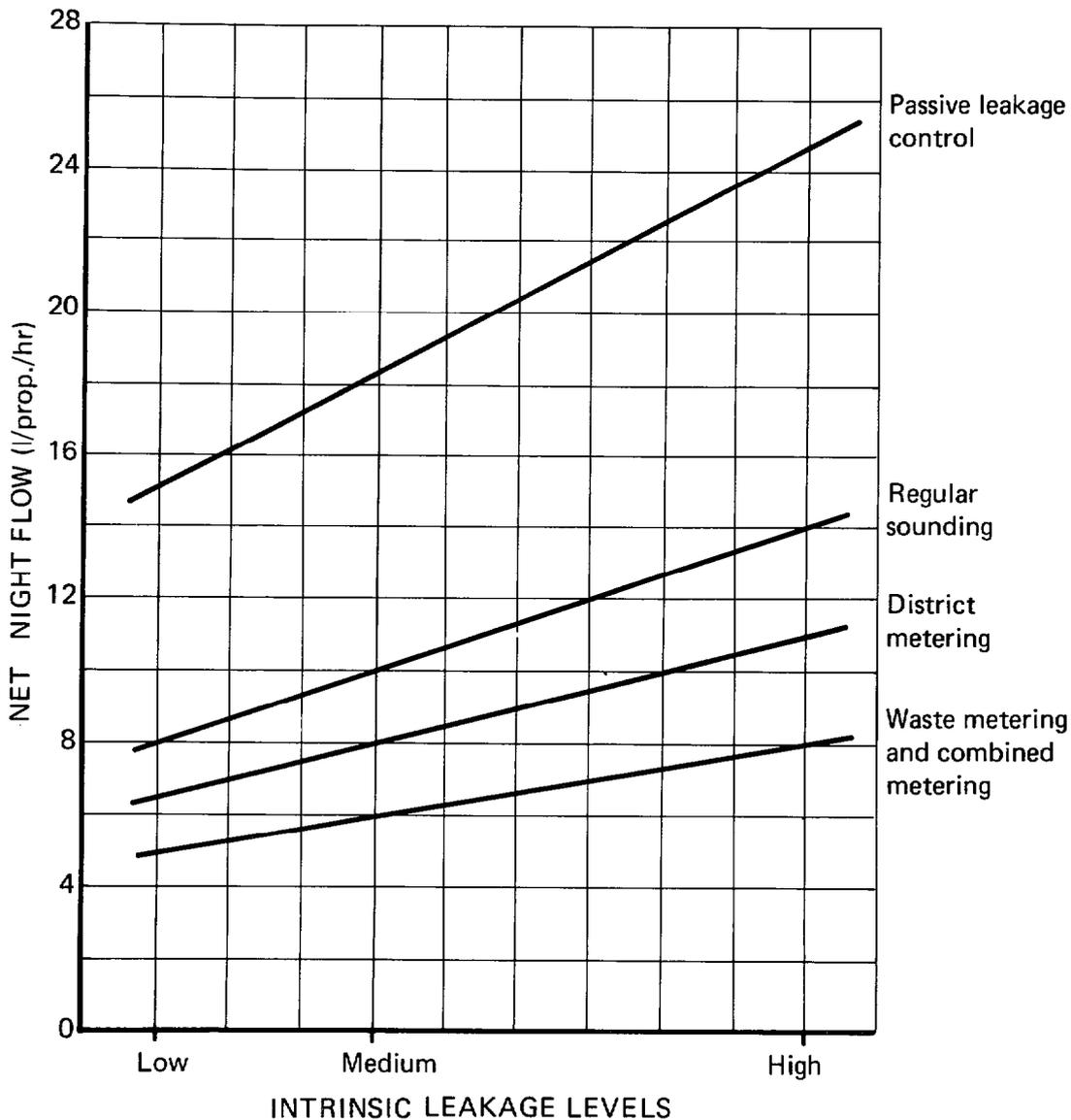


Fig. 9. Graph for prediction of net night flows

5.27 It should be realised that although each figure taken in isolation has little meaning because many fixed costs of supplying water have been excluded, when used comparatively they will accurately reflect the differing costs incurred in supplying different levels of leakage.

Calculation of costs of leakage control

5.28 The cost components of implementing and subsequently regularly operating each method of leakage control will vary between undertakings as shown in Table 2.

5.29 Therefore, where possible, actual costs relevant to the study area should be determined. As an aid to this process, details of the components of these costs are given in Appendix D so that total costs at a level appropriate to the year in which the calculations are being performed may be more easily derived. An alternative method of revising the costs to some other year is to update those quoted (at 1979 levels) by suitable indices.

5.30 From these component costs it is possible to derive the expected cost per property of implementing and operating each of the methods of leakage control at an intermediate frequency of operation. Examples of these total costs based on the mean component costs are shown in Table 3 and their derivation is also given in Appendix D. It should be emphasised that these particular figures should be used only if the mean component costs shown in Appendix D are considered reasonable for the area under consideration.

Table 3. Typical annual costs per property of different methods of leakage control

<i>Method of leakage control</i>	<i>Initial cost (£/prop)</i>	<i>Annual cost (£/prop/year)</i>	<i>Total annual cost (£/prop/year)</i>
Passive leakage control	0.00	0.06	0.06
Regular sounding	0.45	0.15	0.17
District metering	1.00	0.16	0.21
Waste metering	1.35	0.46	0.53
Combined district and waste metering	1.48	0.47	0.55

5.31 For those undertakings that are using the procedure to review an existing policy certain cost components, such as the cost of installing meters, may have already been incurred and should therefore be excluded from the calculations. This is demonstrated by example in Appendix D.06.

Comparison of the sum of the costs of leakage and leakage control for each of the methods

5.32 The total cost of each method of leakage control is the sum of the annual costs of leakage and the costs of leakage control.

5.33 Because of the assumptions and estimates inherent in the procedure, it is unlikely that total cost differences of less than about 10 per cent will have much significance. Consequently, those methods with total costs less than 10 per cent apart cannot be distinguished on economic grounds.

5.34 The aim at this stage is solely to identify and discard those methods which are clearly uneconomic. It is proposed, therefore, that those methods with a total annual cost greater than 20 per cent above the minimum total cost, should be excluded as being uneconomic options.

Final choice of method

5.35 Exclusion of the uneconomic options will normally leave a final choice between two or perhaps three methods of control which, whilst costing different amounts to implement and operate, will all result in similar total costs to the undertaking. The final choice will then be determined by consideration of local factors which, although real, cannot easily be quantified in economic terms.

5.36 Unquantifiable benefits of more intensive leakage control are likely to include:

- Better knowledge of the system
- Better accounting of water put into supply
- Better maintenance of systems
- Improved public relations

5.37 Constraints on the method of leakage control which must be considered will include:

- Manpower policies
- Limitations of night working
- Financial constraints
- Political constraints
- Local physical features, eg type of area, status of existing apparatus
- Current leakage control methods

Trunk mains and service reservoirs

5.38 It is apparent from the results of the experimental programme that, in general, the leakage from most trunk mains and service reservoirs is relatively small. Nevertheless some trunk mains and reservoirs do have significant levels of leakage and so these parts of the system cannot be ignored. As they are key components in a water supply and distribution system any policy for locating leaks will not be solely based on the economics of saving water. Security of supply, water quality and structural safety will be major considerations in many cases and thus a policy decision must take these matters into account. Nevertheless the likely costs of leakage and the economic benefits derivable by reducing that leakage can be quantified by the use of the unit cost of leakage. Thus, part of the subjectivity can be removed and unnecessary expenditure avoided.

Service reservoirs

5.39 The methods available for the measurement of leakage from service reservoirs are detailed fully in Part 3 and involve direct measurement. Because all leakage cannot be eliminated, the leakage after completing repair should be estimated by reference to either (i) previous local measurement or (ii) the results of the experimental programme.

5.40 The annual economic saving obtainable by reducing leakage can be calculated using the unit cost of leakage.

5.41 The costs of location and repair of leaks vary greatly, depending, for example, on the size and type of construction of the reservoir. The variation in costs of repair is so great as to preclude any further general recommendations being given.

Trunk mains

5.42 The methods available for the measurement of leakage from trunk mains are also detailed in Part 3 and in most cases these involve direct measurement. Absolute measurement of leakage from differences between inlet and outlet meters are not normally reliable due to the problems of detecting small differences between large quantities.

5.43 Because in most cases low leakage levels will be encountered in both service reservoirs and trunk mains, measurements of trunk main leakage combined with a reservoir level drop test are often advantageous.

5.44 Any likely reduction in leakage can be calculated by reference to either previous measurement or to the results of the experimental programme and the annual economic saving calculated using the unit cost of leakage in the formula.

$$\begin{array}{l} \text{annual} \\ \text{cost} \quad (\text{£}) \\ \text{saving} \end{array} = \begin{array}{l} \text{reduction} \\ \text{in leakage} \end{array} \times 24 \times 365 \times C \div 100,000$$

Where the reduction in leakage is in litres per hour and C is the unit cost of leakage in pence per cubic metre.

5.45 For trunk mains the available options for locating leakage identified below are described fully in Part 3.

- Walking and sounding the main
- Pressure measurements
- Halving techniques using either
 - (i) WRC heat pulse flow meter
 - (ii) Pairs of insertion turbine meters
 - (iii) Sectioning

5.46 Once the leakage has been isolated to a suitable length of main it can be located either using direct sounding, SF₆ gas tracing or the leak noise correlator.

5.47 The costs of these methods are given in Table 2. Based on these figures it can be shown that:

- (a) Sounding the main or, if appropriate, pressure measurement, is relatively inexpensive and should always be a first consideration.
- (b) If these methods are not used or do not locate the leaks, a repeated halving of the main using either the low flow meter or pairs of insertion turbine meters should be carried out until a length of main short enough to be inspected in detail is identified. (For SF₆ gas tracing this length will typically be about 1 km).
- (c) The expected cost of inspection is the cost of halving the required number of times and the cost of the final detailed inspection. The cost of the initial direct sounding can be excluded to compensate for the possibility that this method will detect all of the leakage. The required number of halving measurements can be found by counting the number of times the length of the main must be halved until a length of less than 1 kilometre is obtained. This assumes that the majority of leakage will be confined to a single kilometre length of main which is likely to be the case for a main that receives regular inspection.

5.48 The net benefit of the inspection is the expected annual saving in leakage multiplied by the expected running time of the leaks (in years) less the cost of the inspection. Owing to the lack of knowledge regarding the running time of leaks, various values can be inserted from one month to twelve months and in many cases may thus indicate the future course of action. In some cases however, the decision must be subjective and will depend upon the importance of the main in the system and other local factors.

5.49 An example of these calculations can be found in Appendix E.

6. APPLICATION OF THE PROCEDURE

General results

6.01 The procedure proposed in Chapter 5 has been applied to a typical system and the results and implications can be found as a case study in Appendix E. The calculations involved in the procedure have also been performed for hypothetical systems encompassing the likely range of unit costs of leakage. The results of this process which is based on average costs and leakage levels, are shown in Table 4.

Table 4. Total annual costs of leakage and leakage control (£/prop/year)

<i>Leakage control method</i>	<i>unit cost of leakage (p/m³)</i>					
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>
Passive leakage control	1.40	2.73	4.07	5.40	6.74	8.08
Regular sounding	0.90*	1.63*	2.36	3.09	3.82	4.55
District metering	0.79*	1.38*	1.96*	2.55*	3.13*	3.71*
Waste metering	0.97	1.41*	1.84*	2.28*	2.72*	3.16*
Combined district and waste metering	0.99	1.43*	1.86*	2.30*	2.74*	3.18*

6.02 The figures shown in Table 4 are the sum of the annual costs of performing leakage control and the costs of the associated leakage. The minimum cost, and those costs which are less than 20 per cent above the minimum cost, are marked with an asterisk to identify the range of the economic options for each unit cost of leakage. It should be emphasised that this particular table is presented simply as an example and the results are no substitute for following the procedure and including realistic costs and leakage levels appropriate to the area under consideration. Nevertheless, from consideration of Table 4 together with many similar ones which incorporate the likely variations both in the costs of the leakage control methods and in leakage, the following general results become apparent.

- (a) Passive leakage control is only economic below 1p a cubic metre
- (b) Regular sounding is economic up to 2p a cubic metre
- (c) District metering is economic between 1p and 5p a cubic metre
- (d) Waste metering is economic above 3p a cubic metre.
- (e) Combined district and waste metering is economic above 3p a cubic metre.

6.03 These general results do not give the complete picture because of the large variation inherent in some of the components included in the procedure. For example, it is possible to justify waste metering for unit costs of 3 p/m³ and above in nearly all areas even in those with below average leakage levels and above average costs of waste metering. However, with more favourable costs and leakage, waste metering can also be justified at much lower unit costs of leakage. This is the case in Table 4 and demonstrates the necessity of working through the procedure and incorporating relevant data.

6.04 Further, although regular sounding is an economic option for areas with a cost of leakage of less than 2p a cubic metre, the small extra cost of district metering makes it an attractive option when its benefits are considered.

- 6.05 These results can be generalised to produce the following conclusions:
- (a) An active leakage control policy can be economically justified in all but a few distribution systems.
 - (b) District metering is a sensible first stage in all but a few areas.
 - (c) Waste metering (or combined district and waste metering) is worthwhile where the unit cost of leakage is greater than 3 pence a cubic metre and can be worthwhile at lower values.

Implementation of the leakage control policy

6.06 Having determined the most appropriate methods of control for each separate supply and distribution system or area, the operational resources which should be applied to that method must then be decided. Just as an undertaking can fail to reap the maximum economic benefits by an incorrect choice of method, an inappropriate application of that method can also cause excessive expenditure. Guidelines for the efficient operation of each of the activities inherent in the methods of leakage control, such as reading waste meters or sounding districts, are given in Part 3.

Frequencies of leakage control activities

6.07 The frequencies shown in Table 5 are based upon current practice within the industry with due regard having been given to their economic implications. The acceptable range of some frequencies is relatively large which reflects the limit of current knowledge of these methods of leakage control. However further work, particularly on district metering, is in hand.

Table 5. Recommended frequencies of leakage control activities

<i>Leakage control method</i>	<i>Recommended frequencies</i>	<i>Acceptable range Once every</i>
Regular sounding	yearly	0.5 to 2 years
District metering		
Read district meters	weekly	1 to 30 days
Inspection	yearly	0.5 to 2 years
Measure trunk main leakage	every 5 years	1 to 10 years
Measure service reservoir leakage	every 5 years	2 to 10 years

6.08 The frequency of regular sounding represents the rate at which each stop cock is sounded whereas for district metering the average frequency of inspection represents a capacity for inspection or the operational resources required. The actual frequency of inspection in each district will depend upon the results of the district meter reading.

6.09 Table 6 gives the recommended frequencies appropriate to waste metering, or waste meters used with combined metering. These are based upon current practice throughout the industry and also upon a computer simulation of waste metering. This enabled the effects on leakage levels (and hence overall costs), of changes in the various frequencies to be examined for a variety of districts exhibiting a range of propensities for leakage.

- 6.10 Two points are worthy of note concerning these frequencies:
- (a) The appropriate frequencies depend upon both the size of the waste meter district and the potential economic benefits; more frequent measurements and inspections are worthwhile in larger waste districts and in waste districts with a higher unit cost of leakage.
 - (b) The acceptable ranges of frequencies given in Table 6 are those for which the economic implications are similar to those of the recommended frequencies. If frequencies within this acceptable range are adopted, rather than the recommended frequencies, a balance should be maintained between meter reading and inspection frequencies in order to ensure effective use of resources. The frequencies chosen should occupy a similar ranking within their respective ranges.

Table 6. Recommended monitoring and corresponding inspection frequencies for waste districts

	<i>Recommended frequencies (No/year)</i>		<i>Acceptable range (No/year)</i>	
	<i>Monitoring</i>	<i>Inspection</i>	<i>Monitoring</i>	<i>Inspection</i>
Small districts (up to 1,500 properties)				
<i>Unit cost of leakage:</i>				
4p/m ³ or less	3	1.25	2–4	1 – 1.5
more than 4p/m ³	4	1.5	3–6	1.25– 2
Large districts (over 1,500 properties)				
<i>Unit cost of leakage:</i>				
4p/m ³ or less	4	2	3–6	1.75– 2.5
more than 4p/m ³	6	2.5	4–12	2 –3

6.11 It should be realised that, as with district metering, the inspection frequency does not imply a fixed frequency for each district but a level of operational resources required for all districts. Thus an undertaking with 70 waste meter districts adopting an average inspection frequency of 1.5 times per year should perform 105 inspections per year or 2 per week.

6.12 These comments also apply to measurements of minimum night flows in systems subject to combined district and waste metering.

Waste district sizing

6.13 The computer simulation of waste metering enabled the economic implications of various sizes of waste meter district to be examined.

6.14 The majority of existing urban districts consists of between 500 and 1,000 properties, but there are economic advantages in making them larger. These advantages include a reduction in the number of waste meter installations required with a consequent reduction in the number of night flow measurements needed. On the other hand, inspection will be more complex in larger districts with possibly greater difficulty in maintaining low leakage levels.

6.15 These factors were incorporated into the computer simulation and Table 7 shows the resultant leakage control expenditure and total cost implications for a range of waste district sizes. The unit cost of leakage for these districts was taken as 5 pence a cubic metre, but the economic implications for other unit costs of leakage are similar.

Table 7 Total annual costs of leakage control for various sizes of waste district

	<i>Size of waste meter district (Number of properties)</i>				
	500	1,000	2,000	3,000	4,000
Annual leakage control expenditure (per property)	£0.82	£0.48	£0.53	£0.47	£0.47
Total annual cost of leakage and leakage control (per property)	£3.25	£2.81	£2.72	£2.67	£2.63

Note: leakage control expenditure is based upon recommended frequencies, not typical frequencies. Therefore it does not agree with the costs given in Table 3 which are based on typical frequencies.

6.16 It is emphasised that the total costs shown in Table 7 can only be used comparatively and that it is the differences between them that are significant. The annual leakage control expenditure however, is an absolute figure and can be used to put the differences in total costs into perspective.

6.17 It can be seen that the total annual cost of leakage and leakage control per property is a minimum (at £2.63) for a district size of 4,000 properties although very similar total costs, within the limits of accuracy of the calculations, are also incurred for districts of 1,000 properties or more. The annual leakage control expenditure is also very similar for districts of between 1,000 and 4,000 properties and so the economic implications of this range of waste district sizes are virtually identical.

6.18 For waste districts consisting of 500 properties both leakage control expenditure and total annual costs are significantly higher than for the larger districts. Consequently urban districts of less than 1,000 properties are economically unjustified.

6.19 Practical considerations such as meter sizing and resolution are relevant and further discussion of the practicalities and the economics can be found in Part 3, Chapter 7. It is concluded that urban waste districts should ideally contain between 1,000 and 3,000 properties.

6.20 The costs used in this report are based on districts of 2,000 properties.

Operational resources

6.21 Once the appropriate method of leakage control has been chosen and the effort to be applied has been determined, it is possible to decide upon the operational resources required by this policy. Eventual staffing levels can be estimated from the total work required using the frequencies given in Tables 6 and 7 in conjunction with the labour required for each leakage control activity. These will have been determined for the leakage control costs used in the procedure.

6.22 Examples of these labour requirements and an example of the procedure to be followed are given in Appendix E.

6.23 Whilst no extra employees will be required in the long term specifically to repair the leaks found by inspection (as a consequence of the steady state theory discussed in Chapter 2), extra effort will be required during implementation of a new method to repair the backlog of leaks identified by the inspectors and to implement the new method, ie planning, installation etc. The extra staff required for this will depend upon the rate at which the method is implemented over the area supplied by the undertaking and this will normally take several years.

Implications

Timing

6.24 It is practical to phase the implementation of the recommended procedure over several years taking into account the time required for meter installation and staff training. Consequently it is likely to be advantageous to determine those parts of the undertaking where the greatest savings are expected.

6.25 The results of the experimental programme have shown that the greatest savings are likely to be made in the distribution system; therefore service reservoirs and trunk main measurements can usually be given a lower priority.

6.26 Priorities for adopting the procedure throughout the various areas or distribution systems within an undertaking can be determined by quantifying both the leakage levels and the unit costs of leakage and making a first assessment of the likely overall savings for each area or system.

System capabilities

6.27 Because accurate measurements of leakage levels are fundamental not only to the assessment of a leakage control policy but to many other subjects, eg charging policy, system management, and demand forecasting, it is highly desirable that it should be possible, in all supply and distribution systems, to:

- (a) Measure minimum night rates of flow either separately by districts or in total within each distribution system.
- (b) Measure directly the leakage from all trunk mains. This may or may not involve isolation of the main (see Part 3).

- (c) Measure directly the leakage from all service reservoirs. Again this may not involve complete isolation of the whole reservoir (see Part 3).

6.28 These requirements have implications upon the design of new water supply schemes. It is recommended that all new works should possess the following facilities to enable these basic measurements to be performed.

- (a) New trunk mains should incorporate tappings and chambers suitable for insertion meters of the types mentioned in Part 3.
- (b) New service reservoirs should possess stilling tubes and access chambers, ideally for each compartment. Additionally, a bypass may be required together with provision for checking the water-tightness of isolating valves.
- (c) Metering points for either district or waste meters should be incorporated, as appropriate in distribution system extensions, and whenever other opportunity is afforded when making distribution system improvements.

Monitoring and reviewing leakage control policy

6.29 Once an appropriate leakage control method has been implemented, it will be necessary to monitor or re-calculate at regular intervals,

- (a) The cost of operating the method
- (b) The leakage within each part of the system
- (c) The unit cost of leakage (if significant changes occur to the system or to the capital programme)

6.30 It will also be necessary to record the costs incurred in implementing the method in order to improve subsequent applications of the recommended procedure.

6.31 Reiteration of the calculations detailed in 5.19 will reveal whether the expected savings are being achieved. This feedback is an essential part of the procedure so that early results can be used to improve the accuracy of future applications of the recommended procedure. In addition, if significant changes do occur within the system, the information is available to enable a review of the current leakage control policy to be made more easily.

APPENDIX A

GLOSSARY OF TERMS

area: a part or subdivision of a supply and distribution system of unspecified size or characteristic.

communication pipe: that part of a service pipe which runs from a main to, and including, a stopcock at or as close as is reasonably practicable to the boundary of the street in which the main is laid.

consumer: a person supplied, or about to be supplied, with water by a water supply undertaking.

consumption: a volume of water taken from a water supply main into a consumer's installation.

demand: the volume of water which has to be put into a supply and distribution system to satisfy the requirements of consumers plus leakage and other waste which may be incurred in the process.

distribution main: a pipe laid by the water supply undertaking for the purpose of giving a general supply of water, as distinct from a supply to individual consumers, and including any apparatus used in connection with such a pipe.

district: an area of a supply and distribution system (but usually of a distribution system) which is or can be specifically defined, eg by the closure of valves, and in which the quantities of water entering and leaving the area are metered.

district meter: see meter – district.

inspection: physical investigation to locate leaks by sounding and metering methods eg step tests.

leak detection: the process of detecting and locating leaks.

leakage: that part of waste which leaks or escapes or is lost other than by a deliberate or controllable action.

meter – combination: a meter installation consisting of two or more devices, usually of different types used preferentially such that the best characteristic of each device is used at that flow range at which it is most accurate.

meter – district: a device for measuring the quantity of water passing into or leaving a district.

meter – source: a device for measuring the quantity of water entering a supply and distribution system from source works.

meter – waste: a device capable of measuring and recording the range of rates of flow passing into a waste district overnight.

metered consumption: quantity of water registered on consumers' meters.

Note: this quantity will include waste and/or leakage occurring on the consumers' premises and meter error.

minimum night flow: the minimum rate of supply of water into any area during the night.

net night flow: the difference between minimum night flow and metered consumption.

night line: see minimum night flow.

pipe locator: portable electrical or electronic instrument specifically designed for use in the field to assist in locating buried pipes.

pressure control: the reduction of hydraulic pressure to, or the maintenance of pressure at, a predetermined desired range of pressures within defined zones.

property: building premises or structure occupied by a consumer as separately identified for billing purposes.

section: a subdivision or 'step' in a waste district.

service pipe: so much of any pipe for supplying water from a main to any premises as is subject to water pressure from that main, or would be so subject but for the closing of some tap.

service reservoir: a water-retaining structure hydraulically linked into a supply and distribution system to provide storage capacity to meet diurnal variations in demand and to provide reserve supplies of water for emergency purposes.

sounding – direct: a method of searching for leaks in which trained inspectors listen with a stethoscope or electronic leak detector applied directly on to a main, valve or stopcock for the characteristic noise of escaping water. It may be carried out at night when both ambient noise and consumption are at a minimum.

sounding – indirect: a method of searching for leaks, similar to direct sounding but with the stethoscope or electronic leak detector in contact with the ground surface. The method is dependent upon sound being transmitted through soils, backfill, road material etc.

sounding – stop tap, stop cock: see sounding – direct. Particularly used to detect leakage from a consumer's installations.

sounding – surface: see sounding – indirect.

sounding – valve and hydrant: a form of direct sounding applied initially to the undertaking's valves and hydrants.

step tests: a method of enhancing the effectiveness of waste metering whereby successive valve closures are made to reduce the size of the waste district temporarily whilst simultaneous measures of rate of flow are being made.

supply: amount of water made available to satisfy demand.

supply and distribution system: an arrangement of apparatus, installations and works operated by a water supply undertaking between the point of abstraction from a source and a consumer's installation.

supply pipe: so much of any service pipe as is not a communication pipe.

system: an arrangement of apparatus, installations and works operated by the water supply undertaking.

trunk main: a main with few branches constructed for conveying relatively large volumes of water.

undertaking: see water supply undertaking.

unmetered consumption: volume of water taken by consumers other than through metered connections.

valve inspections: see step tests.

waste: that water which, having been obtained from a source and put into a water supply and distribution system and consumers' installations, leaks or is allowed to escape or is taken therefrom for no useful purpose.

waste district: a qualified form of district, the inflow to which is or is capable of being measured through a waste meter and in which tests can be carried out such that leakage can be traced to relatively small sections.

waste inspector: an employee or other person skilled in the practical work involved in identifying causes of waste and, in particular, locating leakage.

waste meter: see meter — waste.

water unaccounted for: that water which is the difference between the total put into a supply and distribution system and the water accounted for.

water supply undertaking: a statutory organisation with the responsibility of providing a public water supply.

zone: an area of a supply and distribution system which is or can be specifically defined by the closure of valves or other physical constraint within which the hydraulic pressure of the public water supply is reduced to, maintained at or increased to a preferred limited operational range.

APPENDIX B

PROCEDURE FOR THE DETERMINATION OF THE UNIT COST OF LEAKAGE

B.01 A discussion of the theory and a summary of the procedure for the determination of the unit cost of leakage was given in Chapter 4. Further details of the procedure are set out in this appendix to enable the staff of a water undertaking to apply this procedure to their supply and distribution systems. The numbers before the headings indicate the steps as outlined in 4.12. The three case studies, which can be found in Appendix C, are examples of the application of the procedure and are similarly numbered.

1. Operating costs

Relevant sources of supply

B.02 Determine the source or sources of water where output would be reduced if demand decreased.

B.03 Relevant annual operating costs depend upon the amount of water which is actually supplied and consist of:

- (a) Pumping or boosting
- (b) Water treatment
- (c) Bulk purchase

B.04 In order to decide which of the above costs should be included in the cost of leakage it is necessary to determine at which of the present sources output would be reduced if demand were to decrease. A reduction in leakage will then cause a reduction in the annual operating costs incurred at these sources. The unit operating cost of leakage is the reduction in these costs expressed per unit reduction in demand. Whilst in some cases this reduction will be achieved at one source only, in many cases, because of various practical considerations, savings will be made at several sources. In this case the appropriate unit operating cost is the average of these individual costs suitably weighted by the proportions of the reductions in demand achieved at each source.

B.05 Because the adopted approach is long-term, immediate but short-term reductions are not relevant. For example, if an undertaking encounters difficulties in meeting demand until a new source is commissioned and is forced to purchase water at a cost much greater than its own operating cost, it does not necessarily follow that this cost should be included in the unit operating cost. Although a reduction in leakage would reduce these charges, if the purchase is short-term (less than five years) the reductions will be insignificant compared with the smaller but much more long-term savings in the undertakings own operating costs. This cost can be excluded in these circumstances.

B.06 Having determined those sources of supply where savings would be made, it is then possible to calculate the reduction in costs at each of them. The costs incurred at each source will consist of a fixed element and a variable element. The fixed element, eg labour, maintenance, maximum demand charge will, for practical purposes, be incurred independently of the

quantity of water supplied and therefore is irrelevant to the unit cost of leakage. Only the variable elements of the costs are relevant and in most cases these will be continuously variable (ie will increase as the amount of water supplied increases). Bulk purchase costs may also vary in steps (ie the cost may depend upon the amount of water previously requested rather than the amount taken).

2. Unit pumping cost

B.07 Pumping and boosting costs can be considered together as both of these costs are incurred in a similar fashion. The figure required is the reduction in costs that would be achieved if supply were decreased and therefore it is possible to exclude any pumpsets at the relevant pumping stations where output is relatively constant. As with the pumping stations it is only those pumpsets the output of which would be reduced that will affect the costs and are therefore relevant.

B.08 Having identified these pumpsets it is necessary to determine the energy which they consume and the amount of water which they pump. Whilst these may be obtained theoretically from the performance specification, it is more reliable for these quantities to be measured directly. If only a single pumpset is operating at any one time the current or power meter and the station output meter will yield these values directly. However if other sets are also operating it may be necessary to carry out a pump test. This will involve shutting down the pumpset in question and noting a reduction in the readings both of the current or power meters and of the station output flow meter.

B.09 In some pumping stations the rate of energy consumption (power) in kilowatts can be obtained directly from a power meter; however if only voltage and current meters are available the following formula can be used which will apply to most pumpsets used in the industry

$$\text{power input} = 1.73 \times \text{volts} \times \text{amperes} \times \text{power factor} \div 1,000.$$

B.10 The remaining element of the pumping costs is the cost of the energy consumed. On most tariffs this depends on both the number of units (kW hrs) of electricity used and also on the maximum rate at which it is used (usually measured as kVA). Although the maximum demand charge increases in steps it has been found that in most cases this represents a small proportion of the electricity cost so that future changes in maximum demand can be excluded. On some tariffs the unit charge may change slightly as the number of units used exceeds some limit (often linked to the maximum demand). However this variation is also too insignificant for the effect of future variations to be included. The figure required is the unit charge of the last unit of electricity being consumed and this can be obtained most simply from the previous years electricity bills together with the current tariff structure.

B.11 Where the unit charge varies either from daytime to night time and/or monthly, it will be necessary to calculate an average unit charge for energy based upon the individual unit charges and weighted, either by the relative quantities by which supply would decrease when each rate is in operation or, in the case of seasonal variations, by the proportion of the year for which each unit charge applies.

It is then possible to calculate the unit pumping cost from the formula:

$$\text{unit pumping cost} = \frac{\text{power input}}{\text{input}} \times \frac{\text{average unit charge}}{\text{charge}} \div \frac{\text{water supplied}}{\text{per hour}}$$

where: power input is in kilowatts
 average unit charge is in pence per unit
 and the water supplied is in cubic metres per hour

The unit pumping cost will then be in pence per cubic metre (p/m³).

B.12 In some undertakings pumping costs are calculated regularly. However, these are normally an average cost (periodic energy charges ÷ periodic quantity supplied). It has been found that these figures bear little relation to the unit pumping cost and consequently should not be used.

B.13 If, as current estimates predict, electricity prices grow at a rate higher than the general rate of inflation, an allowance should be made for this increase in real costs. This can be achieved by multiplying the unit pumping cost by the inflation multiplier as calculated from the formula:

$$\text{inflation multiplier} = \text{discount rate} \div \left\{ \frac{\text{discount rate} - \text{differential}}{\text{inflation rate}} \right\}$$

B.14 Where boosting takes place the unit boosting cost can be calculated by following the above procedure. However it is only applicable to that part of the system downstream of the boosters. Therefore each part of the system will have a different unit operating cost. If only a small part of the supply system receives boosted water this cost can be excluded, but if a large part of the system receives water which has been boosted, this cost is relevant as different methods of leakage control or levels of operational resources may be appropriate in these different parts of the system.

3. Unit treatment costs

B.15 Treatment costs are relatively simply obtained because the major variable cost of treating water is the cost of the chemicals. These costs will vary in direct proportion to the quantity of water supplied.

Thus the unit cost of treatment can be either calculated from the sum of the unit treatment costs for each chemical used where,

$$\text{unit treatment cost} = \text{dosage rate of chemical} \times \text{unit quantity cost of chemical}$$

or from the formula,

$$\text{unit treatment cost} = \frac{\text{annual chemical costs}}{\text{annual quantity of water supplied}}$$

Both of these formulae will require suitable manipulation of the units to obtain a figure in pence per cubic metre.

B.16 Energy costs reductions incurred purely for treatment processes will normally be negligible and need not be considered. Energy costs incurred in pumping water through or out of treatment works can be considered as for source works pumping. In many cases these costs will be subject to the same tariff structure and can therefore be considered together.

4. Unit purchase cost

B.17 Charges for bulk purchase should only be considered for inclusion in the unit operating cost if they are long term arrangements (more than five years say) and are paid by one undertaking to another. Internal accounting arrangements do not affect the overall costs incurred whereas undertakings paying these charges externally may have reduced operating and capital costs because of the arrangement.

B.18 At their simplest these charges will be completely variable and will depend directly upon the quantity of water involved. However in some cases there may be a fixed element which depends upon the amount which is previously requested or licensed rather than the amount which is actually taken. If this fixed cost increases annually as more water is requested the variable cost should be increased by this annual cost expressed as a rate as shown below:

$$\text{unit purchase cost} = \text{unit charge} + \left\{ \frac{\text{Annual fixed charge}}{\text{Annual quantity purchased}} \right\}$$

B.19 Usually these costs are much greater than equivalent pumping and treatment costs and for this reason they will be short-term arrangements in most cases and therefore irrelevant. For long-term arrangements the unit cost of leakage may not necessarily be high as the associated capital programme will reflect the availability of this source of supply.

5. Unit operating cost

B.20 The unit operating costs for each of the sources of supply whose output would be reduced can then be obtained by adding together the appropriate unit pumping, treatment and/or purchase costs as previously calculated.

B.21 The unit operating cost of the whole system is the average of these individual unit operating costs, weighted according to the likely magnitudes of the reductions in supply at each source. In situations where one reduction is fixed in size, eg termination of the bulk purchase of water, variation of the total reduction in supply will alter the weightings of the various unit operating costs. Therefore the reduction in supply should be reasonably typical of the likely reduction in leakage obtained by reference to Table 1.

Local authority rates and abstractions charges

B.22 Although these costs may change as the quantities of water supplied change they should be excluded from this economic analysis because, among other things, the benefit to the community as a whole is unlikely to change. If a financial appraisal is being undertaken their inclusion can be considered.

Capital costs

B.23 The calculation of the unit capital cost element of the unit cost of leakage is more complicated. However reference to the case studies in Appendix C will show it is considerably more difficult and lengthy to explain than to actually perform the necessary calculations. The method involves setting out the costs of those capital schemes which will be incurred in satisfying future demands and incorporating corrections to allow for future schemes beyond the current planning horizon. These costs are then discounted and summed to produce a total discounted capital cost of supplying future demand. The change in this figure brought about by a reduction in supply of one year's growth, when expressed in terms of the magnitude of this change in supply, is the required unit capital cost component of the unit cost of leakage.

6. Relevant future capital costs

B.24 The first stage is to extract from the five year plan those capital costs which are relevant. These are the costs of those schemes which would be affected by changes in the demand trend and in general will be:

- (a) Source works
- (b) Treatment works
- (c) Pumping stations
- (d) Service reservoirs
- (e) Trunk mains
- (f) Distribution mains reinforcements.

B.25 As an aid to the calculation of the unit capital cost a table has been prepared (Figure B1) and these schemes and the appropriate expenditure planned should be inserted in the upper part of the appropriate spaces. (Columns (ii) to (xi)). Although this table commences at year 0 this will normally be the following financial year.

B.26 Obviously, some schemes of the above types will not be capable of being deferred: for example the purpose of the scheme may not be to extend capacity but perhaps to modernise facilities or renew existing works or mains. In cases such as these, the schemes should not be included in the table.

B.27 Furthermore, some costs in the five year plan may not be for particular schemes but may be recurring capital annual costs for general distribution improvements. If any proportion of this annual cost is used for work which could be deferred as a result of a decrease in demand, it should be entered in the table, but in the first year only.

B.28 It is important that the schemes listed in Figure B1 include all of the relevant types of scheme. For example, if capacity is such that no new source work is required within the five year plan, the unit cost of leakage will be underestimated by this component and consequently, an inappropriate method of control may be chosen.

B.29 Thus if the first new source works will not be required until year 12 this should be entered in the table in one of the spaces beneath year 4 and the appropriate discount factor $1 \div (1 + r)^{12}$ inserted in column (xiii).

B.30 On the other hand, if current capacity is such that no works of a particular type will be required for the next 20 years, the contribution to the unit capital cost will be small and can therefore be excluded.

7. Fixed annual operating cost

B.31 Whilst for existing schemes the relevant operating costs need only consist of the variable element, this is not true for future schemes. As new schemes are deferred, the fixed operating costs, ie labour, maintenance etc, will also be deferred. Therefore an estimate of this quantity should be included in the capital cost of the scheme. This will only apply to source and treatment works and if estimates of fixed costs have not been made these can be estimated from the annual costs of existing similar works less the variable elements ie power (strictly the unit costs) and chemicals. This annual cost should be entered in the year of commissioning of the appropriate schemes and converted to a total cost by multiplying by 21. For discount rates other than 5 per cent this factor should be changed to $(1 + r) \div r$.

8. Demand multipliers for each scheme

B.32 Whilst many of the schemes listed in the table will be capable of being deferred in their entirety, some schemes may not. Part of the scheme may be for the modernisation or replacement of existing works and in this situation only a proportion of the appropriate cost of the scheme should be included. This process is facilitated by the inclusion at the bottom of the table of a factor termed the demand multiplier. This multiplier which lies within the range 0–1 represents the proportion of the cost of each of the schemes which is related to increases in demand. Thus for an extension to a treatment works of which only half of the cost contributes to an increase in the maximum throughput, the demand multiplier will be 0.5 and for a trunk main which is replacing one the capacity of which is only 75 per cent of the new one the multiplier will be 0.25. In most cases however the multiplier will be 1.

9. Capacity multipliers for each scheme

B.33 Although the costs in the table include for all of the relevant types of scheme, it is possible that the future capital schemes to further extend capacity may radically change the unit cost of leakage and perhaps imply a change in the type of leakage control. Whilst it may be possible to vary the operational resources applied to leakage control it is obviously impractical to vary the method adopted every few years. Therefore costs incurred beyond the five year plan must also be included.

B.34 The simplest way of including these costs without recourse to a complete long-term plan is to increase the costs included in the table to allow for all future costs. Thus if a new source is constructed in year 5 which will satisfy demand for twelve years, the cost of this source is increased by an appropriate multiplier which takes into account the likely cost of the next source which will be required in year 17. This procedure can be simplified by the use of the graph in Figure B2 which relates the desired multiplier, termed here the capacity multiplier, to the interval between the construction of a particular scheme and the point in time at which a further scheme of the same type will be required. This can be calculated from the capacity or yield of the scheme and the annual increase in the peak week's demand. It should be noted that this approach does not assume that similar works of the same size will actually be constructed at that date but that the cost of the listed scheme per unit of capacity is reasonably typical of future schemes. If there are several schemes of the same type eg source works, within the capital programme, the capacity multiplier for each of these should be the same and based upon the sum of their individual capacities.

B.35 The capacity multiplier for annual recurring capital costs inserted in the first year is 21 for a 5 per cent discount rate, or $(1 + r) \div r$ for other discount rates.

10, 11, 12 . Total discounted capital cost

B.36 The next stage is to calculate the modified cost of each of the capital schemes by multiplying together the actual capital cost by the demand and capacity multipliers. These values

should be entered into the lower half of the prepared spaces beneath the actual capital costs. Summing the values for each year produces the total modified cost incurred in that year which can be entered in column (xii) and multiplying each by the appropriate discount factor (shown in column (xiii) for 5 per cent) produces the discounted value of these costs to be entered in column (xiv). The sum of these costs is the total discounted capital cost, (TDCC), which represents the present value of all future capital costs needed to satisfy increasing demand.

13. Unit capital cost

B.37 In order to convert the total discounted capital cost into the unit capital cost it is necessary to calculate the change brought about in this total by a unit change in supply.

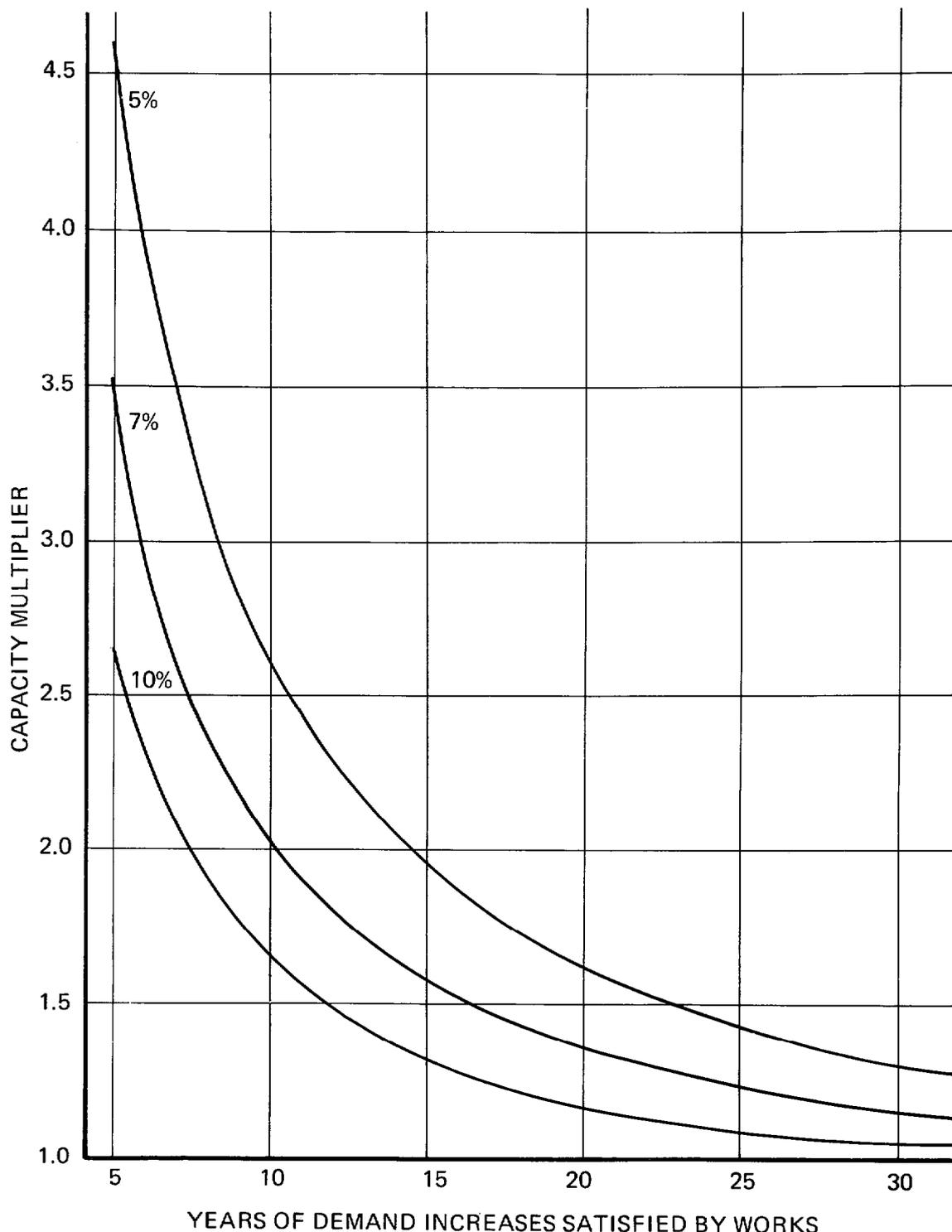


Fig. B2. Capacity multipliers for various discount rates

This conversion is simplified by the use of the formula:

$$\text{unit capital cost} = (\text{TDCC} \times r^2) \div [(1 + r) \times 3.65 \times d]$$

Where r is the discount rate

and d is the annual change in demand (m^3/day)

A brief derivation of the formula is given below.

Using the notation above, if supply were to be reduced by one year's growth (d), all capital schemes would be deferred by one year.

Therefore:

$$\text{Total discounted capital cost} = \text{TDCC} \div (1 + r)$$

Thus:

$$\begin{aligned} \text{Change in total discounted} &= \text{TDCC} - [\text{TDCC} \div (1 + r)] \\ \text{capital cost} &= \text{TDCC} \times [r \div (1 + r)] \end{aligned}$$

Expressing this change as an annual figure commencing in year 1 as does the reduction in supply d ;

$$\begin{aligned} \text{Annual change in costs} &= \text{TDCC} \times [r^2 \div (1 + r)] \\ (\text{£/year}) & \end{aligned}$$

Further:

$$\text{Annual change in water supplied} = 365 \times d \text{ m}^3/\text{year}$$

Therefore, dividing and converting to pence/cubic metre:

$$\text{Unit capital cost} = (\text{TDCC} \times r^2) \div [(1 + r) \times 3.65 \times d]$$

14. The unit cost of leakage

Unit cost of leakage = unit operating cost + unit capital cost.

B.38 This figure is the cost saving achieved by the undertaking for every cubic metre by which average leakage levels are reduced. This will be the case for even relatively small reductions in leakage. Although a reduction in supply of three months growth may not defer any of the schemes already planned, because costs are included for many years into the future, on average, approximately a quarter of these costs would be deferred for one year. It is therefore not essential to achieve reductions in supply of more than one year's growth before capital cost savings can be included.

APPENDIX C

CASE STUDIES OF THE DETERMINATION OF THE UNIT COST OF LEAKAGE

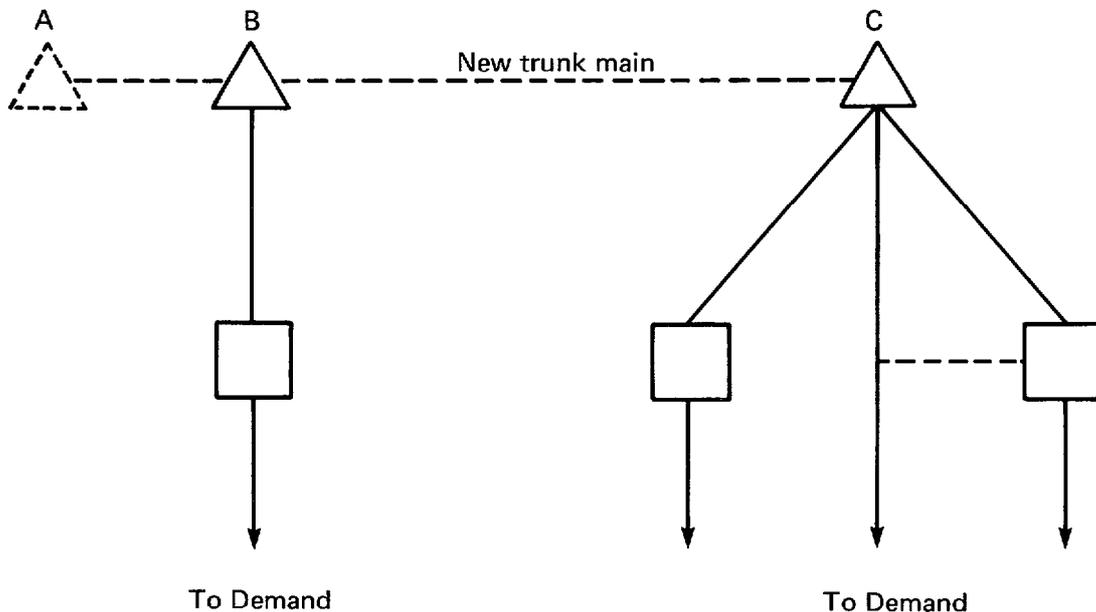
C.01 This appendix consists of three case studies which have been performed in three very different systems. They demonstrate the majority of the points discussed in Chapter 4 and Appendix B and can therefore be used as examples.

Case study 1

Background details

C.02 A diagrammatic sketch of the simplified supply system is shown in Figure C1.

Existing sources of supply are at B and C. Source A is currently under construction together with associated trunk mains. The population supplied by the system is 103,000 which increases by 20,000 during the summer. Current average supply is 29 MI/day rising by 1.9 per cent per year ie 551 cubic metres per day per year.



Key: (Figs. C1, C3, C5)

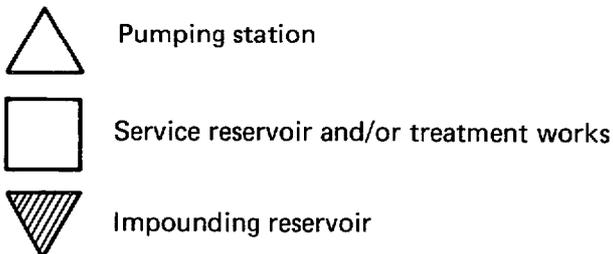


Fig. C1. Schematic of supply system

Calculation of unit operating cost

C.03 1. Source B is currently utilised to meet increases in demand. Source C is operated continuously and Source A is not yet operational.

C.04 2. The relevant pumpsets at Source B are a submersible pump and a relift pump. These pumpsets draw 530 amps at 415 volts with a power factor of 0.85 and the water output is 540 m³/hr.

$$\begin{aligned} \text{Power input} &= 1.73 \times 415 \times 530 \times 0.85 \div 1000 \\ &= 330 \text{ kW} \end{aligned}$$

From the last year's electricity bills the cost of electricity is 1.619 pence per unit, therefore:

$$\begin{aligned} \text{Unit pumping cost} &= 330 \times 1.619 \div 540 \\ &= 0.99 \text{ p/m}^3 \end{aligned}$$

Energy costs are expected to grow at about 2 per cent per year in real terms.

$$\begin{aligned} \text{Thus inflation multiplier} &= 5 \div (5 - 2) \\ &= 1.67 \end{aligned}$$

$$\begin{aligned} \text{Inflated unit pumping cost} &= 0.99 \times 1.67 \\ &= 1.65 \text{ p/m}^3 \end{aligned}$$

C.05 **3.** Treatment consists solely of chlorination. Chlorine at £320 a tonne is used at a rate of 154 grams per hour for a throughput of 540 cubic metres per hour.

$$\begin{aligned} \text{The dosage rate} &= 154 \div 540 \text{ grams/m}^3 \\ \text{The chemical cost} &= 32 \text{ p/kg} \\ \text{Unit treatment cost} &= 2.85 \times 10^{-4} \times 32 \\ &= 0.009 \text{ p/m}^3 \end{aligned}$$

This is negligible and is ignored.

C.06 **4.** No water is purchased

C.07 **5.** Unit operating cost = 1.65 p/m³

Calculation of the unit capital cost.

C.08 **6.** The relevant capital costs are entered in the upper part of the spaces in Figure C2.

C.09 No source works or trunk mains are planned as current works are nearing completion. The yield of this scheme is 9 MI/day and the annual growth of demand is 1.9 per cent. The supply in the peak week is 37 MI/day. Therefore further source works will be required in

$$9 \div (37 \times 0.019) = 12.8 \text{ say } 13 \text{ years.}$$

The cost of source and trunk mains are therefore entered in year 12 as an approximation of source works costs. No service reservoirs are included as network analysis has shown that present capacity is satisfactory for the medium term.

C.10 **7.** Fixed annual operating costs of the source are considered to be around £5,000 per year based on existing labour and maintenance costs at Source B. There is no maximum demand charge. This cost is entered in year 13.

C.11 **8.** Half the capacity of the treatment works extension scheme in column (iv) of Figure C2 is to replace an existing works and only seventy per cent of the mains strengthening scheme in column (v) is required to meet increasing demand. Therefore the demand multipliers for these schemes are 0.5 and 0.7 respectively. The remaining schemes would be fully affected by a change in supply and consequently demand multipliers of 1.0 are inserted in Figure C2.

C.12 **9.** As calculated in 6 the source works have the capacity to satisfy 13 years demand. From Figure B2 the capacity multiplier is 2.15. The treatment works extension will increase treatment capacity by 9 MI/day. Further extension will be required in

$$9 \div (37 \times 0.019) = 12.8 \text{ say } 13 \text{ years}$$

The capacity multiplier is therefore 2.15.

YEAR	COSTS OF CAPITAL WORKS (x £1000)										TOTAL MODIFIED CAPITAL COST (x £1000)	DISCOUNT FACTOR (5%)	DISCOUNTED CAPITAL COST (x £1000)	
	i	ii	iii	iv	v	vi	vii	viii	ix	x				xi
0	178	82	156	6								500	1.00	500
1	74	338	63	6								204	0.95	194
2	106	141	96	79	128							414	0.9	377
3		201	98	6	130							136	0.86	117
4			178	6	191							191	0.82	157
12						500	370					1871	0.56	1048
13						1075	796					226	0.53	120
						5x21	226							
DEMAND MULTIPLIER	1.0	1.0	0.7	1.0	2.15	1.0	1.0					TOTAL	£	2,513,000
CAPACITY MULTIPLIER	1.9	1.9	1.9	2.15	1.9	2.15	2.15							

Fig. C2. Capital costs

The mains strengthening and other extensions are planned to satisfy demand increases for 15 years. The capacity multiplier is thus 1.9.

C.13 10, 11, 12. The modified capital costs are shown below the capital costs in Figure C2. The total modified costs for each year are set out in column (xii) and the discounted capital cost in column (xiv). The total discounted capital cost (TDCC) is £2,513,000.

C.14 13. The unit capital cost is given by:

$$\begin{aligned} \text{Unit capital cost} &= 2513000 \times 0.05^2 \div (1.05 \times 3.65 \times 551) \\ &= 2.98 \text{ p/m}^3 \end{aligned}$$

Calculation of unit cost of leakage

C.15 14. Unit cost of leakage = 1.65 + 2.98
= 4.6 p/m³

Case study 2

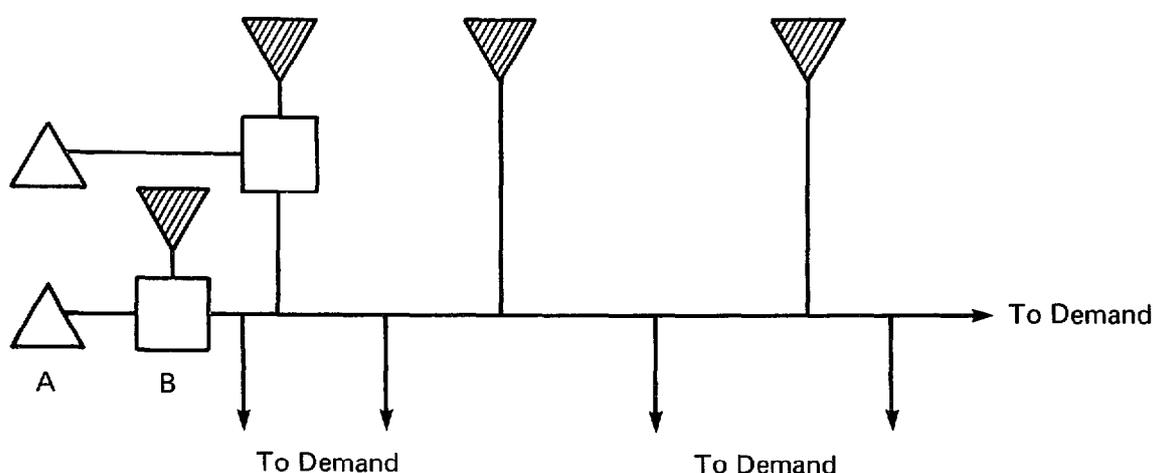


Fig. C3. Schematic of supply system

Background details

C.16 A diagrammatic sketch of the simplified supply system is shown in Figure C3.

The population supplied by the system is 648,000 and the current average supply of 100 MI/day is increasing by 4820 m³/day/year. The supply in the peak week is 25 per cent higher.

Calculation of the unit operating cost

C.17 1. All sources other than Source A are used to supply base demand. Source A is utilised to meet demand changes.

C.18 2. Two pumpsets are normally used at Source A which require 5,600 kW and deliver 10,000 m³/hr.

The cost of electricity depends upon the following tariffs and pumping practices.

December, January and February:	Night pumping only	0.840 p/unit
October, November and March:	Night pumping and 8 hours daytime pumping	1.545 p/unit
April to September:	Night pumping and 16 hours daytime pumping	1.428 p/unit

The average unit cost is the average of these rates, weighted by the operative period of each rate.

$$\begin{aligned} \text{Average unit cost of electricity} &= (0.840 \times 0.25) + (1.545 \times 0.25) + (1.428 \times 0.5) \\ &= 1.31 \text{ p/unit} \end{aligned}$$

$$\begin{aligned} \text{The unit pumping cost equals } 5,600 \times 1.31 \div 10,000 \\ &= 0.73 \text{ p/m}^3 \end{aligned}$$

Energy costs are expected to grow at 2 per cent a year in real terms.

Thus the inflation multiplier

$$\begin{aligned} &= 5 \div (5-2) \\ &= 1.67 \end{aligned}$$

Inflated unit pumping cost

$$\begin{aligned} &= 0.73 \times 1.67 \\ &= 1.22 \text{ p/m}^3 \end{aligned}$$

C.19 3. Throughput of the treatment works B in 1978 was 40,798 MI and the annual cost of materials and power was £104,000.

$$\begin{aligned} \text{Unit treatment cost} &= (104,000 \times 100) \div (40,798 \times 1,000) \\ &= 0.25 \text{ p/m}^3 \end{aligned}$$

C.20 4. No water is purchased.

$$\begin{aligned} \text{C.21 5. Unit operating cost} &= 1.22 + 0.25 \\ &= 1.47 \text{ p/m}^3 \end{aligned}$$

Calculation of the unit capital cost

C.22 6. There is a continuing capital programme consisting of mains extensions and reinforcements, service reservoirs and booster pumps over the foreseeable future of about £900,000 a year at current prices. No source works are contemplated until 1995 (year 16) when additional capacity of 93 MI/day will be required at treatment works B. The estimated construction cost of these works in 1972 was £3.4m for 230 MI/day or £14,800 per MI/day. The cost of the extension of 93 MI/day is estimated to be £1.4m which at 1979 costs corresponds to £4.2m (plus 200 per cent).

C.23 These costs are inserted in the upper part of the spaces in Figure C4.

C.24 7. Fixed annual operating costs are negligible compared with the annual capital programme costs.

C.25 8. All schemes would be affected fully by changes in demand. The demand multipliers are 1.0 and are inserted in Figure C4.

C.26 9. The capacity multiplier for the annual capital cost is 21.

The treatment works extension will satisfy the annual increase in demand in the peak week for,

$$93 \div (4.82 \times 1.25) = 15.4 \text{ years}$$

where 1.25 is the ratio of peak week supply to average supply.

The capacity multiplier is thus 1.90 (from Figure B2).

C.28 13. The unit capital cost

$$= 22,571,000 \times 0.05^2 \div (1.05 \times 3.65 \times 4,820)$$

$$= 3.05 \text{ p/m}^3$$

Calculation of unit cost of leakage

C.29 14. Unit cost of leakage = 1.47 + 3.05

$$= 4.5 \text{ p/m}^3$$

Note: If the capital programme is not firm, then the possible variations in the programme should be examined to determine if they affect the subsequent calculations to find the most economic leakage control method.

Case study 3

Background details

C.30 A diagrammatic sketch of the simplified supply system is shown below in Figure C5.

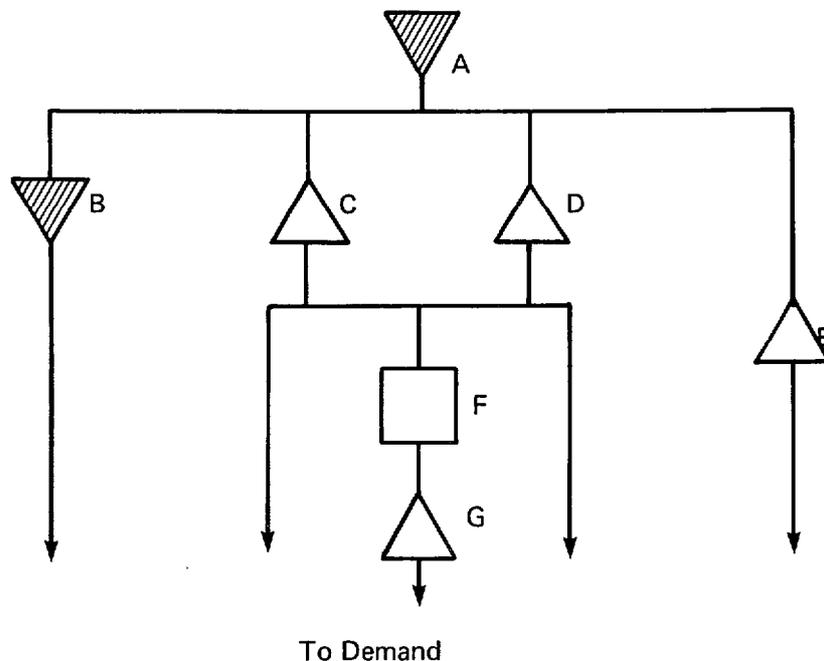


Fig. C5. Schematic of supply system

Existing sources of supply are B, C, D and E. A new source at A, currently under construction, will supply the whole system via the existing sources. Water from service reservoir F is boosted at G. The current supply is 271 MI/day which is predicted to increase at 4.8 MI/day/year. In addition industrial use will cause an increase in demand of a further 16 MI/day in 1982.

Calculation of the unit operating cost

C.31 1. Source B is operated at maximum capacity and sources C, D and E are utilised to meet changing demand. Source A will become operational within the next few years.

C.32 2. The pumping costs at source A are estimated to be:

April to October	1.38 p/m ³
November and March	1.46 p/m ³
December to February	1.67 p/m ³

Thus unit pumping cost at A = (7/12 × 1.38) + (1/6 × 1.46) + (1/4 × 1.67)

$$= 1.47 \text{ p/m}^3$$

At all remaining sources the cost of the last unit of electricity used is 1.6 pence per unit.

At source C the relevant pumpsets are:—

Two variable speed pumps which require 1212 kW to produce 6,000 m³/hr

One fixed speed pump producing 1666 m³/hr at 3,300V, 99A and a power factor of 0.8.

$$\begin{aligned}\text{Power input} &= 1.73 \times 3,300 \times 99 \times 0.8 \div 1,000 \\ &= 452 \text{ kW}\end{aligned}$$

The unit pumping cost at C

$$\begin{aligned}&= (1212 \times 1.6 \div 6,000) + (452 \times 1.6 \div 1666) \\ &= 0.76 \text{ p/m}^3\end{aligned}$$

At source D the relevant pumps are:

Two variable speed pumps as at source C.

Two variable speed pumps which require 810 kW to produce 4,375 m³/hr.

The unit pumping cost at D

$$\begin{aligned}&= (1212 \times 1.6 \div 6,000) + (810 \times 1.6 \div 4,375) \\ &= 0.62 \text{ p/m}^3\end{aligned}$$

At source E the relevant pumps are:

Two 57 hp pumps which together produce a total of 10,000 m³/hr.

Assuming 85 per cent efficiency

$$\begin{aligned}\text{Power input} &= 2 \times 57 \times 0.75 \div 0.85 \\ &= 100 \text{ kW}\end{aligned}$$

Two variable speed pumps each with a power rating of 110 hp and an output of 790 m³/hr.

Assuming 85 per cent efficiency:

$$\begin{aligned}\text{Power input} &= 110 \times 0.75 \div 0.85 \\ &= 47 \text{ kW}\end{aligned}$$

Two 69.5 hp pumps each with an output of 317 m³/hr.

$$\begin{aligned}\text{Power input} &= 69.5 \times 0.75 \div 0.85 \\ &= 61 \text{ kW}.\end{aligned}$$

The unit pumping cost at E

$$\begin{aligned}&= (100 \times 1.6 \div 1,000) + (97 \times 1.6 \div 790) + (61 \times 1.6 \div 317) \\ &= 0.66 \text{ p/m}^3\end{aligned}$$

At booster station G the pumps produce 2,125 m³/hr and draw a current of 600A at 415 V and a power factor of 0.8.

$$\begin{aligned}\text{Power input} &= 600 \times 415 \times 1.73 \times 0.8 \div 1,000 \\ &= 345 \text{ kW}.\end{aligned}$$

The unit pumping cost at G

$$\begin{aligned}&= 345 \times 1.6 \div 2125 \\ &= 0.26 \text{ p/m}^3\end{aligned}$$

Energy costs are expected to grow at 2 per cent per year in real terms and thus

$$\begin{aligned}\text{inflation multiplier} &= 5 \div (5-2) \\ &= 1.67\end{aligned}$$

The inflated unit pumping costs at A, C, D, E and G are 2.45, 1.27, 1.04, 1.10 and 0.43 p/m³ respectively.

C.33 3. Treatment costs at the sources are:

Source	Chemicals (£/year)	Throughput (MI/year)	Unit Cost (p/m ³)
C	97,407	16,425	0.59
D	146,454	30,295	0.48
E	51,515	8,702	0.59
F	9,652	36,696	0.03

C.34 4. No water is purchased.

C.35 5. The unit operating cost is calculated from an average of the individual source costs, weighted according to the proportion of the total supply pumped at each station. This assumes that reduction in leakage would affect the whole system uniformly. Source A costs are incurred at all sources and boosting costs at G, being relatively small, are also apportioned across the whole system.

Source	Unit pumping costs (p/m ³)	Unit treatment costs (p/m ³)	Unit operating costs (p/m ³)	Average daily supply (MI/d)	Weighting factor
A	2.45	0	2.45	45	1.00
C	1.27	0.59	1.86	45	45/152
D	1.04	0.48	1.52	88	83/152
E	1.10	0.59	1.69	24	24/152
G	0.43	0.03	0.46	100	100/152

Note: the total supply of the sources, C, D and E is 152 MI/day.

$$\begin{aligned} \text{unit operating cost} &= 2.45 + (1.86 \times 45 \div 152) + (1.52 \times 83 \div 152) \\ &\quad + (1.69 \times 24 \div 152) + (0.46 \times 100 \div 152) \\ &= 4.40 \text{ p/m}^3 \end{aligned}$$

Calculation of the unit capital cost

C.36 6. The capital costs are entered in the upper part of the appropriate spaces in Figures C6a and C6b. The capital cost of source A has been excluded as no part of the scheme can now be affected. No new source works are included as scheme A will satisfy demand increases for the foreseeable future.

C.37 7. Fixed annual operating costs are shown where relevant and are estimated from similar existing works.

C.38 8. Demand multipliers are inserted for each scheme.

C.39 9. The treatment works extensions and new pumps (C6a (iii), (x), C6b (iv)) will provide an additional capacity of 68 MI/d which will satisfy demand increases for approximately

$$(68 - 16) \div (4.8 \times 1.2) = 9 \text{ years.}$$

where 1.2 is the peak week factor.

The capacity multiplier is 2.8 from Figure B2.

The booster station and trunk main (C6a (iv) and (xi)) are expected to satisfy demand increases for 20 years and the capacity multiplier is 1.6.

The remaining schemes are designed to satisfy demand for 15 years and the multiplier is thus 1.9.

C.40 10, 11, 12. The modified capital costs are shown below their corresponding capital costs in Figures C6a and C6b. The sum of the modified costs from Figure C6a are carried forward in column (ii) of Figure C6b and the total modified costs are set out in column (xii). The discounted capital costs in column (xiv) are summed to produce a total discounted capital cost (TDCC) of £9,162,000.

C.41 13. The unit capital cost = $9,162,000 \times 0.05^2 \div 1.05 \times 3.65 \times 4,800$
= 1.24 p/m³

Note: This figure is relatively low, reflecting the long term capacity of source A. It is compensated by increased operating costs.

Calculation of unit cost of leakage

C.42 14. Unit cost of leakage = $4.40 + 1.24$
= 5.6 p/m³

APPENDIX D

PROCEDURE FOR THE CALCULATION OF THE COSTS OF LEAKAGE CONTROL

Costs of components of leakage control methods

D.01 In this Appendix an example is given of the procedure for calculating the total costs of each of the methods of leakage control from their component costs. Although realistic component costs should be used in applying the recommended procedure, average costs are used in this example. These have been given in Table 2 and are repeated here as Table D1 for ease of reference:

Table D1 Costs of components of leakage control methods

<i>Operation</i>	<i>Cost</i>	<i>Details</i>
Install a waste or district meter and set up district	£1,650	Capital for installation £1,400: £250 for planning and checking district
Record mnf	£36	8 man hours including 3 at overtime rates
Perform a step test	£85	13 man hours at overtime rates
Sound 1,000 houses	£150	20 properties per hour
Read 100 district meters	£80	1 man and van reads 40/day
Repair backlog of leaks (per 1,000 properties)	£300	
Locate reported leaks with passive leakage control (per 1,000 properties)	£60	<i>Source: The results of the experimental programme on leakage and leakage control</i>

D.02 The following additional information from the experimental programme is also required:

Typical proportion of 2,000 property district requiring sounding following a step test 65 per cent

Note: These costs are based on labour rates of £2.5 per hour, overtime at double the normal rate and £1 per hour for the use of a van, if appropriate. Overheads are not and should not be included because these reflect fixed costs that would not be affected by a change in leakage control method. Supervision costs are assumed to add a further 20 per cent to labour rates. More appropriate local figures should be used if available.

D.03 Tables D2 and D3 indicate the composition of the initial and annual costs respectively of each of the methods of leakage control.

Table D2. Initial costs of different methods of leakage control

<i>Leakage control method</i>	<i>Activity</i>	<i>Refer to note</i>	<i>Cost</i> £	<i>Average cost per property</i> £
Passive (1,000 properties)	None	—	NIL	NIL
Regular sounding (1,000 properties)	Inspect properties	—	150	0.45
	Repair backlog of leaks	—	<u>300</u>	
			450	
District metering (3,000 properties)		(ii)		1.00
	Install meter		1,650	
	Read meter		1	
	Inspect district		450	
	Repair backlog of leaks		900	
	Read meter	(iii)	<u>1</u>	
			3,002	
Waste metering (2000 properties)		(v)		1.35
	Install meter	(vi)	1,650	
	Record mnf		36	
	Perform step test		85	
	Sound whole district	(vii)	300	
	Repair backlog of leaks		600	
	Record mnf	(iii)	<u>36</u>	
			2,707	
Combined district and waste metering (4,000 properties in 2 waste meter districts)	Install meters	(x)	3,800	1.48
	Read district meter		1	
	Record mnf's		72	
	Perform step tests		170	
	Sound whole district	(vii)	600	
	Repair backlog of leaks		1,200	
	Record mnf's	(iii)	72	
	Read district meter	(iii)	<u>1</u>	
			5,916	

Table D3. Annual costs of different methods of leakage control

<i>Leakage control method</i>	<i>Activity</i>	<i>Refer to note</i>	<i>Cost £</i>	<i>Average cost per property £</i>
Passive (1,000 properties)	Locate reported leaks		60	0.06
Regular sounding (1,000 properties)	Inspect properties	(i)	150	0.15
District metering (3,000 properties)	Read meter	(ii) (iv)	42	
	Inspect district	(iv)	<u>450</u>	
			492	0.16
Waste metering (2,000 properties)	Record mnf	(v) (viii)	216	
	Perform step test	(viii)	212	
	Inspect district	(ix)	<u>488</u>	
			916	0.46
Combined district and waste metering (4,000 properties)	Read district meter	(iv)	42	
	Record mnf	(viii)	432	
	Perform step test	(viii)	425	
	Inspect district	(ix)	<u>975</u>	
			1,874	0.47

Notes on Tables D2 and D3

- (i) Proposed frequency of inspection for regular sounding is annually (Table 5).
- (ii) Typical district meter area is 3,000 properties within the recommended range of 2,000 to 5,000 properties.
- (iii) District meter should be read or mnf recorded following initial repairs in order to establish norm (Part 3, 7.45).
- (iv) Proposed frequencies for district metering are weekly and annually (Table 5).
- (v) The recommended size of waste district of 2,000 properties for urban areas is chosen for this example.
- (vi) The installation cost may be effectively reduced if one meter is arranged to monitor several districts.
- (vii) Initial inspection should be for the whole district (Part 3, 7.44).
- (viii) The proposed frequencies are six a year and 2.5 a year for districts of 2,000 properties. These are within the acceptable ranges of frequencies for all unit costs of leakage and should be used in these calculations even if it is subsequently proposed to adopt different frequencies. Increases in these costs (within the acceptable range in Table 6) will be balanced by decreases in leakage levels. For budgetary purposes and determining staffing requirements, the actual frequencies should be used. For smaller waste districts the frequencies to be used in the above calculations are 4 a year and 1.5 a year.
- (ix) These costs are at day sounding rates for 65 per cent of the steps sounded 2.5 times a year. Night sounding rates are higher but the actual cost to locate leakage may be similar as it may not be necessary to sound on every stop cock at night.
- (x) This figure consists of the cost of installing two waste meters and setting up these districts plus £500 for the district meter which could conveniently be installed with one of the waste meters.

D.04 The information contained in Tables D2 and D3 is summarised in Table D4.

Table D4. Typical annual costs per property of different methods of leakage control

<i>Method of leakage control</i>	<i>Initial cost (£/prop)</i>	<i>Annual cost (£/prop/year)</i>	<i>Total annual cost (£/prop/year)</i>
Passive leakage control	0.00	0.06	0.06
Regular sounding	0.45	0.15	0.17
District metering	1.00	0.16	0.21
Waste metering	1.35	0.46	0.53
Combined district and waste metering	1.48	0.47	0.55

The total annual cost consists of the annual cost added to the initial cost expressed as an annual amount. This annual amount is considered to commence in the year following the year of installation as significant changes in leakage levels will not normally be achieved until then. It is obtained by multiplying the initial cost by the chosen discount rate (ie 0.05 for a rate of 5 per cent).

D.05 The above costs apply to implementing the leakage control methods in an area subject to passive control. Modification is required when implementing them in an area currently subject to an active policy as the backlog of leak repairs will not occur. Also, in assessing the costs of the current policy, only the annual operating costs are relevant as the initial costs have already been incurred. This cost information is shown in Table D5 and an example derivation in D.06.

Table D5. Typical annual costs of implementing different methods of leakage control

<i>Method of leakage control</i>	<i>Implement from passive policy (£/prop/year)</i>	<i>Implement from active policy (£/prop/year)</i>	<i>Operate current policy (£/prop/year)</i>
Passive control	0.06	—	0.06
Regular sounding	0.17	—	0.15
District metering	0.21	0.19	0.16
Waste metering	0.53	0.51	0.46
Combined district and waste metering	0.55	0.53	0.47

D.06 Example – Implement waste metering in an area subject to regular sounding

	<i>Cost (£)</i>	<i>Average cost per property (£)</i>
<i>Initial cost</i>		
Waste metering (from Table D2)	2,707	
less backlog of repairs	<u>600</u>	
	2,107	1.05
<i>Annual cost</i>		
Waste metering (from Table D3)	916	0.46
Total annual cost = $(1.05 \times 0.05) + 0.46$		
= £0.51/prop/year		

APPENDIX E

EXAMPLES OF APPLYING THE RECOMMENDED PROCEDURE

E.01 The following calculations in this appendix are given simply as examples of the procedure. The costs and leakage levels used are averages; consequently the results obtained should not be taken as being generally valid.

To determine the leakage control policy where none currently exists

E.02 The stages in this example follow the steps in the recommended procedure as given in 5.04.

Measurement of existing leakage levels (net night flow).

A typical net night flow for an area with passive leakage control is 18.3 l/prop/hr.

Determination of the unit cost of leakage.

From the case studies in Appendix C, a typical figure for the unit cost of leakage is 4 p/m³.

Estimation of costs and potential savings brought about by pressure control.

An example of this is given separately in E14 to E19.

Calculation of the costs of leakage and of the leakage control methods.

The likely net night flows achieved by the introduction of each of the methods of leakage control is determined by the use of Figure 9 as described in 5.19. This is repeated below in Figure E1. The horizontal line at 18.3 l/prop/hr contacts the passive leakage control line at point A. The vertical line at this point crosses the lines for the remaining methods of control at the net night flows which can be read off the vertical scale ie the likely net night flow for waste metering is 6 l/prop/hr.

These figures are shown in column (ii) of Table E1 and their annual costs in column (iii).

The annual costs of these levels are obtained by the use of the formula:

$$\text{Annual cost of leakage} = \text{net night flow} \times 20 \times 365 \times C \div 100,000$$

where the net night flow is in litres per property per hour and C is the unit cost of leakage (4 p/m³ in this example).

The annual costs of the leakage control methods derived in Appendix D are repeated in column (iv).

Table E1. Comparison of the sum of the costs of leakage and leakage control

<i>(i)</i>	<i>(ii)</i>	<i>(iii)</i>	<i>(iv)</i>	<i>(v)</i>
<i>Method of leakage control</i>	<i>Net night flow</i>	<i>Annual cost of leakage</i>	<i>Annual cost of leakage control</i>	<i>Total annual cost of leakage and leakage control</i>
	<i>(l/prop/hr)</i>	<i>(£/prop/yr)</i>	<i>(£/prop/yr)</i>	<i>(£/prop/yr)</i>
Passive control	18.3	5.34	0.06	5.40
Regular sounding	10	2.92	0.17	3.09
District metering	8	2.34	0.21	2.55
Waste metering	6	1.75	0.53	2.28
Combined metering	6	1.75	0.55	2.30

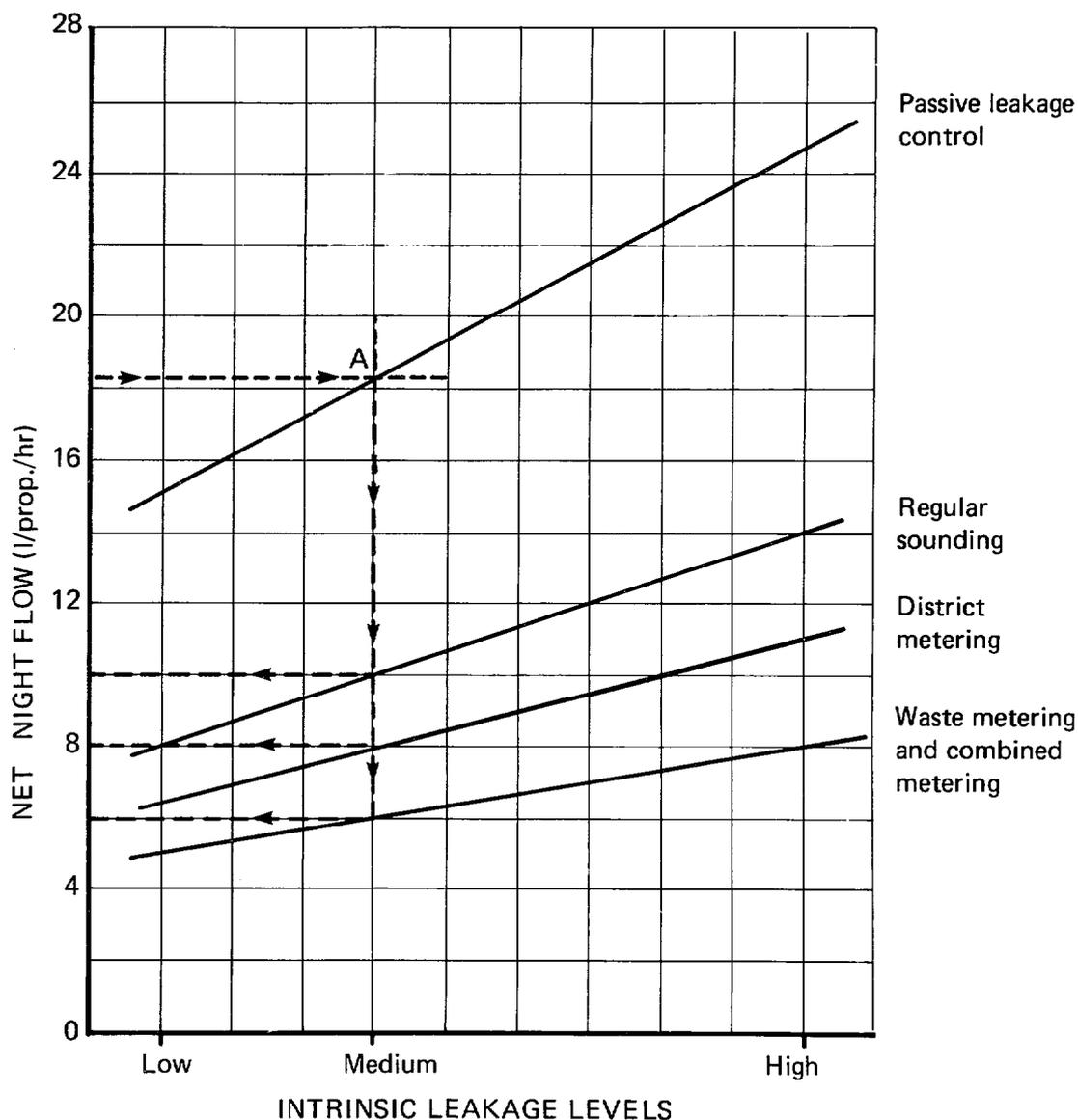


Fig. E1. Example of prediction of net night flows

Comparison of the sum of the costs of leakage and leakage control

The sum of these costs is shown in Column (v) of Table E1. The minimum total cost of £2.28 per property per year occurs for the option of waste metering; however at this stage the intention is to exclude the clearly uneconomic options. In this case passive control and regular sounding are excluded as their total costs are greater than 20 per cent above the minimum.

Final choice of method

The final choice of method rests between district, waste or combined metering and must be based upon local factors. The following economic factors should also be considered.

- (a) The total cost of district metering, although similar to that for waste metering (difference less than 20 per cent), is more than 10 per cent higher.
- (b) The implementation and operating costs of district metering are less than half of those of waste metering.
- (c) Although combined metering costs marginally more than waste metering to implement and operate, its total cost implications are identical (difference of less than 10 per cent).

To review an existing leakage control policy

E.03 In this example it is assumed that the current policy consists not of a single method, but a combination of methods; a quarter of the study area is subject to each of the methods, passive

control, regular sounding, district metering and waste metering. (This is considered to be typical of the range of current policies in the United Kingdom).

E.04 The procedure and calculations to review an existing leakage control policy are similar to those for determining a policy where none exists except that the costs of the methods of leakage control vary according to current policy. This is discussed in Appendix D and the average costs are given in Table D5.

E.05 The annual costs for the current policy are shown in Table E2 for each of the four quarters of the study area and the average costs for the whole area are also given. Table E3 shows the costs associated with introducing district metering throughout the area except in the quarter currently waste metered as it is unlikely that the capital investment in the meters would be abandoned. This is designated 'Future policy 1'.

E.06 The costs associated with introducing waste metering throughout are shown in Table E4. This is designated 'Future policy 2'.

E.07 The minimum total cost of £2.25/prop/year occurs for Future policy 2; Future policy 1 is also an economic option as it is less than 20 per cent above this cost. The current policy is clearly the least favourable economically.

E.08 Cost savings are estimated by subtraction of the total costs. This information is summarised in Table E5 together with the cost saving appropriate to unit costs of leakage of 3 and 5 p/m³

To determine the operational resources required by the methods of leakage control

E.09 For the purposes of this example, an area consisting of 24,000 properties is considered which has a unit cost of leakage of 4 pence a cubic metre. The recommended frequencies of operation for each of the leakage control methods are given in Tables 5 and 6. The most complex of these are for waste metering; therefore it is assumed that 12 districts are to be formed each consisting of more than 1,500 properties.

E.10 From Table 6 the recommended frequencies of monitoring and inspection are 12 a year and three a year respectively. This implies that the operational resources should be capable of performing 144 night flow measurements each year and 36 inspections (ie steps), each year. Based on the average costs in Appendix D this work will cost:

Record mnf	144 x £36	=	5,184
Perform step test	36 x £85	=	3,060
Sounding	36 x 0.65 x £300	=	7,020
	Total cost	=	£15,264

E.11 This figure corresponds approximately to the annual cost of two men at £2.5 per man hour, with a limited amount of night work for step tests and the use of a van as needed. Supervision at 20 per cent of the labour cost is included.

E.12 It is also necessary to check that the above work load is practicable for these staff. If not, the costs of the various activities should be altered accordingly.

E.13 In this case the work load for a 21 working day month is:

12 night flow measurements at 8 man hours	=	96 man hours
3 step tests at 13 man hours	=	39 man hours
Sounding, 3 x 0.65 x 2,000 properties at 20 per man hour	=	195 man hours
	Total labour	= 330 man hours a month
		= 16 man hours a day

This corresponds to two men.

To determine the scope for pressure control

E.14 In this example an area (zone) of 5,000 properties is considered, with a current net night flow of 18 l/prop/hr and a unit cost of leakage of 4 p/m³. The maximum and minimum night pressures recorded in the system are 73 and 68 metres and the minimum daily pressure (at peak flow) is 51 metres.

Table E2. Annual costs of current policy

<i>Method</i>	<i>Annual cost of leakage (£/prop/yr)</i>	<i>Annual cost of leakage control (£/prop/yr)</i>	<i>Total annual cost of leakage and leakage control (£/prop/yr)</i>
Passive control	5.34	0.06*	5.40
Regular sounding	2.92	0.15*	3.07
District metering	2.34	0.16*	2.50
Waste metering	1.75	0.46*	2.21
Mean	3.09	0.21	3.30

Table E3. Future policy 1: Costs of introducing district metering

<i>Method</i>	<i>Annual cost of leakage (£/prop/yr)</i>	<i>Annual cost of leakage control (£/prop/yr)</i>	<i>Total annual cost of leakage and leakage control (£/prop/yr)</i>
District metering	2.34	0.21**	2.55
District metering	2.34	0.19†	2.53
District metering	2.34	0.16*	2.50
Waste metering	1.75	0.46*	2.21
Mean	2.19	0.26	2.45

Table E4. Future policy 2: Costs of introducing waste metering

<i>Method</i>	<i>Annual cost of leakage (£/prop/yr)</i>	<i>Annual cost of leakage control (£/prop/yr)</i>	<i>Total annual cost of leakage and leakage control (£/prop/yr)</i>
Waste metering	1.75	0.53**	2.28
Waste metering	1.75	0.51†	2.26
Waste metering	1.75	0.51†	2.26
Waste metering	1.75	0.46*	2.21
Mean	1.75	0.50	2.25

Table E5. Cost savings from future policies at different unit costs of leakage

<i>Unit cost of leakage (p/m³)</i>	<i>Future policy</i>	<i>Increase in leakage control expenditure (£/prop/year)</i>	<i>Decrease in total costs of leakage and leakage control (£/prop/year)</i>
3	1	0.05	0.63
	2	0.29	0.72
4	1	0.05	0.85
	2	0.29	1.15
5	1	0.05	1.07
	2	0.29	1.38

Notes:

* These are the annual operating costs of each of the methods as any initial or capital sums will have been spent.

** These are the annual costs associated with implementing the methods in the quarter of the area currently subject to a passive control.

† These are the annual costs associated with implementing the methods in the part of the area currently subject to an active policy.

E.15 The average zone night pressure (AZNP) is given by:

$$\text{AZNP} = S \times \text{maximum night pressure} + (1 - S) \times \text{minimum night pressure}$$

where S is the proportion of the system with pressures greater than the average of the maximum and minimum night pressures.

This average pressure is $(73 + 68) \div 2 = 70.5$ metres.

From the topography of the system and the hydraulic losses, S is estimated to be 0.4. Therefore:

$$\begin{aligned} \text{AZNP} &= (0.4 \times 73) + (0.6 \times 68) \\ &= 70 \text{ metres} \end{aligned}$$

E.16 The minimum pressure within the system in order to maintain adequate supplies is considered to be 20 metres. Consequently the potential reduction in pressure = $51 - 20 = 31$ metres. Therefore the proposed average zone night pressure = $70 - 31 = 39$ metres.

E.17 The derivation of the leakage indices appropriate to the original and proposed AZNPs is demonstrated in Figure E2.

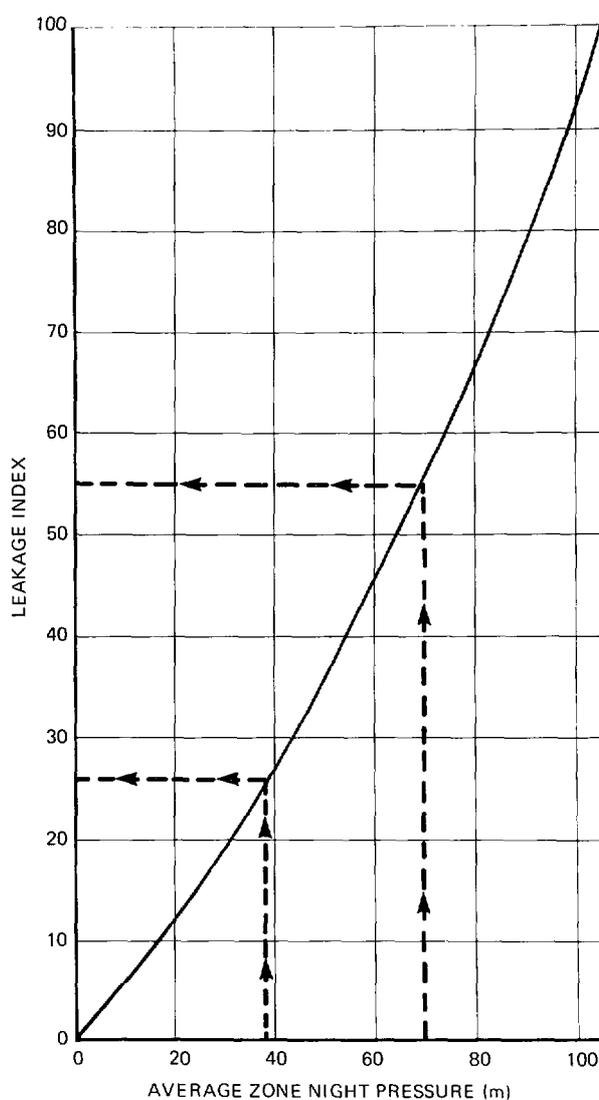


Fig. E2. Example of prediction of change in leakage

The values obtained are:

Original leakage index (70 metres) = 55

Proposed leakage index (39 metres) = 26

The reduced net night flow is given by:

$$\begin{aligned} \text{Reduced net night flow} &= \text{original net night flow} \times \text{proposed leakage index} \div \text{original leakage index} \\ &= 18 \times 26 \div 55 \\ &= 8.5 \text{ l/prop/hr} \end{aligned}$$

and the reduction in net night flow is $18 - 8.5$

$$\begin{aligned} &= 9.5 \text{ l/prop/hr} \\ &= 47.5 \text{ m}^3/\text{hr}. \end{aligned}$$

E.18 The annual cost saving = change in net night flow $\times 20 \times 365 \times C \div 100$ where C is the unit cost of leakage (4p/m³) and the net night flow is in m³/hr

$$\begin{aligned} &= 47.5 \times 20 \times 365 \times 4 \div 100 \\ &= 13,870 \text{ £/year} \end{aligned}$$

Note: the factor of 20 is used (rather than 24) to convert the net night flow rate into an equivalent daily quantity as discussed in 5.17. If however the daily pressure variation is altered eg by reducing night pressures only, it will be necessary to make proper allowance as discussed in Part Three, 5.07.

E.19 Typical installation costs for, say, the four pressure reducing valves necessary for an area of this size are £7,000 with annual maintenance costs of £100.

The annual cost of pressure control is:

$$\begin{aligned} &(\text{installation cost} \div \text{payback period}) + \text{annual maintenance} \\ &= (7,000 \div 5) + 100 \\ &= \text{£1,500 per year for the suggested payback period of five years.} \end{aligned}$$

E.20 The potential annual cost savings are in excess of the annual cost of achieving those savings. Thus in this example, pressure control is worthwhile.

To determine the need for trunk main inspection

E.21 In this example a 3 km trunk main is considered with a leakage of 2,500 litres per kilometre per hour (l/km/hr). No previous measurements have been taken so that a norm of 1,000 l/km/hr is assumed.

Thus:

$$\begin{aligned} \text{likely reduction in leakage} &= 2,500 - 1,000 \text{ l/km/hr} \\ &= 1,500 \text{ l/km/hr} \\ &= 4,500 \text{ l/hr} \end{aligned}$$

Assuming a unit cost of leakage of 4p/m³

$$\begin{aligned} \text{likely reduction in costs} &= \text{reduction in leakage} \times 24 \times 365 \times C \div 100,000 \\ &= 4,500 \times 24 \times 365 \times 4 \div 100,000 \\ &= \text{£1,577/year} \end{aligned}$$

The cost of inspection is derived in this example by using the following average costs, which are taken from Table 2. Local costs should be used if available.

Measure leakage with the heat pulse meter	£35
Install a tapping and chamber	£150 ⁽ⁱ⁾
Effective cost of tapping (assuming 10 uses during the life of the main)	£15 ⁽ⁱ⁾
Locate leakage using SF ₆ gas tracer (1 kilometre)	£60 ⁽ⁱⁱ⁾

For a three kilometre main two halving measurements will be required. The first will isolate the leakage to a 1.5 km length and the second to within a 750 metre length. This length is then short enough for pinpointing the leak using SF₆.

Thus:

$$\begin{aligned} \text{Cost of inspection} &= [2 \times (15 + 35)] + 50^{(iii)} \\ &= \text{£150} \end{aligned}$$

If a halving measurement identifies significant leakage in both sections of the main, each section should be considered as a separate main and likely cost reductions and inspection costs calculated for each of them.

Notes:

- (i) The costs in this example are for a tapping and permanent chamber. The effective cost of the tapping is thus reduced as it is available for further use. The effective cost of a tapping would be higher than this for a temporary installation.
- (ii) The cost of locating leakage using SF₆ consists mainly of the cost of sinking and subsequently inspecting the bar holes. This depends upon the length tested. For 750 metres the cost is reduced to around £50.
- (iii) The cost of inspection excludes the cost of initially walking and sounding the main, which should always be an initial stage, to cater for the possibility that this method will detect the leakage.

Additionally, this cost of inspection may be reduced significantly by initially closing any valves along the main in the manner of a step test.

The net benefit of inspection is given by:

$$\begin{aligned} \text{net benefit} &= \left[\begin{array}{l} \text{annual reduction} \times \text{expected running} \\ \text{in costs} \qquad \qquad \text{time of leakage} \end{array} \right] - \text{cost of inspection} \\ &= \left[\begin{array}{l} 1577 \times \text{running time} \\ \text{(years)} \end{array} \right] - 150 \end{aligned}$$

The net benefits for various running times are shown below:

Running time	Net benefit
1 month	– £19
2 months	£113
3 months	£244
6 months	£639

E.22 Thus in this example, if it is suspected that the leakage will continue for more than one month, a reasonable assumption, as the leakage has most probably been running for several months before being detected by the initial measurement, inspection will be worthwhile.

Technical Working Group on Waste of Water

FINAL REPORT

PART THREE

Leakage Control Practice

A manual of equipment and techniques for
leakage control and leak detection

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PART 3

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1. INTRODUCTION

1.01 This part of the report revises and replaces Water Research Centre Publication TP 109, *Waste control*, and deals with the equipment and methods for both leakage control and leak detection. It covers the measurement of leakage and the location of leaks in the component parts of a supply and distribution system. The various types of measuring equipment available are discussed together with techniques for their use.

1.02 Before making any decisions as to the type of leakage control to be undertaken in any system, it is important to consider the economics of the problem. A procedure is given in Part 2 for determining the method of leakage control most appropriate for a given system; it takes into account both the economic and engineering considerations.

1.03 There are several terms used in connection with leakage control and leak detection which are interpreted differently throughout the industry. In order to avoid confusion, definitions of terms used in this report are given in Appendix A. However it is considered important for the reader to understand, before reading this part of the report, the use of a few key words.

Waste is that water which, having been obtained from a source and put into a supply and distribution system and into consumers' installations, leaks or is allowed to escape or is taken therefrom for no useful purpose.

Leakage is that part of waste which leaks or escapes therefrom other than by a deliberate or controllable action.

It is leakage from reservoirs, mains, communication and consumer's supply pipes which is the main concern of this report although leakage control methods can also serve to identify leakage on other apparatus belonging to the consumer.

The terms 'waste meter' and 'waste district' are used in a particular method of leakage control and these widely accepted terms are therefore used within the report.

2. FACTORS AFFECTING LEAKAGE

Introduction

2.01 There are several factors which affect the leakage from a supply and distribution system. These can be put under broad headings as follows:—

Pressure

2.02 Pressure can affect the losses from a system in a number of ways, some of which are described below.

Rate of leakage

For a system with a number of leaking or broken pipes and leaking or faulty fittings, a change in the pressure will change the rate of loss of water through those faults. The effect of pressure on leakage from a distribution mains system is very much greater than that predicted by the theoretical square root relationship (See Chapter 5).

Frequency of bursts

Increase of the pressure within a system, in some cases only by a few metres, can result in a fairly large number of bursts occurring within a relatively short period of time. Similarly, reducing the pressure may reduce the frequency at which future bursts occur. Instances of both of these effects have been reported. These effects, however, are likely to be transient and the burst frequency may eventually return to that recorded before the pressure change was made. The time taken for the burst frequency to return to its original frequency will depend upon the rate of corrosion or weakening of the pipe and can vary from a few months to many years.

Location of leaks

Higher pressures will increase the rate of loss of water from an individual leak and this may cause that leak to appear sooner. This higher rate of loss usually makes the leak easier to locate using sounding methods; only occasionally is it more difficult.

Pressure surge

Surges, sometimes greater than the design strength of the pipeline, can be caused when a pumpset or booster is switched on or off or when a valve is opened or closed too quickly. The effects of surges can cause the main or service to fracture, thrust blocks to move or joint sealant to be blown from the joint cavity. There is also some evidence that surges or other fluctuating pressures cause pipes to flex and move against rocks or other firm obstacles, resulting in local stress concentrations and sometimes failure of the pipe.

Pressure cycling

Fatigue is caused by cycling the pressure between high and low value within the design pressure. such as occurs when a pumpset or booster is switching on and off or by badly maintained or faulty pressure reducing valves. Although the contribution of this effect to leakage is probably quite small, special care may be required during the design of plastic pipelines because they can be more susceptible to fatigue than other pipes.

Soil movement

2.03 Among the causes of soil movement are changes in moisture content, particularly in clays, changes in temperature, frost heave and subsidence. Movement of the soil may cause a pipeline to break, joints to move, or result in local stress concentrations within the pipe or fittings which eventually lead to its failure.

2.04 There is some evidence to suggest that small amounts of soil movement can also cause local stress concentrations, and hence the onset of fissure corrosion, in grey iron pipes.

Deterioration of water mains and pipes

2.05 The most serious problem is the corrosion of metallic pipes.

2.06 Internal corrosion is generally more severe in soft waters from upland sources. In the case of iron water mains it is manifested by the development of nodules, termed tubercles, on the pipe bore. The tubercles are associated with pitting and usually overlie anodic areas where localised attack of the metal is occurring. As corrosion of iron and steel pipes proceeds, the residual thickness of metal is reduced and hence the ability of the pipe to withstand internal pressure diminishes. Ultimately, this process leads to complete penetration of the pipe wall and failure of the pipe with resultant leakage. The common forms of failure are hole formation and transverse or longitudinal fracture of the pipe.

2.07 External corrosion can arise from a variety of causes including differential aeration, bimetallic corrosion, variations in concentrations of dissolved salts and microbiological action. The effects of external corrosion are similar to those of internal corrosion.

2.08 Corrosion of concrete or asbestos cement pipes can be caused by soils or waters containing high levels of sulphates.

Poor quality of fittings, materials and workmanship

2.09 Leakage under this heading can occur in the apparatus of both the water undertakings and the consumers. The possible causes of leakage are far too numerous to recount in this report. Careful design and specification of installations and components coupled with a high standard of supervision of construction are required in order to keep faults to the minimum.

Soil characteristics

2.10 An important factor which affects the running time of individual leaks is the permeability of the soil in which the pipes are laid. In some soils, water from underground leaks may show on the surface fairly quickly whereas similar leaks in soils such as chalk can run indefinitely without showing.

Traffic loading

2.11 The effects of vibration and high roadway loading caused by heavy lorries and other traffic is thought, by many engineers, to be a major factor affecting the failure of buried pipelines. There is insufficient data to quantify this problem, although it is the subject of further investigation.

Age

2.12 Many of the factors listed above are time-dependent ie their effect will be greater as time goes on. Consequently age of a pipeline can appear to be the most significant factor affecting the likelihood of leakage but, on its own, age is not necessarily a factor.

Summary

2.13 With the exception of pressure, none of the factors listed above can be easily altered by a water undertaking once a pipeline has been laid. It is, therefore, extremely important that due consideration of these factors is taken during the design and construction stages and that adequate supervision is given to ensure that the desired standards are obtained.

2.14 The other major factor which affects leakage from a supply and distribution system is the method or methods of leakage control undertaken. This is, of course, within the complete control of the water undertaking.

3. ESTIMATION OF LEAKAGE

Introduction

3.01 A figure representing the level of leakage within an undertaking may be required for purposes other than leakage control but the only practical way of obtaining an acceptable figure is by making an estimate of unmetered consumption (either total daily consumption or night consumption). The inherent inaccuracies of any such estimate result in the figure obtained for leakage being somewhat approximate.

3.02 Of the two methods available for making this approximate estimate of leakage ie,
(a) total integrated flow,
(b) total night flow rate,

the latter is the more accurate. Both estimates are made in a similar way, that is by subtracting from the measured input, the metered consumption and the estimated unmeasured use; the remainder is the unaccounted for water of which a substantial part is leakage.

3.03 The recommended procedure for determining the appropriate leakage control methods for any system does not require the determination of an absolute figure for the leakage from the system. Because it utilises differences in net night flows appropriate to differences in methods of control the difficulty of determining the unmetered night consumption is avoided. (See Part 2, 5.10).

3.04 It should be made clear that unaccounted-for water includes,
(a) errors in the flow measurements (these may be positive or negative)
(b) water which is used legitimately but which is not accounted for
(c) leakage

Total integrated flow

3.05 The formula used for the estimation of unaccounted-for water is:

$$u = s - (m + ap).$$

where u = unknown or unaccounted-for quantities of water.

s = sum of all inputs into the system.

m = sum of all water accounted for by measure.

a = average domestic consumption per capita of population plus an allowance for unmetered commercial consumption.

p = population supplied.

3.06 All of the terms in the formula are likely to be subject to seasonal variation and it is important therefore to ensure that the figures used for each factor relate to the same accounting period. The accounting period will normally be a minimum of three months since this is the usual period between reading consumers' meters and is thus the minimum period over which the quantity m can be obtained. More reliable results may be obtained by extending the accounting period to a half or a full year as this will tend to smooth out some of the seasonal variations. In resort areas however, this will not be the case because seasonal changes in population will have a marked effect on the total water supplied. The accounting period used for m must also be used for s and all flows averaged over this period.

3.07 Each of the measured quantities will be subject to meter error and, where possible, source meters should be calibrated prior to making any measurements. Details of an *in situ* calibration technique are given in WRC Technical Report *In situ calibration of flow meters using a dilution method*.

3.08 It will obviously not be possible to calibrate all the meters used for measuring the term m , metered consumption. These meters will, however, normally be of the mechanical type and therefore will tend, because of wear, to under-read rather than over-read. There is also the problem of under-registration at low flow rates. It is interesting to note that some overseas undertakings which have universal metering, add 10 per cent of the total reading to allow for the under-reading of meters at low flow rates.

3.09 There is currently insufficient information available concerning average domestic consumption a , to be able to quote figures of general application. It is likely to vary widely over the country, particularly in small areas. The unmetered commercial consumption is also very variable.

3.10 Population estimates can normally be obtained from local statistics or by multiplying the average occupancy rate for the area by the number of properties served.

3.11 It must be emphasised that whilst estimating unaccounted-for water from total integrated flow measurements is probably the simplest method to undertake, it is also the least accurate. The errors arise from the fact that relatively large quantities subject to certain errors, are being subtracted in order to obtain a relatively small quantity.

3.12 The method may be used to assess changing circumstances, as these errors will affect comparative sets of figures equally.

Total night flow rate

3.13 Estimation of leakage from total night flow measurements requires more effort than the total integrated flow method, but is likely to yield a more accurate and reliable figure. The formula used is similar to that used for the integrated quantity method, but each of the measured terms is a flow rate rather than a quantity. In addition, the allowance for domestic consumption is expressed per property rather than per capita. Hence the equation is:

$$u' = s' - (m' + a'n')$$

where u' = unknown or unaccounted for night flow rate

s' = sum of all input flow rates into the system (minimum night flow)

m' = total night flow rate of all trade and commercial users

a' = average domestic night flow rate per property

n' = number of properties supplied.

3.14 The total night flow rate measurement method for estimating leakage essentially consists of subtracting small flows, subject to certain errors, from relatively large flows, in order to obtain a relatively large flow. The method therefore is inherently more accurate than the total quantity method. The figure obtained from this method is strictly an unaccounted for night flow rate but by eliminating as much legitimate use as possible the leakage element becomes dominant. For certain purposes it may be necessary to convert this night flow rate into a total daily quantity, making allowances for the fact that pressures at night are likely to be higher than those encountered during the day. Details of a method for making this conversion are given in 5.07 to 5.10.

3.15 In many systems it may be possible to turn off the inlet to the controlling service reservoirs for the night period and supply the system from these reservoirs. This will enable flow rates to be obtained from reservoir drop tests and hence will provide a reasonably accurate measurement of the factor s' .

3.16 The factor m' is obtained from direct measurement of night flow rates of the very large consumers coupled with estimates of night flow rates for other metered users. When determining which meters need to be read or how much to allow for those to be estimated, consideration must be given to the size and type of user together with other factors such as whether or not automatic flushing urinals are installed.

3.17 The results from the experimental programme have shown that the average domestic night flow rate is relatively small, on average less than 2 litres per property per hour.

3.18 The number of properties supplied can usually be obtained from plans or from direct billing records or from the electoral roll.

3.19 In many cases it will be possible to subdivide the system into smaller areas. This will enable night flow rate measurements to be made in different areas on different dates and thus reduce the amount of effort required on any one night.

3.20 In small areas of under 5,000 properties, variation in leakage levels and legitimate unmetered consumption may cause significant variation in the estimate of u' . Several measurements may be necessary to be confident of a reliable estimate. In larger areas or when summing measurements from smaller areas, this variation will not be so evident and a single measurement will be satisfactory.

3.21 In areas where waste meters or district meters exist, it is possible to obtain reliable estimates of leakage from the meter readings, although in the former case it is unlikely that the large diameter mains would be covered by waste meters.

3.22 A more detailed procedure for the determination of leakage from measurement of night flow rates is given in Appendix D.

Expressions for leakage

3.23 Whilst in many circumstances it is sufficient to express leakage as an absolute quantity ie litres per hour or cubic metres per day, these expressions are unsuitable for comparative purposes. Several methods are currently in use within the industry, the most common of which is to express the minimum night flow or the leakage, as a percentage of some measure of the total water supplied.

3.24 There are several reasons why this is not recommended. Firstly there are many measures for which a percentage can be expressed eg total supply, total unmetered supply or peak flow. Secondly, even if a single measure were to be adopted, it would not be comparable in all areas. Total supply may vary considerably depending upon the amount of metered consumption within the area and even unmetered supply will vary because of differences in domestic consumption and policies for metering small trade consumers. The third limitation of the use of percentage is that the measure of the total water supplied includes leakage so that a leakage of 30 per cent does not represent three times a leakage of 10 per cent.

3.25 Consequently it is recommended that leakage should be expressed in terms of the number of properties within the system ie litres per property per hour. In rural areas with long lengths of main and few properties, a better comparative index is to express the leakage in terms of the mains length eg litres per kilometre per hour. For large areas or systems containing both urban and rural housing it is normally satisfactory to express leakage in litres per property per hour.

4. METHODS OF LEAKAGE CONTROL

Introduction

4.01 There are six methods of leakage control currently practised within the United Kingdom. Five of these involve leakage detection; the remaining method, pressure control, can be considered to be supplementary to each of the other methods. Each method requires a different level of staff input and equipment and consequently each has different capital and operating costs. However, each method will also maintain leakage at different levels and consequently, depending upon the costs of supplying water and the characteristics of the system, different types of leakage control will be appropriate in different situations. In order to determine the type of leakage control most appropriate to a particular system, the procedure given in Part 2 of this report should be followed. Details of the procedures and equipment used for each type of leakage control are outlined below.

Pressure control

4.02 Leakage reduction by pressure control is probably the simplest and most immediate way of reducing leakage within the distribution system as detection of leaks is not involved. Pressure reductions may be achieved in a number of ways such as reducing pumping heads, installing break pressure tanks and, most commonly, using pressure reducing valves.

4.03 Although this method of leakage control has limited application, it has been found to be more beneficial than theoretical considerations suggest. It is likely to be most worthwhile not only in areas with generally high pressures but also where the pressure rises to high levels at night.

Passive leakage control

4.04 This requires the least effort on the part of the water undertaking but in most cases also results in the highest levels of leakage. No attempt is made to measure or detect leaks and generally only those leaks are repaired which are reported as a result of either water showing on the ground surface or of consumer complaints such as poor pressure or noise in the plumbing system. Reports of this nature are normally made by the police, public, or water undertaking personnel going about some other duty. Leak location may still be required for some of these self-evident leaks.

4.05 This type of leakage control will not normally be cost effective except in areas where water is very cheap and/or soil conditions are such that underground leaks quickly come to the surface.

Routine or regular sounding

4.06 Leaks are located by deploying teams of inspectors who systematically work their way around the system sounding all stopcocks, hydrants, valves and other convenient fittings listening for the characteristic noise of leaking water. The frequency of sounding varies from undertaking to undertaking.

4.07 An alternative method of regular sounding, known as differential sounding, was first proposed by Gledhill in 1957. The method consists of dividing the system into a number of sections and records of the number of faults found in each section are then used to determine the future inspection frequency for that part of the system; it results in those parts of the system with the greatest number of faults being sounded more frequently than the rest.

4.08 The arguments normally put forward in favour of these methods are based on the premise that most leaks are located by sounding and each part of the distribution system will always contain a certain number of unknown leaks. Consequently, time spent on metering can be more effectively used for locating leaks. These conclusions would be true provided leaks were evenly distributed throughout the system and occurred at evenly spaced intervals of time. This, however, is not usually the case. Therefore although this method of leakage control normally costs less to implement than those incorporating metering, it results in higher average leakage levels.

4.09 Regular sounding will probably be most effective in areas where the value of saving water is fairly low and where the soil conditions are such that large leaks show themselves fairly quickly so that only small underground leaks need to be detected by inspection staff.

District metering

4.10 Flow meters are installed at strategic points within the system so that areas of about 2,000 to 5,000 properties are supplied via meters and the integrated flow into each area measured.

4.11 Meters are normally read at regular periods, weekly or monthly, and the results analysed to determine any areas in which significant increases in supply have occurred. If no legitimate reason can be found for the increase in an area, the inspection teams sound all stopcocks, hydrants, valves and other fittings searching for the characteristic noise of leaking water.

4.12 This method of leakage control has the advantage that the inspectors are always working in those districts where leakage is anticipated to be highest and therefore are likely to return the greatest benefits for their efforts. It also has the added advantage that information regarding flows and use of water within the network is obtained which can be useful for the day to day running of the network and for the planning and design of future extensions.

4.13 District metering is not as sensitive to changes in leakage as is waste metering nor does it so closely determine the position of leaks.

4.14 It can be seen from the economic analysis in Part 2 of this report that this type of control can be justified in the majority of systems in the United Kingdom.

Waste metering

4.15 Waste metering involves setting up areas of, ideally, between 1,000 and 3,000 properties such that when appropriate valves are closed these areas can be supplied via a single pipe in which it is possible to site a flow meter. The flow meter used is one which is capable of measuring low rates of flow and is normally referred to as a waste meter.

4.16 The waste meter, which may be permanently installed on a by-pass, or carried on a mobile trailer and connected temporarily into the system via hydrants, is normally used only to measure night flow rates. Recording charts are put on to the waste meter and the night flow rates recorded for subsequent examination. If the minimum night flow rate has increased above some predetermined level or if it is above the previously recorded minimum night flow in that waste district, then it is indicative of leakage and the area is inspected. The inspection may consist of sounding the entire area supplied by that meter or more commonly by repeating the measurement and successively closing valves within the district, thus isolating sections of the district and enabling the corresponding reduction in flow rate to be determined. A large reduction in flow rate indicates the existence of a leak within the section last isolated. This procedure obviously has to be performed at night and is generally known as either a step test or a valve inspection. At the end of the step test, those sections showing evidence of leakage are investigated by the inspectors.

4.17 Night flow rate measurements are normally made on a regular basis varying from one to twelve times a year with four times a year being the most common.

4.18 This type of leakage control has the advantages that it is sensitive to small leaks and also establishes the position of that leak between valves. The disadvantage is that time must be spent in monitoring districts where no leakage has occurred and hence no benefits obtained. This type of leakage control is likely to be appropriate in areas where the value of saving water is fairly high.

Combined district and waste metering

4.19 This method of leakage control consists of a combination of the last two methods discussed. District meters are used to monitor large areas (ideally 2,000–5,000 properties) of the system and when these indicate an increase in consumption, waste meters are used downstream of them to determine more precisely the position of the leak. By suitable selection of district sizes and of meters, both waste and district meter areas can effectively coincide.

5. PRESSURE CONTROL

Introduction

5.01 The various ways in which pressure can affect leakage levels have been detailed fully in 2.02. A reduction in pressure will reduce the rate of leakage from each of the leaks within the system and may also affect the incidence and detection of these leaks. The control of pressure surges and cycling is likely to reduce the numbers of bursts and leaks which occur, especially in plastic pipes. These latter effects will be dependent upon the type and condition of the system in which they are found and therefore little generally applicable information can be derived.

5.02 The effect of pressure on the rate of leakage, which perhaps has the greatest and most immediate effect on the total leakage, is common to all systems. Theoretically it is known that the flow through an orifice of fixed dimensions is proportional to the square root of the pressure drop across it. However, a series of experiments has shown that this relationship does not hold for the effect of pressure on leakage from water supply systems. The result of these experiments is shown in Figure 1. Because leakage does not depend solely upon pressure, the vertical scale represents as index of the leakage (strictly net night flow) rather than leakage alone. The average zone night pressure is the mean pressure occurring within the system at night taking account of variations in ground level and any hydraulic friction losses across the zone. Full details of the experiments together with the derivation of Figure 1 can be found in WRC Technical Report *The results of the experimental programme on leakage and leakage control*.

5.03 It can be seen that the curve steepens at higher pressure so that, in complete contrast to the square root law, even small reductions of high pressures can cause correspondingly larger reductions in leakage. Whilst the apparent discrepancy between the two relationships is not completely understood, it is probably caused by the orifice of some leaks becoming larger at higher pressures. In addition whilst the square root law only applies to a single leak, within a distribution system there may be many sources of leakage each experiencing a different pressure.

5.04 Many systems are already operated at optimum pressures and in some systems, high pressures cannot be reduced significantly without creating supply problems elsewhere. A reduction of pressure may cause unforeseen operational problems such as diminishing supply to properties with old and corroded or shared services and to some automatic sprinkler systems. Nevertheless, now that the effect of reducing pressures can be predicted and is known to be much greater than was previously thought, further consideration should be given to pressure reduction, not only in areas with high pressures but also in areas with a large daily pressure variation. To this end, the relationship shown in Figure 1 can be used in two ways:

- (a) To predict the change in leakage that would occur for a given change in pressure.
- (b) To convert measurements of night flow rates into total daily leakage.

Prediction of change in net night flow rate for a given change in average system pressure

5.05 The curve in Figure 1 shows the relationship between leakage (strictly net night flow) and average pressure. The curve can be used to predict the effect of either increasing or decreasing the system pressure. It is possible, however, that increasing the pressure will increase the number of leaks, as discussed in 2.02, in which case Figure 1 will underestimate the effect of the change.

5.06 The effect of pressure change can be predicted as follows;

- (a) Determine average zone night pressure as described in 5.09 and 5.10.
- (b) On the pressure axis of Figure 1, draw a vertical line; at this pressure point, up to the curve and a horizontal line across to the vertical axis. Read off the leakage index at the original pressure.
- (c) On the pressure axis draw a vertical line at the new pressure point and a horizontal line at the point of intersection with the curve. Read off the leakage index at the modified pressure.
- (d) The factor to apply to the existing net night flow rate in order to predict the new rate is the leakage index of the proposed pressure divided by the leakage index at the original pressure.

Figure 2 indicates this point graphically.

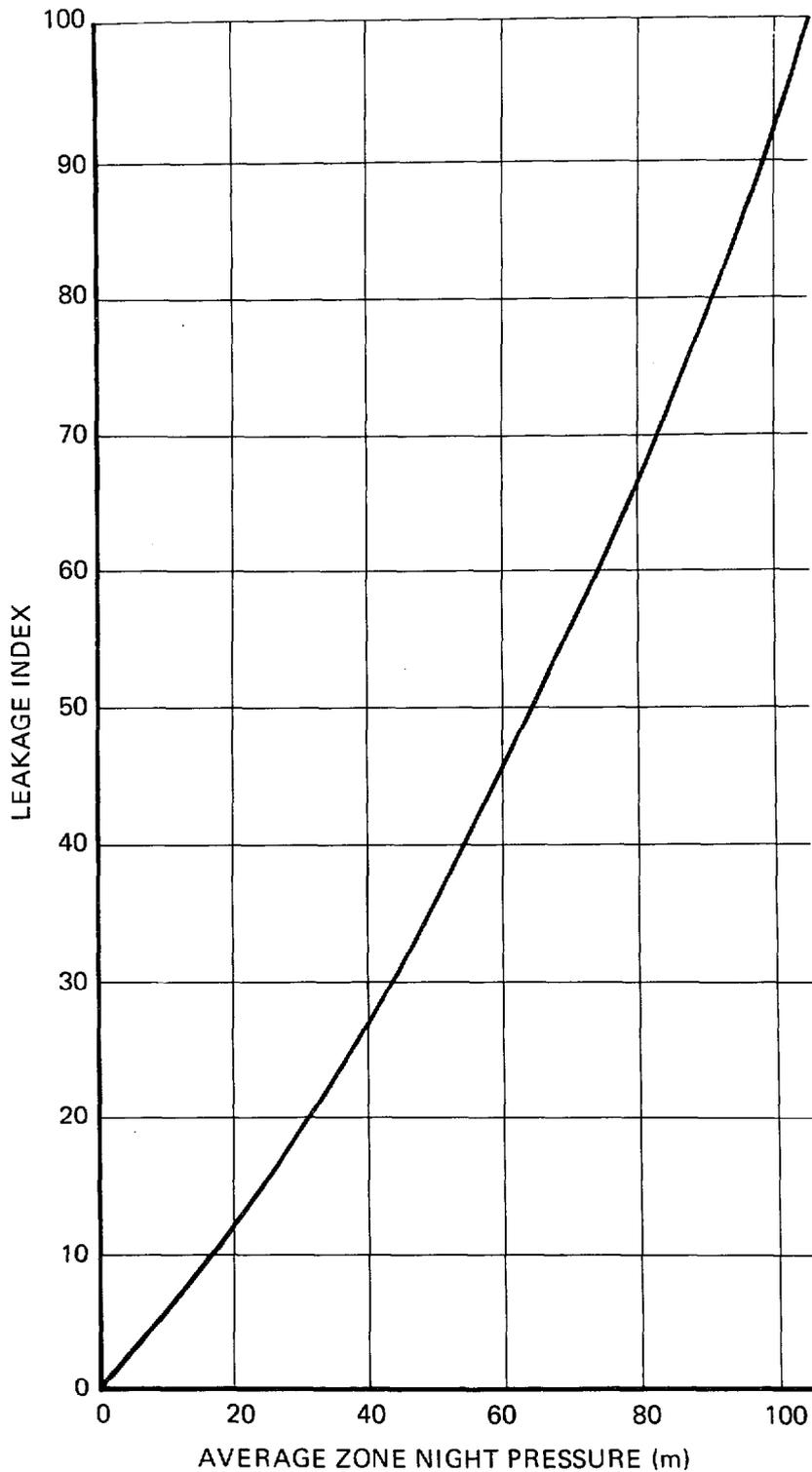


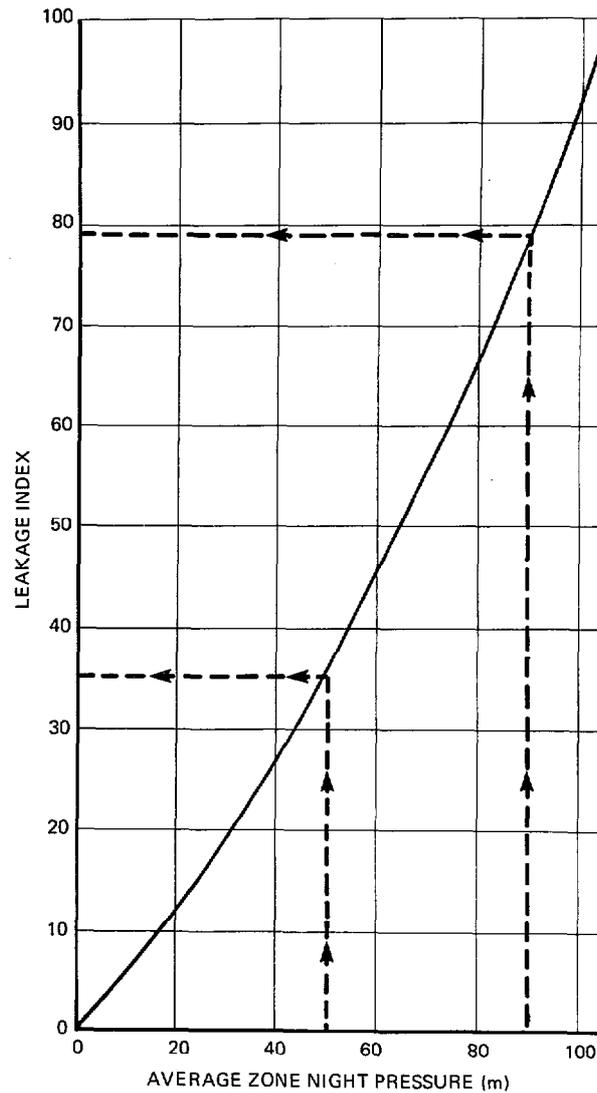
Fig. 1. Relationship between leakage (net night flow) and pressure

Calculation of daily leakage from night flow measurements

5.07 To convert night flow rates into total daily quantities it is necessary to take account of the pressure variations which occur during the 24 hour period. In order to perform this conversion it is convenient to define factor T such that

$$\text{Total daily leakage} = T \times \text{night leakage rate.}$$

For use within the procedure the net night flow should be substituted for the night leakage rate. (See Part 2, E.14 to E.20).



- (a) Present net night flow = 18 l/prop/hr
Average zone night pressure = 90 metres
- (b) Original leakage index = 79
- (c) Proposed average zone night pressure = 50 metres
Proposed leakage index = 35
- (d) Reduction factor = $\frac{\text{Proposed leakage index}}{\text{Original leakage index}}$
= 0.443

$$\begin{aligned} \text{Predicted net night flow} &= 18 \times 0.443 \\ &= 8.0 \text{ l/prop/hr} \end{aligned}$$

Fig. 2. Example of prediction of changes in nnf

5.08 T is thus the factor which must be applied to the night flow rate in order to obtain the total daily quantity and can be considered as the period of the day, in hours, for which the night flow rate applies. For the majority of areas with pressure variations of about 10 metres of water, T has values of between 19 hours and 21 hours. For general use, or for application to an entire system, a factor of 20 hours is normally sufficiently accurate, particularly when errors in the terms are considered. If, however, it is desired to calculate the factor T more accurately, or if the area in question has a very large pressure variation over 24 hours, the following procedure should be followed.

- (a) Construct a table as shown in Table 1.
- (b) Divide the day into twelve periods of two hours.
- (c) For each period determine the average zone pressure (see 5.09 and 5.10) and insert in column (ii)
- (d) Determine the leakage index from Figure 1 for the average zone pressure at each period and insert in column (iii).
- (e) Add together all the values in the third column.
- (f) Divide by the value for the night period and multiply by two.

Table 1. Example calculation of correction factor, T.

<i>(i)</i> Period	<i>(ii)</i> Average zone pressure (metres)	<i>(iii)</i> Leakage index (metres)
12 – 2 am	47	32
2 – 4	48	33
4 - 6	48	33
6 - 8	42.5	28
8 – 10	32.5	20
10 - 12	36	23
12 – 2 pm	39	25
2 – 4	39	25
4 - 6	36	23
6 - 8	32.5	20
8 - 10	35	22
10 – 12	42.5	28

Sum of leakage indices in column (iii) = 312

Leakage index for the night period = 33

Therefore T = $312 \div 33 \times 2$
= 18.9 hours

Estimation of average zone pressure

5.09 The zone pressures required for the calculations in sections 5.06 and 5.08 are mean pressures within the area, and hence should take account of both the differences in ground level within the area and hydraulic friction losses across the system. There are several ways in which the mean pressure can be calculated and an accurate method is to use a network analysis model. An alternative method is to install a number of pressure recorders in the area and to use the recordings of plot pressure contours onto a map of the distribution system.

5.10 It is however seldom necessary to utilise such complicated methods for calculating the average zone pressure and in the majority of cases the procedure outlined below will be sufficient. An example of this procedure is shown in Table 2.

- From a map showing ground contours and from a knowledge of the system determine the points of highest and lowest pressure. These will often be on low ground near to the input to the area and on high ground remote from the input.
- Place pressure recorders at or near to these places. Let the pressures recorded, ie gauge pressures be P_{high} and P_{low} .
- Calculate the mid pressure which is given by $(P_{high} + P_{low}) \div 2$ for a period during the daytime when pressures are stable.
- Estimate S , the estimated proportion of the system which experiences pressures above the mid pressure for this period.
- The average zone pressure P for each period during the day is given by:

$$P = SxP_{high} + (1-S)xP_{low}$$

Table 2. Example of calculation of average zone pressure

<i>(i)</i> Period	<i>(ii)</i> High pressure (metres)	<i>(iii)</i> Low pressure (metres)	<i>(iv)</i> Average zone pressure (metres)
12-2 am	50	45	47
2-4	51	46	48
4-6	51	46	48
6-8	46	40	42.5
8-10	38	29	32.5
10-12	41	33	36
12-2 pm	43	36	39
2-4	43	36	39
4-6	41	33	36
6-8	38	29	32.5
8-10	40	32	35
10-12	46	40	42.5

Pressures recorded at the point in the system which experiences highest pressures are shown in column (ii).

Pressures recorded at the point in the system which experiences lowest pressure are shown in column (iii).

$$\begin{aligned} \text{Mid pressure (4pm to 6pm)} &= (41 + 33) \div 2 \\ &= 37 \text{ metres} \end{aligned}$$

From topography and hydraulic losses, S , the proportion of the system which experiences pressures above 37 metres between 4 and 6 pm is 40 per cent.

$$\begin{aligned} \text{Average zone pressure} &= S \times P_{high} + (1-S) P_{low} \\ &= 0.4 \times P_{high} + 0.6 \times P_{low} \\ &\text{and is shown in column (iv)} \end{aligned}$$

Methods of reducing pressures

5.11 Pressure reduction may be achieved in a number of ways, some or all of which may be appropriate in differing circumstances. Brief details of each of the available methods are given below together with a discussion of some of their advantages and disadvantages.

Valving or zoning

5.12 This is most probably the simplest and cheapest way of reducing pressures but is only feasible in limited circumstances. Basically it consists of closing valves within the system so that areas are fed from existing service reservoirs. These areas are termed pressure zones and the pressures within them are limited by the level of the upstream reservoir. Care must be taken in sizing the zones so that emergency conditions, such as fire fighting or restoring supplies following a significant burst, are adequately provided for.

5.13 A variation of this technique is to install time controlled valves on major mains, whereby an area which is normally supplied by three mains may be supplied by two in the afternoon and only one at night. This will increase the effective head loss of the mains into the area at times of low flow, thus reducing high pressures.

Reducing pumping heads

5.14 This technique is simple but has limited application. It has the advantage that reductions are made in pumping costs not only because of the reduced quantity of water supplied but also because of the head at which it is pumped. Modifications can also be incorporated in the pump-set control gear so that water is pumped at a lower pressure at night.

Break pressure tanks and service reservoirs

5.15 This method of reducing pressures will not normally be acceptable solely for reducing leakage owing to its high cost. If a service reservoir is being planned, its incorporation into a new pressure zone should be examined.

Pressure reducing valves

5.16 The most commonly used method of pressure reduction is to install pressure reducing valves (PRVs). There is a variety of valves of different designs available and a list of manufacturers is given in Appendix C. Some valves maintain a constant outlet pressure whilst others produce an outlet pressure which is a fixed proportion of the inlet pressure. Some of these valves can have several set pressures, controlled by a clock mechanism so that, for example, lower pressures can be achieved at night.

5.17 Examples of the likely range of costs involved in the formation of PRV controlled pressure zones are given in Part 2, Table 2. PRVs are very versatile and have the advantages that pressures are easily controlled and varied. They normally present little restriction when unusually high rates of flow are required such as for firefighting.

5.18 There is currently some doubt within the industry concerning the performance of PRVs. The following factors are thought to be important:

Design and siting of the PRV installation. PRVs may interact with other valves within the system (eg with reservoir float valves or other PRVs) and may also adversely affect meters.

Size of the PRV. Some types require high velocities to work effectively and will therefore need to be smaller than the main in which they are installed.

The necessity of regular maintenance.

Liberation of air. An air valve may be required downstream of a pressure reducing valve to ensure satisfactory operation.

5.19 In order to assess the performance of PRVs and the importance of the above factors, a programme of field measurements is currently being undertaken by the Water Research Centre.

6. DISTRICT METERING

Introduction

6.01 The term district metering is used to describe the method whereby flow meters are installed such that several thousand consumers are supplied via each meter or combination of meters. The meters are usually of the integrating type and record the total quantity of water having passed. Changes in this quantity are used to guide the inspection staff.

Initial planning

6.02 The configuration of the distribution network has the greatest effect on the size and boundaries of a district. However, the following guidelines should be considered. Meters should be arranged to measure the flow from the larger diameter distributors into the smaller distribution mains; the flow through larger diameter mains will be measured at some upstream position. District meter areas should ideally consist of 2,000 to 5,000 properties. When determining suitable district meter areas it will be necessary in those areas to sum all meter readings in order to obtain the total flow. Similarly in other areas water will enter via a meter to feed other areas at some downstream position. Here it will be necessary to subtract meter readings to obtain the total flow. These two conditions amount to the use of flow meters in parallel and flow meters in series respectively and it may well be found that both parallel and series meters have to be used in a single district meter area.

6.03 When establishing district metering, a plan should be produced which shows the limits of each of the districts and the positions of the meters. It will often be necessary to shut certain valves within the system in order to limit the number of inflow and outflow points and a record of these valves should also be made.

6.04 The following information should also be recorded:

- (a) Total number of properties within the system.
- (b) Total number of metered consumers within the area.
- (c) The average daily metered consumption. This should be updated after each quarterly reading.
- (d) Any metered consumers that use large quantities of water in relation to the rest of the area or, if rate of flow measurements are being made, who use high flow rates at specific times of the day or week.
- (e) In rural areas the total length of main may also be required.

Choice of meter

6.05 The flow meters used for district metering are of the integrating type which record the total water having passed. The meter size should be such that it is capable of recording the minimum night flow without loss of accuracy but must also be capable of supplying the peak flow without introducing a serious head loss.

6.06 Consequently it is unlikely that any meters of less than 80 mm diameter (3 inches) would be acceptable, although in small areas combination meters may be necessary.

6.07 There is considerable advantage in having the facility to record rate of flow from the integrating meters as it enables both minimum night flow rate measurement and total quantity measurements to be made by a single instrument. It also enables a district meter to be used for step testing purposes (see Chapter 7). Consideration should therefore be given to meters which possess this facility.

Calibration

6.08 The accuracy of the flow meters used for district metering is obviously important to the method of leakage control particularly if a change in accuracy occurs with time. At present the only satisfactory method of calibration of district meters is to remove them for calibration in a meter shop or laboratory. Techniques for in situ calibration are currently under investigation by WRC.

Monitoring of districts

6.09 Normally all district meters are read at weekly intervals and as far as possible each meter should be read at the same time of day as previous readings of that meter. Weekly measurements of the large consumers in the system should also be made. The measurements obtained should be used to determine the total quantity of water entering the meter areas each week minus any consumption by large metered consumers. For each area, comparison of this quantity with previous measurements and with the norm for that area coupled with a comparison of changes between different areas, will enable individual changes to be distinguished from seasonal changes.

6.10 This procedure may be simplified by maintaining graphs of the meter readings expressed in litres per property per hour. Those areas where it is likely that leakage has increased and hence where the inspectors should operate can then be identified visually.

Determination of district norms

6.11 Determination of the norm can be undertaken in two ways. The first method is to make an arbitrary assessment for each non-metered consumer in the district and to add to this any metered consumption. This total figure can then be taken as the norm. However, this method is not recommended owing to the inherent variation in leakage, domestic consumption and unmetered trade consumption likely in districts of this size.

6.12 The second and preferred way is to thoroughly inspect the district, once it has been established, and to quickly repair all leaks detected. Measurements are then made of the total daily quantity entering the area and this measured flow is taken as the norm. The norm may have to be modified to take account of weekly or seasonal variation in demand and this process may be simplified by the graphical technique mentioned in 6.10. The norms may also be modified if subsequently the leakage in the district is further reduced. It is good practice to ensure that all districts, but especially those with high norms, are inspected at least once every few years to ensure that their norms are still appropriate.

Inspection of districts

6.13 Inspection within district meter areas normally consists of sounding all valves, hydrants and stop cocks searching for the characteristic noise of leaking water.

6.14 If the district meters used are also capable of providing rate of flow information, then techniques similar to those used for waste metering may be employed. Measures of night flow rate can be used to confirm that the identified increase in demand is caused by leakage and valving used to help locate it.

6.15 The amount of inspection performed ie the number of districts selected for inspection each week, will affect the average level of leakage which is achieved within the system. Consequently it is important that sufficient inspection is undertaken. A discussion of the various frequencies is given in Part 2, 6.07 and it is proposed that the average inspection frequency for district meter areas should be about once a year. This implies that for a distribution system consisting of about 50 districts, one district should be selected for inspection each week, but this does not mean that all districts will be inspected each year as some districts may be selected more than once and others not at all.

6.16 The districts selected for inspection will depend upon the flow measurement and should be the one in which the efforts of the inspectors will be most productive. Provided that legitimate changes in metered or unmetered consumption are identified this will be the district in which the difference between the measured quantity and the norm in litres per property per hour is greatest.

Further development of the method

6.17 It is considered that scope exists for improving the method of district metering for leakage control purposes. Possible improvements include more sophisticated statistical analysis of the flow data, use of flow rate information in conjunction with the total flow, recording daily rather than weekly quantities and linking the meters to a telemetry system. This work is the subject of further investigation by the Water Research Centre.

7. WASTE METERING

Introduction

7.01 The term waste metering is used to describe the method whereby small parts of the distribution system are isolated by closing appropriate valves and feeding that district via a single pipe in which it is possible to place a flow meter. Such parts are known as waste districts. The flow meters used are capable of measuring and recording relatively low rates of flow accurately and are known as waste meters. These meters may be either permanently installed, normally on a by-pass with appropriate isolating valves, or may be mounted on a mobile trailer and temporarily connected into the system via fire hydrants or other convenient fittings. The meters are normally used to record night flow rates and from these recordings the minimum night flow is taken as a guide to the leakage in that district. Waste meters can also be used to determine the approximate position of a leak by successively reducing the size of the waste district by closing valves and noting the corresponding reductions in the flow rate.

Determination of waste district size

7.02 The most important factor affecting the choice of a waste district will be the particular configuration of the distribution system and therefore each district must be considered individually. It is, however, possible to give some general guidelines.

7.03 The size of the district, as well as depending upon the actual configuration of the network, will also depend upon the size of the pipe supplying that area and the level of information which is required. Many engineers choose a district which is capable of being isolated and supplied by the waste meter for a 24-hour period, thus providing information not only of minimum night flow rate but also peak and average flow rates. This inevitably means that the district will be relatively small and therefore in the entire system there will be a large number of small waste districts. Part 2 of this report considers the relative economics of step testing, sounding and recording night flows together with the capital cost of equipment and the likely resultant levels of leakage in different size districts. The conclusions are that, provided the resolution of the leakage measurement is not impaired, ie given increases in leakage can still be detected, large districts, between 1,000 and 4,000 properties in urban areas, are the most cost effective. It is necessary therefore to consider whether 24 hour readings provide positive advantages since it is not possible to have large districts and make 24 hour flow measurements whilst maintaining the same measurement resolution.

7.04 Measurements of peak flow rates made with a waste meter are likely to be misleading because flow and pressure constraints imposed by closing the boundary valves will radically alter the normal hydraulic conditions. Also many waste meters have compressed scales at the high flow rates. Measurements of total quantity entering a district, obtained by integrating the area under the flow curve, are tedious to perform and a very inaccurate method of obtaining total flow. In practice this operation is seldom undertaken. It appears therefore that flow information, other than night rate, is of little advantage.

7.05 A second argument in favour of choosing waste districts which can be supplied for 24 hours is that it enables the districts to be set up during the normal working day and thus minimises the amount of night work which has to be undertaken in order to obtain an open reading. This is also of little consequence since, in the majority of districts, it is possible to install the chart and clock mechanism during the day, and close all but one or two of the boundary valves leaving these open until the evening. A number of districts can be set up in this fashion and then one man can close the remaining valves in all sections and open the meters. The amount of night work required to obtain open readings is thus minimised.

7.06 It appears therefore that the advantages of being able to make 24-hour flow recordings are not very great whereas the advantages of having larger waste meter districts include,

- (a) the number of open readings required to obtain measurements of minimum night flow rate in all waste meter districts is reduced.
- (b) the total capital cost of meter installations is reduced.
- (c) more efficient use can be made of employees.

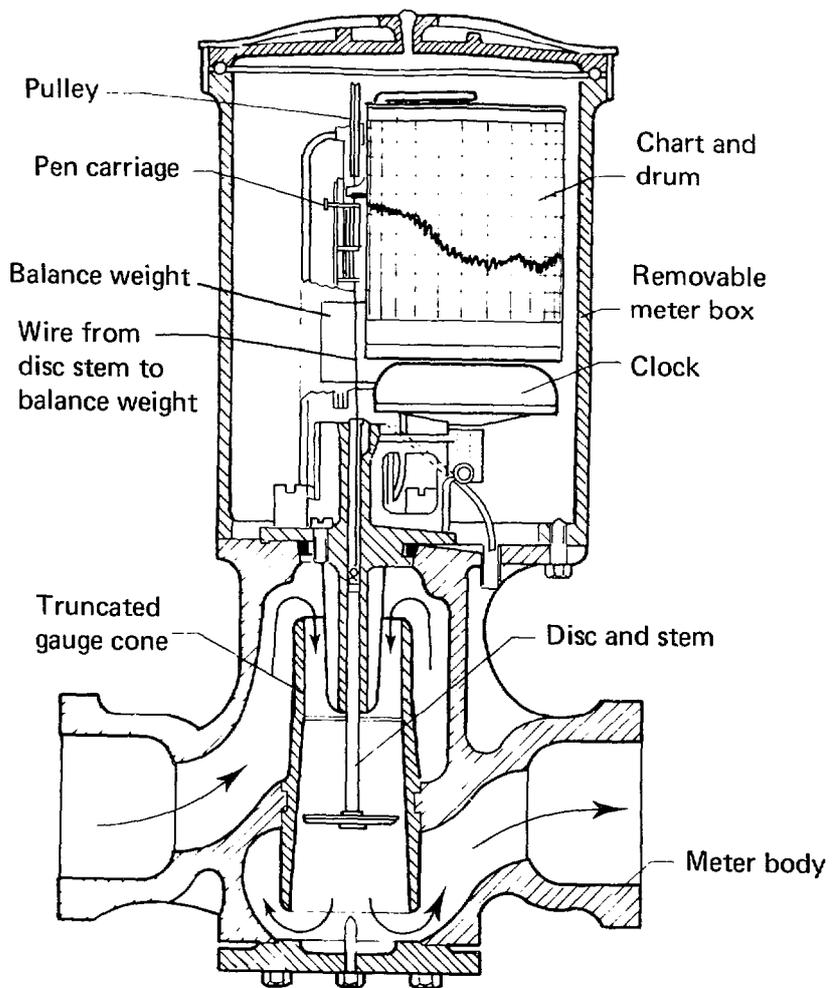


Fig. 3. Deacon waste meter

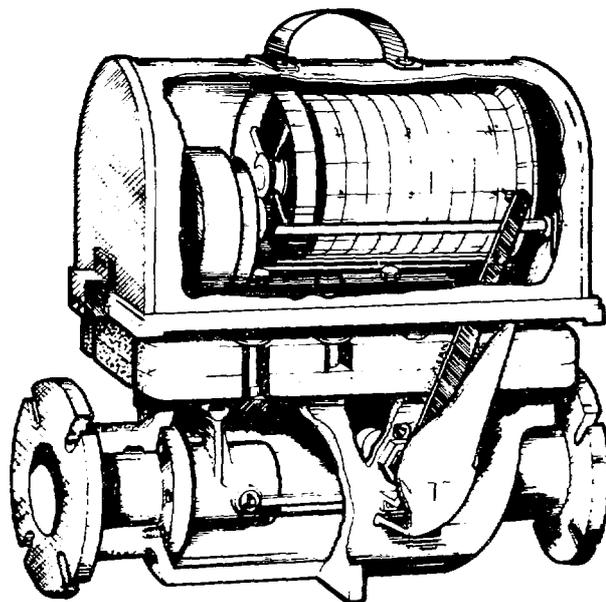


Fig. 4. Kent waste meter

- 7.07 The main disadvantages of larger districts are,
- (a) the inspection of districts, where required, is more expensive and more difficult.
 - (b) average leakage levels may be slightly higher in larger districts.

7.08 The analysis in Part 2 has taken the economic implications of all these factors into consideration and it is shown that the most effective district size is between 1,000 and 4,000 properties. For smaller districts the cost of installation and operation rise sharply. For most districts larger than about 3,000 properties it is unlikely that the size of the waste meter required will be capable of maintaining a suitable degree of resolution. Therefore waste meter districts should ideally contain between 1,000 and 3,000 properties.

7.09 The above guidelines apply mainly to urban situations; in rural areas, the choice of district will be almost entirely governed by the configuration of the system.

Choice of meter

- 7.10 A flow meter used for waste metering purposes must be,
- (a) capable of measuring and recording rates of flow
 - (b) reasonably accurate
 - (c) robust
 - (d) capable of working for a long period of time ie several years with the minimum of maintenance.

7.11 Hitherto the accuracy of a waste meter has not been particularly important, especially for fixed meters, since each measurement is usually compared with previous measurements and hence repeatability is more important than accuracy. If, however, the measurements made on a waste meter are to be used to determine the level of leakage in a supply system or to compare one waste district with another, then accuracy becomes more important.

7.12 Advice on the specification of a meter that can be used for these purposes can be obtained from the Water Research Centre.

7.13 The two meters most commonly used for waste metering purposes are the Deacon, shown diagrammatically in Figure 3 and the Kent, shown diagrammatically in Figure 4. Both meters were developed around the turn of the century; various modifications have been made and both have proved to be reliable, robust and have given good service with the minimum of maintenance. The manufacturer's specification of each meter is given in Tables 3 and 4.

Table 3. Maker's specification for Deacon waste meter

<i>Size of meter (mm)</i>	<i>Maximum registration (m³/hr)</i>
80	46
100	46
125	90
150	90

Accuracy: ± 2 per cent of flow rate

Flow range: maximum registration to 1/200th of maximum

Head loss at maximum flow: 2.2 metres (See Figure 10)

Table 4. Maker's specification for Kent waste meter

Size of meter (mm)	Maximum registration (m ³ /hr)
80	46
100	64
150	140

Accuracy: ± 1 per cent of full scale travel

Flow range: maximum registration to 1/300th of maximum registration

Head loss at maximum flow: 0.76 metres (See Figure 10)

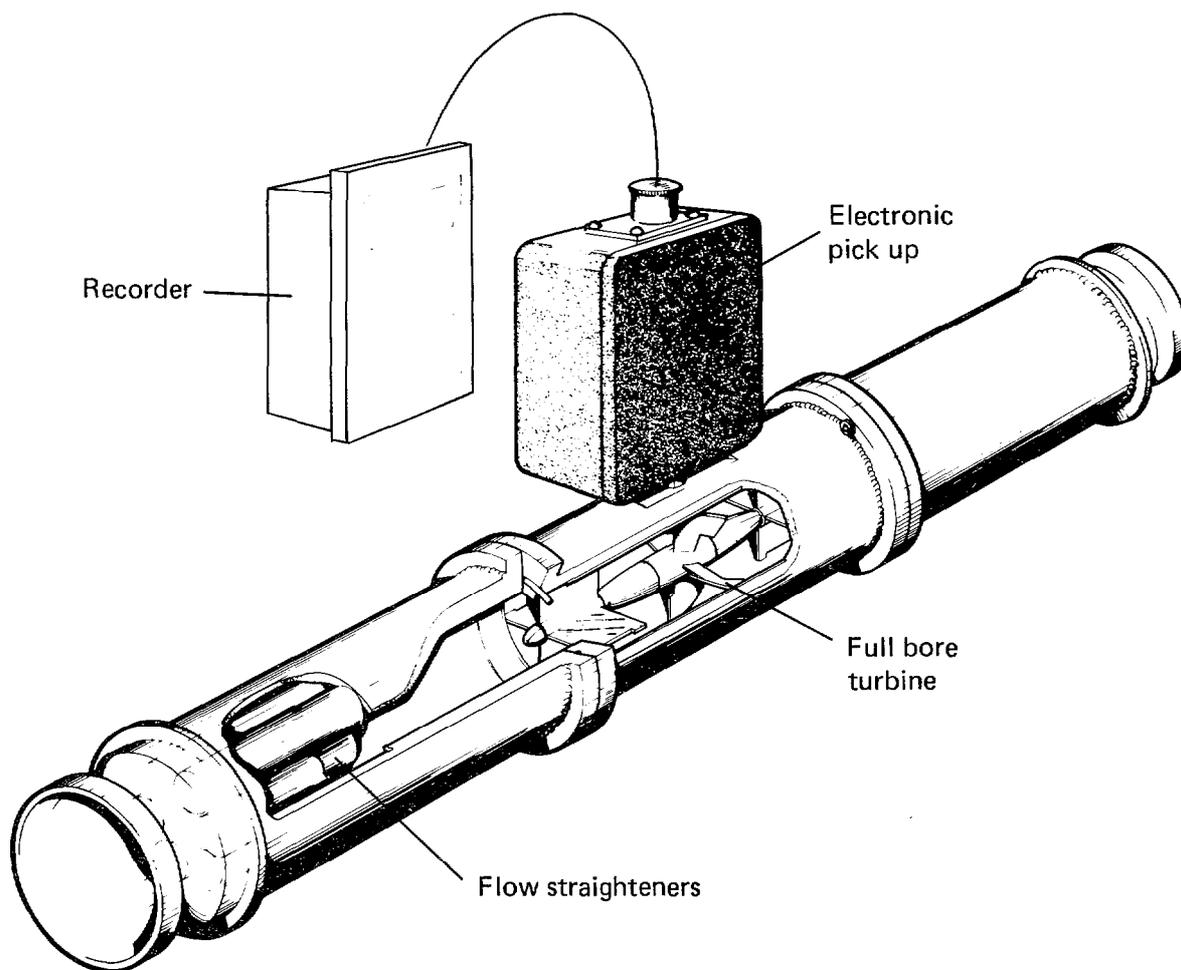


Fig. 5. Turbine flow meter

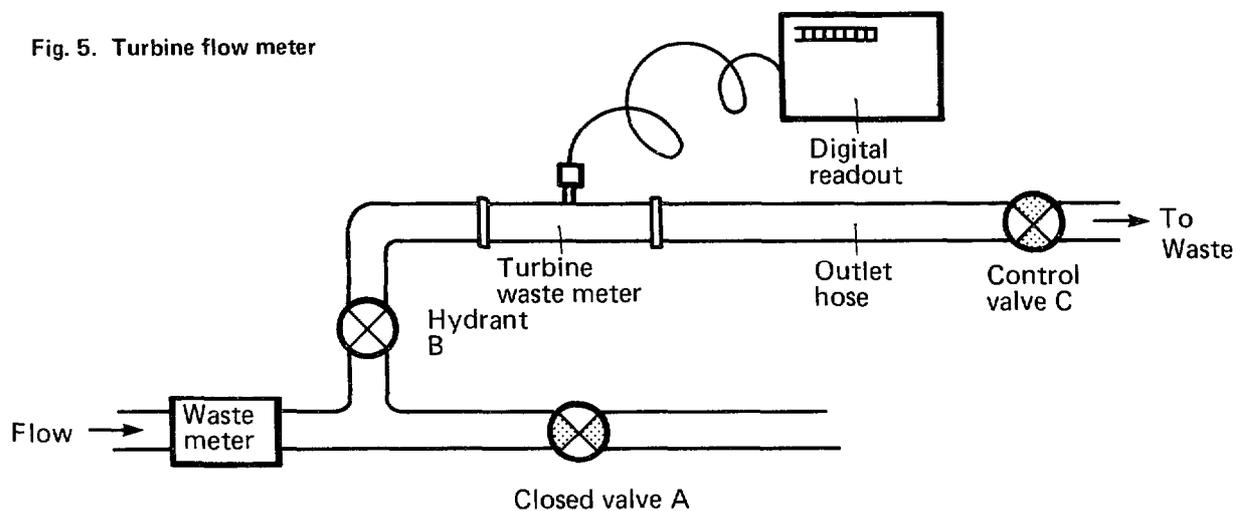


Fig. 6. Waste meter calibration

7.14 A recent development consists of a full bore turbine meter mounted in a stand pipe. This meter is shown diagrammatically in Figure 5 and its specification is shown in Table 5. The meter has the advantages of being light-weight, readily portable and has a remote electronic read-out and recorder which can be sited at some distance remote from the meter if desired. It is however more delicate than the existing meters and requires more careful handling and storage.

Table 5. Maker's specification for turbine waste meter

<i>Nominal size of meter (mm)</i>	<i>Maximum registration (m³/hr)</i>
38	45
50	80
75	140

Linearity (50mm): ± 0.5 per cent of reading.

Flow rate (50mm): 6–80 m³/hr.

Head loss at max flow (50mm): approximately 4 metres.

7.15 The size of the waste meter will depend upon the size of the district and the minimum night flow rate expected, together with the amount of pressure drop acceptable for that district. Using traditional waste meters the best results will be achieved by ensuring that the normal rate of flow encountered is around one third of the maximum registration. This will avoid errors brought about either by the compression of the scales at high flow rates or by large inaccuracies at low flow rates, whilst providing sufficient capacity for step testing.

Calibration

7.16 The accuracy of waste meters can be assessed by connecting a second meter (transfer standard) of known accuracy in series with it and comparing the two readings. The most suitable meter to use for this type of measurement is a turbine meter as shown in Figure 5.

7.17 The arrangement for connecting the meter is shown in Figure 6. Shutting valve A and opening hydrant B allows water to flow through both meters and to waste. The flow rate can be varied by changing the setting of a control valve, which should be placed at the far end of the outlet hose, position C in Figure 6.

7.18 This is particularly important at low flow rates where pulsating flow may result from the hose successively filling and emptying. If a control valve is placed at position C it must be adequately secured to take the end thrust which is produced when the valve is closed. Fixing the valve to the tailgate of a vehicle will normally suffice.

7.19 The calibration should be performed by increasing the flow from zero, in a number of steps, to a maximum, and then decreasing again. At each step the readings on each flow meter should be recorded.

7.20 From time to time the accuracy of the transfer standard meter will need to be checked. This can be undertaken by the meter manufacturer, an independent test house or in the undertakings own meter shop.

7.21 Preliminary calibration results obtained by WRC have shown that the inaccuracy of existing waste meters can be significant at high and low flow rates and that the error can change by a large percentage over the meters working range.

Fixed and mobile meters

7.22 Waste meters may be used either as fixed meters, permanently installed on a by-pass, or as mobile meters connected into the system via fire hydrants.

7.23 Fixed waste meters are normally installed in an underground chamber on a by-pass as shown in Figures 7a and 7b. If different types of meter were to be used in the future, there could be advantages in installing the meter within the straight section of pipe with a by-pass around it as shown in Figure 7c. In some situations it is possible to site the meter such that by suitable valving the meter may be used for several waste districts.

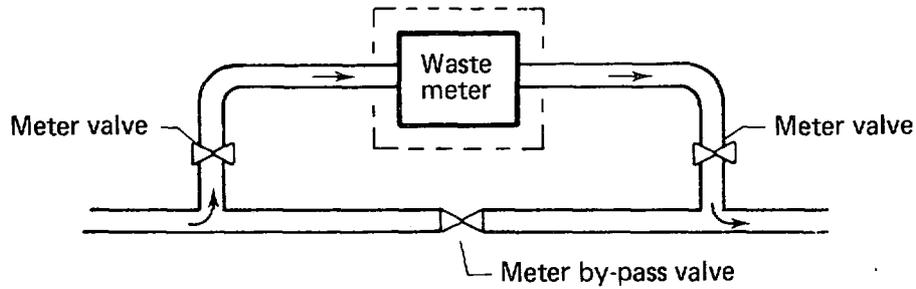


Fig. 7a. Usual meter arrangement

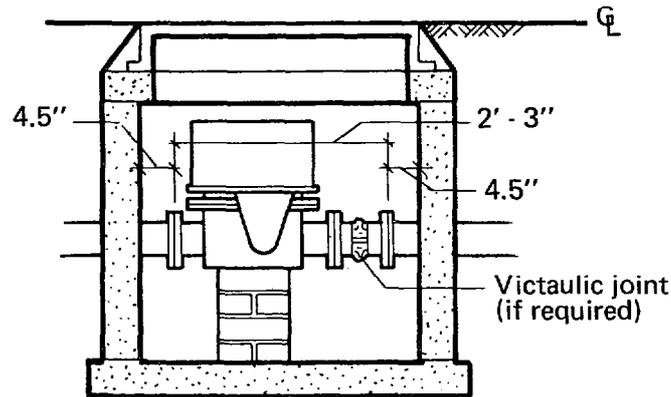


Fig. 7b. Details of installation

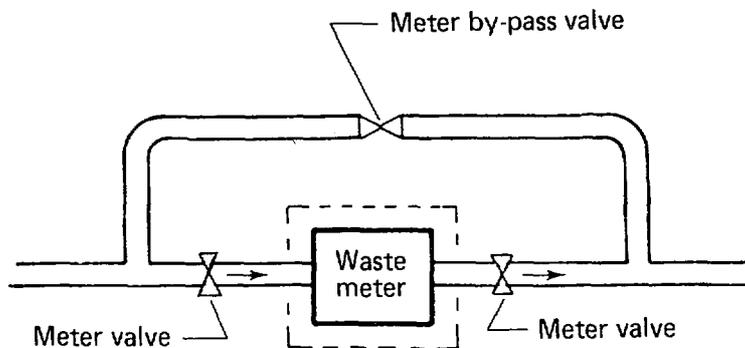


Fig. 7c. Alternative meter arrangement

7.24 Installing the meter in an underground chamber has a number of disadvantages. First there is the problem of drainage of the chamber which could present problems if the most suitable site for the meter coincides with a high water table. Second, it is inconvenient for the inspector to install and interpret charts if he has to descend into a pit to do so. These problems have been overcome by installing the waste meters in an above-ground box as shown in Figure 8 although of course there are the obvious dangers of freezing during the winter period and it may also be necessary to purchase land for the installation.

7.25 All meters should be installed in accordance with the manufacturer's instructions with regard to levelling and the configuration of the upstream and downstream pipework. There should also be a facility to drain off any stagnant water that has been trapped within the by-pass whilst the meter is out of use. The main advantages of fixed waste meters are that they are always available and can be set up at fairly short notice by installing the appropriate chart and clock mechanism. It is also possible to run a number of fixed meters simultaneously.

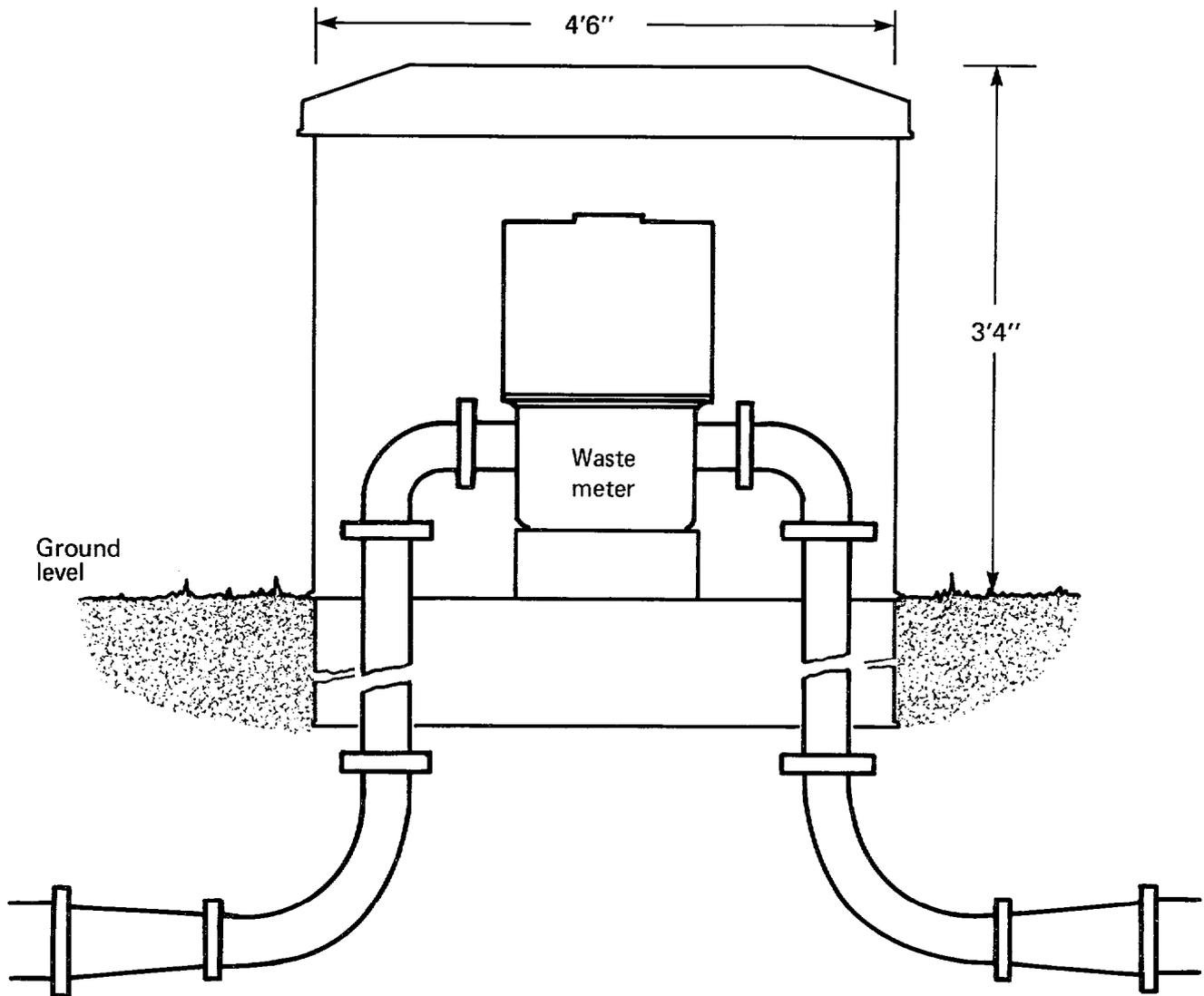


Fig. 8. Details of above ground waste meter kiosk

7.26 Fixed meters, by their very nature, are less convenient than mobile meters to maintain and calibrate and consequently these functions are seldom undertaken unless the meter ceases to work altogether or leaks badly from the various glands.

7.27 Mobile waste meters normally utilise the same meter mechanisms as used for fixed meters but the meter is mounted on a trailer or sometimes in a caravan, as shown in Figure 9. The meters are normally connected into the supply system via fire hydrants and hoses. Closing a valve between the two hydrants diverts the water through the meter, as shown in Figure 7a.

7.28 When using mobile meters it will often be necessary to install extra hydrants in order to connect the waste meter and it is important that the downstream hydrant used should not be of the loose jumper type.

7.29 Consideration should also be given to the head loss through the hydrants and hoses as well as the meter. Table 6 shows typical head loss figures for two hydrants and various lengths of hose, and Figure 10 shows the head loss through waste meters for various rates of flow.

7.30 All mobile meters and hoses should be disinfected before each use in potable water mains.

7.31 The advantages and disadvantages of fixed and mobile meters are listed below. Each engineer must decide which is suitable for his particular system.

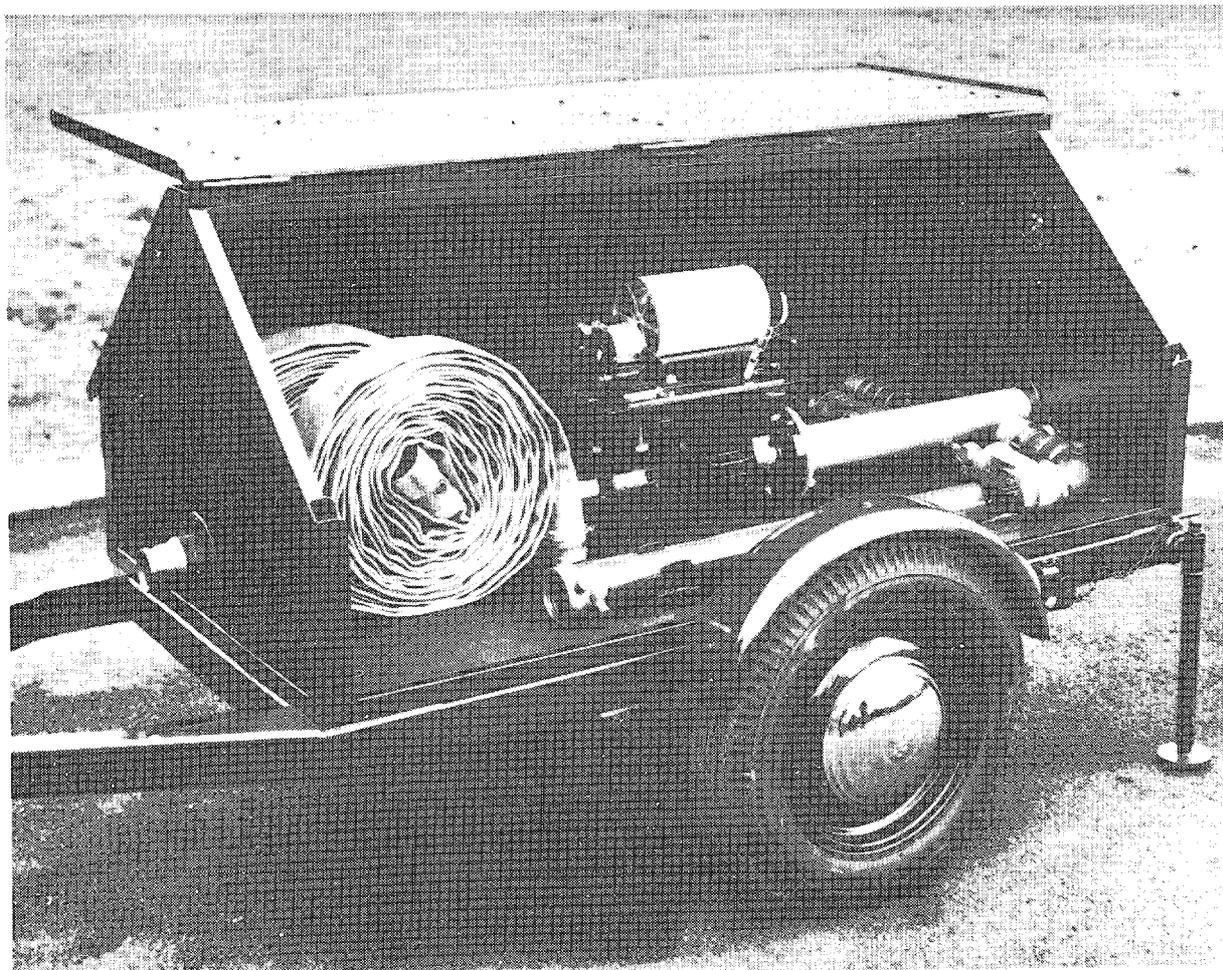


Fig. 9. Waste meter trailer

Table 6. Typical head loss through two hydrants and hose

Flow rate (m ³ /hr)	Head loss (metres) through two hydrants and 65mm rubber lined hose		
	10 metres of hose	20 metres of hose	30 metres of hose
10	2	3	3
20	4	5	6
30	6	7	9
45	9	11	13

7.32 The advantages of fixed meters over mobile meters include:—

- (a) Fixed meters can be quickly and easily set up. Conventional mobile meters usually take much longer to install in the field although waste meters mounted in a standpipe can be set up in a short time.
- (b) A team can set up several fixed waste meters in one night, thus reducing night working to a minimum. An undertaking using mobile meters will normally have only one or two units available thus limiting the number of measurements that can be made simultaneously.
- (c) Fixed meters are not normally subject to vandalism. Mobile meters may need attending in some districts at night.
- (d) Fixed meters are available in a range of sizes whereas mobile meters are normally 80mm in diameter. In many cases this will limit the size of district to under 2,000 properties, a less economic option.
- (e) Draining down of mobile meters can cause hazards particularly in very cold weather.

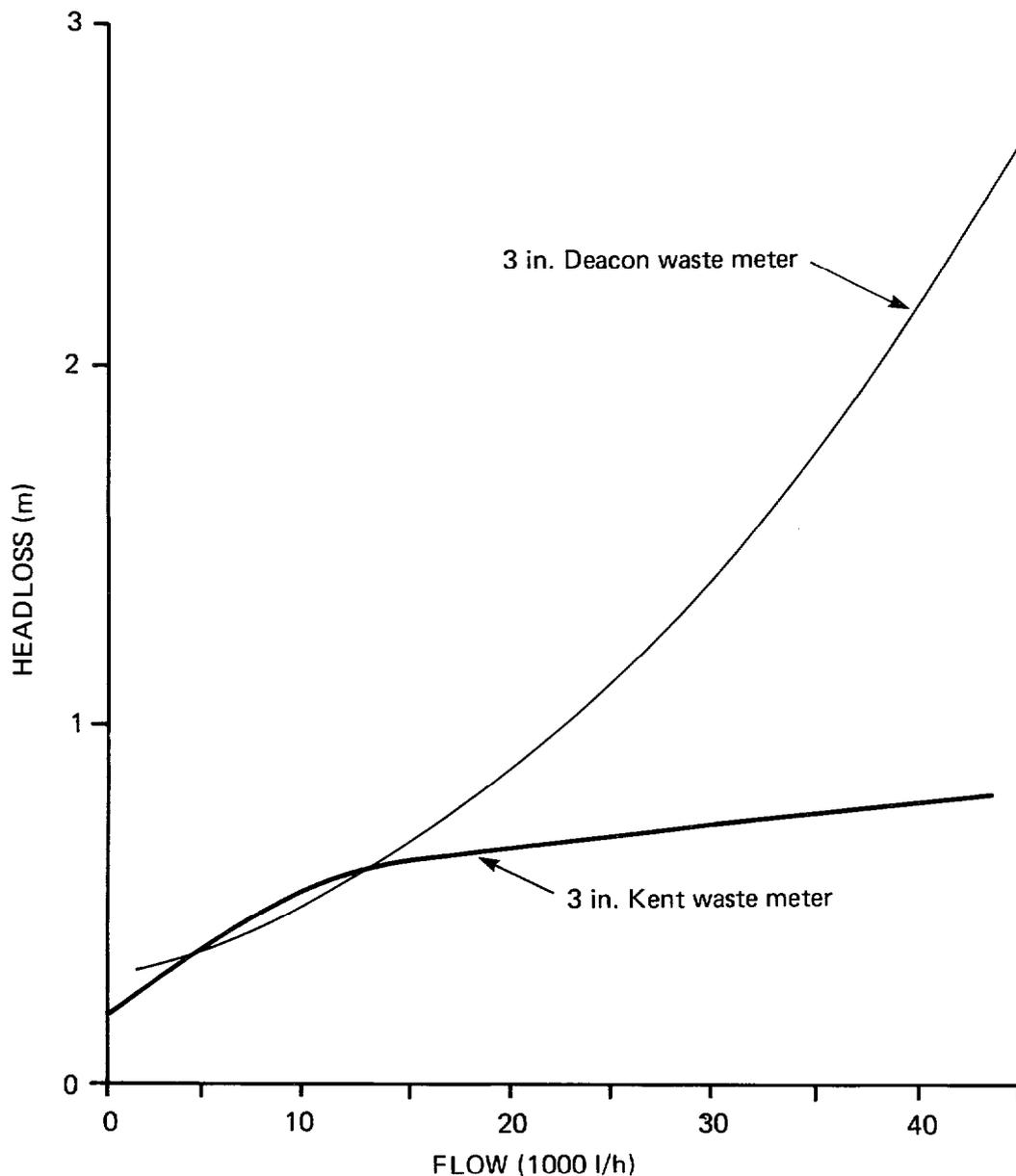


Fig. 10. Headloss through conventional waste meters

7.33 The disadvantages of fixed meters include:—

- (a) It is normally more expensive to implement waste metering using fixed meters because of the increased numbers of meters required. This disadvantage can be reduced by choosing meter sites such that the fixed meters are capable, with suitable valving, of feeding several districts.
- (b) The maintenance and calibration of fixed meters is less convenient than mobile meters although methods for their in situ calibration are given in 7.16.
- (c) Fixed meters are sometimes difficult to read below ground and may become water-logged.

7.34 In summary, the cost of installing fixed meters may be greater than using mobile meters, but they are less expensive to use on a regular basis. Based on the average costs as given in Appendix D of Part 2 it can be shown that for district sizes of less than 1,000 properties there is economically little to choose between the two. However, if it is possible, using suitable valving arrangements, to enable a fixed meter to measure more than one district, fixed meters are preferred. In larger districts of between 2,000 and 4,000 properties, mobile meters will normally only be suitable if the leakage levels are low and there is little night consumption.

7.35 Mobile waste meters can be used to advantage in the following situations:

- (a) For interim leakage control whilst a long term programme of installation of fixed meters is being carried out.
- (b) For exploration purposes to determine the most suitable site and size of future fixed meters.
- (c) Where permanent installations are not practicable because,
 - (a) poor drainage conditions would result in flooded meter pits,
 - (b) the proliferation of buried equipment precludes the siting of a meter pit.
- (d) To sub-divide large district meter areas or waste meter districts where step tests are not possible, in order to aid location of leaks.

Establishing a waste meter district

7.36 When establishing a waste meter district, using either fixed or mobile meters, it will be necessary to carry out the following:

- (a) Determine the total number of properties in the district.
- (b) Determine the total number of metered consumers in the district who use water at night.
- (c) Estimate the total number of non-metered commercial users in the district taking particular note of public houses, offices and public conveniences that are likely to have automatic flushing urinals or other devices which use water overnight.
- (d) Check the condition of all valves that need to be manipulated during the test. In some cases additional valves will be required.

7.37 For each district a plan should be produced indicating the following:

- (a) The size and layout of all mains and the names of the roads in which they are laid.
- (b) Meter installations including valves.
- (c) All boundary valves ie those valves which are closed in order to isolate the district from the rest of the system.
- (d) Circulating valves ie those valves which are closed in order to remove all loops from within the district thus producing a tree-like mains layout.
- (e) Step test valves ie those valves which will be used to perform a step test or valve inspection.
- (f) All remaining valves which are not used for leakage control purposes, to ensure that these valves are not operated in error.

The plans used on site should be water-proofed.

7.38 The positions and details of all commercial users should also be shown on the plan or associated record together with an indication of their nightly water usage. This will aid the interpretation of step test information. All valves should be numbered and marked clockwise or anti-clockwise closing and programme sheets for their operation should be drawn up. Examples of a plan and programme sheet are shown in Figures B1 and B2 in Appendix B.

Measurement of minimum night flows

7.39 Once a waste meter district has been established it is possible to take an initial measurement of the minimum night flow in order to determine the amount of leakage within that district.

7.40 It will often be found that it is not possible to isolate a waste meter district for 24 hours because of lack of meter capacity, low pressure within the district or low pressure in part of the system downstream of the district, when all boundary valves are closed. In these cases it will usually be found that a large number of boundary valves can be closed during the day leaving perhaps two or three open. All consumers continue to receive an adequate supply and only two or three valves need be closed during the evening or night of the test. This procedure reduces the amount of night work required to the minimum and enables one team to set up several districts during one night.

7.41 It has been found that in many undertakings a team of two men can set up a waste meter district and undertake a measurement in around three to four hours using a fixed meter and in about five hours using a conventional mobile meter. Local labour agreements may increase these times.

7.42 Where possible, those metered consumers that are known to use large quantities of water at night or are likely to have tanks filling should be turned off for a period during the recording of the night line. Alternatively their meters should be read over the same period. Leakage on metered premises may sometimes be identified by informing these consumers of their night consumption.

7.43 Once the measurement of minimum night flow has been taken and any metered consumption subtracted, it may be necessary to make an allowance for the reduction in pressure in the system brought about by feeding the district through a meter at one point. Measurements of the night pressure should be made within the district both in the open and the isolated conditions and used as detailed in Chapter 5 to correct for the reduced pressure.

7.44 In most cases an initial inspection will be required and a step test should be performed as detailed in 7.54. For this inspection there are likely to be a few large leaks and many small leaks within the system; therefore the step test will probably indicate that most of the steps require sounding. It is good practice, therefore, to inspect the whole of the district on this first occasion and to use the results of the step test to ensure that no leakage is missed. This will also give the inspection staff a better understanding of the district.

Determination of district norms

7.45 Having inspected the whole district, the leaks found should be repaired as quickly as possible and a second measurement of the minimum night flow made. This figure then becomes the norm for that district as all detectable leaks have been located and repaired. It should be used instead of the assessment previously derived for all subsequent comparisons. This method has the advantage that it automatically takes account of the characteristics of a particular district and adjusts the norm according to the amount of legitimate night use. Unfortunately there is often a lag between inspection and repair and consequently the measured flow could be higher than the achievable target owing to the formation of new leaks. In addition measurements of minimum night flow rate in a district can vary considerably from one night to the next even though the total number of leaks in the district has remained the same. This is caused by different amounts of consumption and/or leakage. It may be necessary therefore, to take a number of night flow rate measurements before the norm for that district can be properly established.

7.46 If, subsequently, a night flow lower than the norm is recorded it is usual to revise the norm to this new figure. Similarly, if it is found that a norm is subsequently impossible to achieve no matter how much inspection is undertaken, the norm is often increased to the achievable figure. The decision to increase a norm should not be taken lightly.

Monitoring and inspection of waste districts

7.47 Once the districts have been set up and the initial measurements and inspections made, they should be monitored on a routine basis at an appropriate frequency. This is best achieved by formulating a periodic work programme so that, for example, the first week of each period is spent taking measurements of night flows with the remaining period available for step testing and sounding.

7.48 The frequency with which the districts are monitored and inspected will depend upon the labour resources made available. However, as this will affect the leakage levels which are achieved

it is important that sufficient effort is applied. It has been found that the most cost effective frequencies depend upon the size of the district and also the value of the water being saved (the unit cost of leakage). More frequent measurements are appropriate in large districts and in areas where the economic benefits are greater. Details of the recommended frequencies in these circumstances are set out in Table 7.

Table 7. Recommended monitoring and corresponding inspection frequencies for waste districts.

	<i>Recommended frequencies (No/year)</i>		<i>Acceptable range (No/year)</i>	
	<i>Monitoring</i>	<i>Inspection</i>	<i>Monitoring</i>	<i>Inspection</i>
Small districts (up to 1500 properties)				
<i>Unit cost of leakage:</i>				
4p/m ³ or less	3	1.25	2-4	1 -1.5
more than 4p/m ³	4	1.5	3-6	1.25-2
Large districts (over 1500 properties)				
<i>Unit cost of leakage:</i>				
4p/m ³ or less	4	2	3-6	1.75-2.5
more than 4p/m ³	6	2.5	4-12	2 -3

7.49 In order to maintain a balance between monitoring and subsequent inspection, it is important that these frequencies occupy a similar position within their respective ranges. A high monitoring frequency combined with a low inspection frequency or vice versa will not achieve maximum effectiveness.

7.50 Thus, to take an example, for a system consisting of 30 waste meter districts of around 2,000 properties each and in which the unit cost of leakage is greater than 4p/m³ the recommended monitoring frequency from Table 7 is six times a year. The corresponding average inspection frequency is 2.5 times a year and therefore this implies that the labour resources should be such that a night flow measurement is taken in each district every two months ie 15 measurements a month with the capability to inspect six of these districts each month (ie 30 x 2.5 per year). If insufficient resources are available for this work, these frequencies can be reduced to four a year and two a year implying 10 night flow measurements and five inspections each month.

7.51 The particular districts which are chosen for inspection will depend upon the results of the night flow measurements and should be those in which the greatest savings are likely. The comparison should be made between the minimum night flow recorded and the norm for that district expressed as a total flow rate ie litres per hour. In order to ensure the effective use of the inspection staff, the minimum night flow must be at least two to three litres per property per hour above the norm for that district before it is worth inspecting.

7.52 This system may mean that in some months there will be spare inspection capacity and this can be used to inspect districts which it was not possible to inspect the previous month. Alternatively it is good practice to ensure that all districts, but especially those with high norms, are inspected at least once every few years to ensure that the norm is still realistic.

7.53 Having identified the districts to be inspected, step tests should be performed.

Step testing or valve inspections

7.54 The method of closing the valves within the district so as to successively reduce the size of the district supplied by the meter is known as step testing or valve inspection. The resultant reduction in flow rate following the closure of a particular valve indicates the total leakage plus legitimate night consumption in that section of the distribution system. If the resultant reduction in flow is greater than the reduction anticipated, taking into account the number and type of consumers in the section isolated, then it is indicative of a leak. There are several ways in which

the step test can be undertaken but in all cases the district is set up as for taking a night line and all circulating valves are closed in order to remove all loops within the district to produce a tree-like mains layout.

Isolation method

7.55 Starting furthest from the waste meter, valves are successively closed so that less and less of the district is supplied via the meter. The sections of the district downstream of the closed valves are without water for the period of the test. If one of the valves used in the step test is not tight, no reduction in flow will show on the chart when that valve is closed but a corresponding larger step will occur when the next valve in the sequence is closed. The sequence of closing valves is followed right up to the meter whereupon the flow should drop to zero. A variation of this method is to re-open valves in the reverse order whilst recording the corresponding increase in flow for each step. This method can, however, give misleading results since some water may have been used from storage systems whilst the district was valved off and hence flows on re-opening may be greater than those observed when closing.

7.56 The main disadvantages of the method are that the water is turned off for a period of time so that consumers are possibly without water; more seriously, the risks of backsiphonage or infiltration of ground water may be increased. Difficulties may also arise from the main draining down and the subsequent problems of discharging large quantities of air from the system.

Close and open method

7.57 This method entails closing valves on each step, noting the resultant drop on the flow meter and then re-opening again. This overcomes the problems of large quantities of air entering the system and since the main is only shut off for a short period of time, substantially reduces the risk of backsiphonage. The disadvantage however is that the drop in flow rate for some steps can include the sum of previous steps and difficulties can arise from looking for small differences between large quantities.

Back feed method

7.58 The method consists of closing valves in the same sequence as that with the isolation method but each time a valve is closed a corresponding valve is opened behind it, starting with the boundary valves, thus allowing water to backfeed from some other part of the distribution system. This method enables the district to be fully charged and under pressure at all times, although for its success, it relies on all valves being drop tight. When this method is used it is common to keep the back-fed water separate from the metered supplies by at least two closed valves. This reduces the likelihood of obtaining spurious results because of valves letting by, but does mean that one section of the district is without water for a period of time.

7.59 With all of these methods of step testing, difficulties may be encountered in subsequently identifying the valve closures on the chart. It is therefore extremely important that detailed records and timing of valve closures are maintained and a sample programme sheet for a step test is shown in Figure B2 of Appendix B. With large numbers of steps it is sometimes beneficial to momentarily open a hydrant after closing half the number of valves in order to simplify the subsequent interpretation of the chart. Alternatively some inspectors return to the meter if convenient or station an inspector at the meter, in radio contact with the personnel closing the valves. These procedures enable the step test to be terminated once all the night flow has been accounted for.

7.60 The success of both waste metering and step testing depends to a large extent upon the ability to isolate completely the waste meter district from the rest of the system and this obviously depends upon valves shutting down tight. As a test, all valves that are supposed to be shut should be sounded to check that no water is passing. This is by no means an absolute test since valves passing water may not make any noise. It is, however, a very simple test and will in many instances indicate a valve which is not tight. (The plan of the waste meter district should of course indicate which valves are clockwise closing and which valves are anti-clockwise closing and ideally these valves should be clearly marked on the ground). If it is suspected that a boundary valve is letting by and yet no noise can be heard, a simple test is to connect a calibrated flow meter to a hydrant at the far end of the district and to discharge water to waste at a known flow rate. Provided that the water being discharged to waste does not produce a significant reduction in pressure, the additional flow should appear on the waste meter. If this is not the case then it indicates that water is coming from elsewhere and one or more of the boundary valves is letting by.

7.61 All measurements of minimum night flow rate and all mains and service breaks and other faults found within the district should be recorded in accordance with the details given in 7.69.

7.62 A systematic approach to setting up a waste meter district and performing a step test is given in Appendix B.

Use of step tests

7.63 It has been found that in most undertakings a step test can be performed by a team of inspectors (usually two or three men) in a night shift of between six and eight hours. Therefore, in general, step testing is a labour intensive and hence an expensive operation. Consequently, the use of step tests and also the number of steps should be considered very carefully.

7.64 Step tests perform two functions and these are,

- (a) isolation of leakage to individual mains or streets resulting in a reduction in the amount of sounding required.
- (b) quantification of the leakage within those steps thus reducing the likelihood of leakage being missed by the sounding team.

7.65 The number of steps possible will depend upon the time available at night for which consumption is at a minimum. In recent years this time has decreased owing to changes in nocturnal habits of consumers, and often only three or four hours are available. The number of shuts or valve closures that can be undertaken during this period will depend upon the type and size of the district and the time taken to travel between the various valve locations. Experience has shown that in urban areas inspectors can normally achieve 20 shuts per night although in rural areas this number may be much lower.

7.66 The use of step tests will depend upon the size of the district under consideration and the amount of leakage to be located. For example in a small district it may be more economical to inspect the whole district than to perform a step test. A series of experiments was performed to resolve this situation and full details of these experiments can be found in WRC Technical Report *Results of the experimental programme on leakage and leakage control*.

7.67 From the experiments it can be concluded that step testing is worthwhile in both large and small areas and an ideal step size is approximately 100 properties. In smaller districts of up to 1,000 properties, the district should be divided into not less than 10 steps; in larger districts it is important that as many steps as possible are achieved.

7.68 In practice, the number of properties within each step will be determined by the location of the existing valves; however, it may not be necessary to use every available valve for step testing purposes. A step size of around 100 properties is also sensible from the flow measurement point of view. The smallest leak that in normal circumstances is worth pursuing is 500 litres per hour and this rate of flow in a step of 100 properties corresponds both to a typical district norm and to the resolution of the measurement of most waste meters.

Records

7.69 The records and plans required by the inspectors in carrying out the leakage control activities have been detailed in 7.36 and 7.37. Examples of these charts are given in Figures B1 and B2 of Appendix B.

7.70 In order to aid in the interpretation of the measurements of minimum night flows, records of all previous measurements should be maintained together with the details of the inspections required. This information is most conveniently recorded graphically. Past variations in the leakage and the inspections required can then be easily identified. A suitable card is shown in Figure 11.

7.71 Although of limited direct use to waste metering practice, it is also worthwhile to keep detailed records of the inspections and the leaks located. This will provide a valuable store of knowledge of the performance of the distribution system and may, for example, help to identify mains or parts of the distribution system which require renovation or replacement. A suitable layout for the recording of this information is shown in Figure 12 and this may be conveniently printed on the reverse of the night flow record card (Figure 11). This card records the steps which require inspection together with brief details of the leaks located.

8. LOCATION OF LEAKS

Introduction

8.01 The previous two chapters have dealt with methods of measurement required to determine whether or not a leak exists in a particular district, road or length of main. These methods are important and useful for directing the inspector to those areas where a leak is likely to exist. It is, however, the job of the inspector to determine the precise location of the leak and to mark the spot where the repair gang will have to excavate. Determining the position of a leak depends greatly on the skill of the individual involved. It is important therefore, that he be given adequate training, reliable equipment and the appropriate encouragement and motivation to carry out his task.

8.02 There are several ways in which the position of a leak may be determined; none of them is infallible, but some will be more appropriate than others in any given situation. It again depends upon the skill and judgement of the inspector to determine which method is most appropriate for the situation in question. All methods, with the exception of the gas tracer technique, rely upon the leak making a noise.

Characteristics of the noise of leaking water

8.03 Water leaking from a pressurised main emits sound over a range of frequencies and produces a hissing noise. The particular distribution of frequencies produced by a leak are specific to that one particular leak and will depend upon such factors as the nature of the leak, size of the orifice, pressure, pipe material, nature of the ground into which the leak is discharging, or whether that ground is waterlogged. The sound so produced will travel through the pipe, at a velocity which depends upon both the characteristics of water and the pipe material, and could also travel through the ground surrounding the pipe. As the sound travels away from the leak its character changes slightly since higher frequencies will be attenuated with distance and other frequencies may be amplified due to the presence of cavities or other buried underground equipment. The leak noise detected therefore, will depend upon the position at which a sounding is made. It is possible however, to make the following general statements.

- (a) Indirect soundings made on the ground surface above the pipeline will generally have a large component of the received sound in the low frequency band. (100–250 Hz).
- (b) Soundings made directly on the main or fittings will have the largest signal in a higher frequency band. (0.3–1 KHz).
- (c) With both surface sounding and direct sounding the position of highest sound intensity is not necessarily the position nearest to the leak.
- (d) Not all leaks produce a detectable noise.

Direct sounding

8.04 The most common way of determining the position of a leak is by direct sounding. This consists of making soundings directly on valves, hydrants, stopcocks and other convenient fittings listening for the characteristic noise of leaking water. The inspector uses his skill and experience to determine which sounds are produced by leaks and which are extraneous or interfering sounds and also to determine which fitting transfers the loudest noise. It can then be assumed that the fitting transferring the loudest noise is the one nearest to the leak but this is not always the case.

8.05 There are two ways in which direct sounding can be undertaken. The first is to sound only valves and hydrants with selected stopcocks and the second is to sound all fittings including valves, hydrants and stopcocks. Field experiments have shown that the second method is nearly always more cost effective than the first. Details of the experiments are given in WRC Technical Report *Results of the experimental programme on leakage and leakage control*.

8.06 An inspector sounding along a typical urban road will listen on valves, hydrants and consumers' stopcocks. If it is found that a particular stopcock is producing a noise, it is normal to note, in a book, the house corresponding to that stopcock and continue sounding other stopcocks in the vicinity, making notes of any others that are producing similar sounds. After some period

of time, he returns to those fittings that were making a noise on the first inspection and a second sounding is made. If it is found that the noise is still present it indicates either a leak on the communication pipe, supply pipe or in the household plumbing, or a continuous use within the house. The next step is usually to close the stopcock and again make a sounding. If the sound continues it indicates a leak on the communication pipe and is hence the water undertaking's responsibility. If the noise ceases it would be normal to undertake a house inspection and issue a waste notice if any fault were discovered. If the noise did not cease when the stopcock was closed, ie the fault is on the undertaking's equipment, then, unless the noise can also be heard on adjacent fittings such as stopcocks, hydrants, valves, etc it is likely that the fault is on the communication pipe and surface sounding is used to determine the position of the fault more precisely.

8.07 The time taken to perform direct sounding can vary greatly depending upon such factors as the type of area and the skill of the inspectors. Whilst sufficient time should be allowed for each sounding operation to ensure that no leakage is missed, experiments have shown that in normal circumstances in an urban area the access points corresponding to around 20 properties can be effectively sounded by one man in one hour. In adverse conditions such as high traffic noise or inaccessible stopcocks or in areas with long lengths of main between properties, this number will be reduced.

Surface sounding

8.08 Surface sounding, also called indirect sounding, consists of making soundings on the ground surface above the line of the pipeline to determine the point of maximum sound intensity. It is often very successful in urban areas where there is a hard surface above the main but is less effective in rural areas or for mains laid in grass verges. The technique can be particularly unreliable where recent excavations have been made and backfilled with imported material of acoustic properties different to the original material, or where other underground apparatus is laid in close proximity to the main containing the leak.

Summary of sounding techniques

8.09 Sounding is the most common and most cost effective method of locating leaks. New developments such as the leak noise correlator or SF₆ gas tracer, both discussed later, are likely to complement sounding rather than replace it. The advantages and disadvantages of sounding are given below. Although the disadvantages may appear formidable, it has been estimated that approximately 80 per cent of all leaks are found using the sounding techniques described. In practice inspectors use other signs such as increased growth of vegetation, moss on ground or walls, wet or damp patches and melted snow or frost to help pinpoint the leak.

8.10 The advantages of sounding are:

- (a) the equipment is relatively simple and inexpensive;
- (b) in conditions of low background noise, a large number of fittings can be inspected fairly rapidly;
- (c) it is possible to detect leakage within the premises, when used in conjunction with the turning off of the consumer's stopcocks.

8.11 The main disadvantages of both direct and surface sounding are:

- (a) it is sometimes difficult to determine the precise position of highest sound intensity;
- (b) the position of highest sound intensity does not always coincide with the position of the leak or the fitting nearest the leak;
- (c) sounding can be very difficult in areas with high background noise such as that produced by traffic in busy streets, or by boosters and certain fittings such as control valves;
- (d) successful sounding is dependent upon operator skill;
- (e) some leaks produce insufficient sound to be detected by any sounding technique.

8.12 The problems associated with extraneous noise can to some extent be overcome by either working at night or by shutting down or by-passing the equipment that is known to be producing noise. Leaks classified as (a) and (c) above, cannot be located by normal sounding techniques nor with conventional detectors. Leaks in category (e) cannot be found by any acoustic technique. The disadvantages listed as (a) (b) (c) and (d) above are overcome by the leak noise correlator.

Equipment used for sounding

8.13 There are two main types of instrument used for sounding purposes. The first is the stethoscope or listening stick and the second an electronic amplifier and detector. Both have advantages and disadvantages as discussed below.

8.14 *Stethoscopes.* A stethoscope or listening stick is a cheap, robust and reliable instrument for leak sounding purposes. It is a passive device, transferring the leak noise to the ear with a minimum of attenuation. Listening sticks are available in a variety of shapes and sizes and in a variety of woods and metals. Some are manufactured as a flat metal bar which enables them to be used for opening stopcock covers as well as for sounding. Others are collapsible with short stems which enables them to be conveniently carried in the pocket and can also be used for sounding on top of valve keys. Stethoscopes can be used for either direct or indirect sounding.

8.15 *Electronic leak locators.* Electronic leak detectors usually consist of a microphone, amplifier and frequency filters. The output of the amplifier can be fed to headphones, to a loud-speaker, to an indicating meter or to a combination of all three. The equipment is capable of detecting and amplifying the sound made by a leak but unfortunately in doing so can also amplify all other noises received by the microphone together with some noises induced by the electronic equipment itself. Electronic frequency filters are used to remove some of the unwanted extraneous noise and in certain circumstances this can be very effective. The indicating meter is used to display a measure of the total sound intensity received by the microphone and hence is a much more sensitive method of determining the position of maximum intensity than is the stethoscope which relies solely upon the skill of the operator.

8.16 As already stated, the characteristics of a leak noise will vary, depending on whether it is sensed by direct sounding or surface sounding. It is theoretically possible to design different microphones which will be more sensitive to these two modes of operation, normally an accelerometer for direct sounding and a geophone for surface sounding. Some commercially available equipment includes these refinements. A list of the more commonly available leak detectors is given in Table 8.

Table 8. Leak detectors in common use

<i>Stethoscopes:</i>	<i>Electronic detectors:</i>
Palatine	Terroscope
Abbot Birks	Sewerin Aquaphone (Zuurbier)
Metchener	Metrotech
John Bailey	Fisher
Drasdo	Capac
	Sharman
	Goldak
	Seba

8.17 *Comparison of detectors.* To the human ear a leak noise heard via a stethoscope is likely to sound quite different in character to the same leak heard by an electronic detector, particularly if filters are used. It follows therefore that even an experienced inspector will require a period of time in which to become accustomed to a particular electronic leak detector and it is likely that an inspector who uses an electronic detector continually will get better results than an equivalent inspector who only uses one occasionally. Unfortunately, it is normal for stethoscopes to be used as a matter of routine and electronic detectors to be used only in difficult cases or by specialist teams.

8.18 Consequently comparing electronic detectors with stethoscopes and comparing one electronic detector with another is extremely difficult since the comparison is not only between instruments but also between individual skills, experience and training and is unlikely to lead to any

convincing conclusions. However, in an attempt to give some guidance to the industry, the following assessment has been made.

8.19 From a purely theoretical point of view, the following conclusions might be expected by comparing the performance of stethoscopes with the electronic detectors and comparing one electronic detector with another.

- (a) All instruments give better response when direct sounding on metallic pipelines than on non-metallic pipes or the surface.
- (b) Electronic detectors are likely to be more effective than stethoscopes in situations when the leak noise signal is low or where the background noise is high.
- (c) Electronic detectors with separate microphones for direct and surface sounding are likely to be more effective than detectors with only a single microphone (normally for surface sounding).

8.20 In order to gauge subjective opinion of the relative merits of stethoscopes and electronic detectors, a questionnaire was circulated throughout the whole of the industry in the United Kingdom.

8.21 It was found that the water industry's subjective assessment of leak location equipment agrees with that expected from a theoretical standpoint. Unfortunately there were insufficient numbers of electronic detectors with separate microphones for direct and surface sounding to determine whether these have a significant advantage. There was also insufficient data to determine whether one leak locator was thought to be more effective than any other.

Leak noise correlator

8.22 The leak noise correlator is a leak locating instrument which does not seek the point of highest sound intensity and is unaffected by background noises. The instrument, which has two microphones, utilises the technique of cross-correlation to determine the difference in time between the leak noise reaching the two microphones.

8.23 The first leak noise correlator was developed by the Water Research Association in the early 1960s. That prototype instrument used a 16-track tape recorder to make sound recordings of the leak noises. These tape recordings were then processed back in the laboratory and the position of the leak determined some days later. This early technique, whilst producing accurate results, was rather expensive in terms of both equipment and manpower and consequently inappropriate for practical use by the water industry. In recent years considerable advances have been made both in the field of micro-electronics and in techniques for cross-correlation. The Water Research Centre has utilised these advances and in conjunction with the Plessey Company has produced a leak noise correlator which is completely portable. The new equipment no longer requires tape recordings to be made; it performs the correlation process in the field and is unlikely to take more than two hours to determine the position of a leak even in the most difficult circumstances. The equipment is self-contained, battery powered and is now commercially available. A brief description of the way in which the correlation technique is used is given below and full details of both the equipment and its use are given in WRC Technical Report *The location of leaks in water mains using the leak noise correlator*.

8.24 Figure 13 shows a length of main which contains a noise producing leak with the microphones, A and B, placed either side. The unknown distance of the leak from microphone A is small 'a' and the total distance between the two microphones L:

The time taken for the leak noise to reach A = $a \div v$
and the time taken for it to reach B = $(L - a) \div v$
where v = velocity of sound in the pipe.
The difference in time to reach the two = $(2a - L) \div v$
microphones (t)
Re-arranging, the position of the leak is given by $a = (tv + L) \div 2$

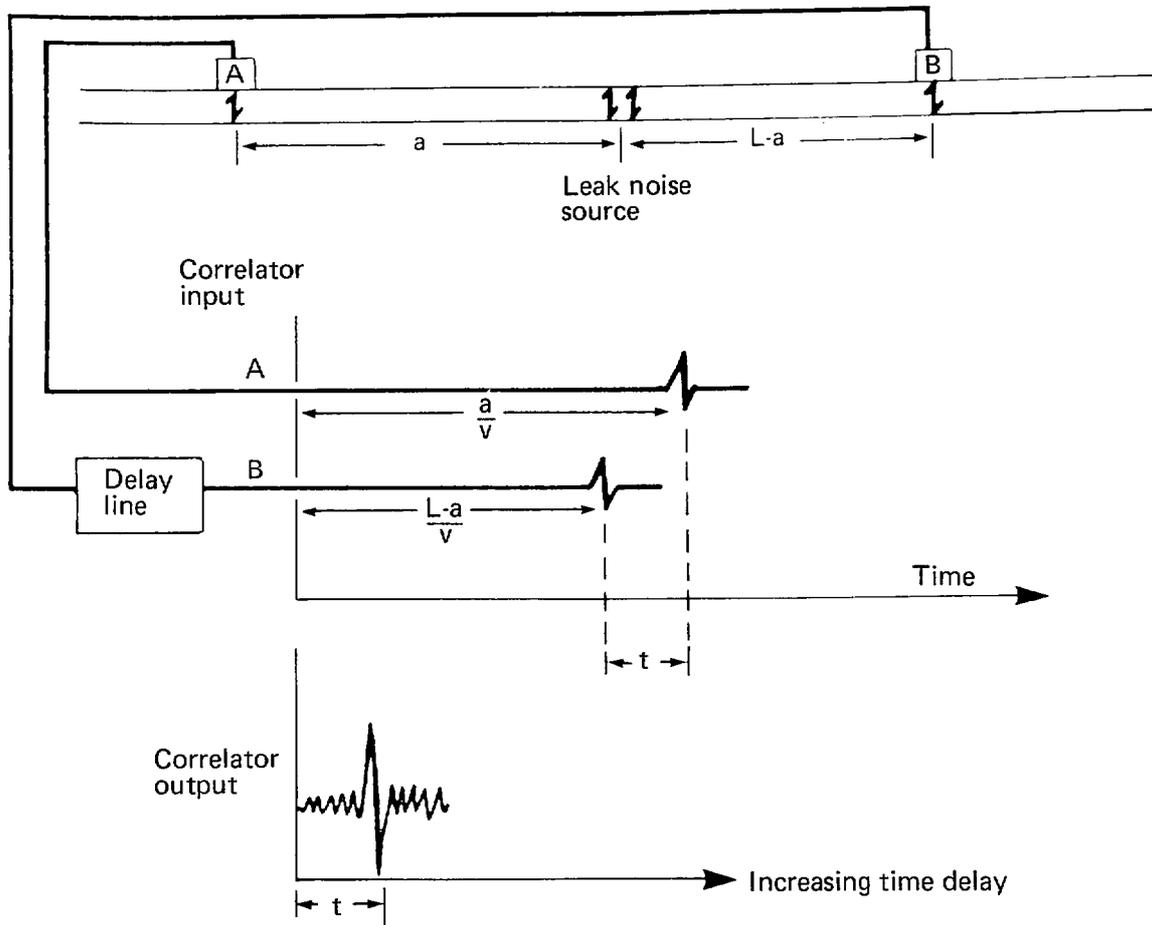


Fig. 13. Correlator diagram

8.25 Consequently, provided the velocity of sound is known, the position of a leak can be determined by measuring the difference in time taken for the noise to reach the two microphones.

8.26 The time difference t , is measured using the leak noise correlator (Figure 14). The correlator receives the signals from the microphones A and B and compares the similarity between them. One signal is then progressively delayed relative to the other whilst continuing to compare the similarity between the two signals. The time delay at which the two signals match is equal to the time difference.

8.27 The leak noise correlator will be particularly useful in urban areas where there is a large number of access points such as valves, hydrants and stopcocks but in rural areas there may be long lengths of main without any access points at all. The alternatives here would be to drill holes through the soil so that access could be made to the pipe with iron bars. This technique is commonly used by one company specialising in leak location.

Gas tracer technique

8.28 If a leak is known to exist, but no leak noise can be detected, a tracer technique is probably the most effective way of determining the position of that leak. The principle of any tracer technique is extremely simple. A substance is injected into the main which will either mix or dissolve in the water and some of which will leave the main at the position of the leak. A detector is then used to search for the substance that escapes from the main and thus the position of the leak is found. The technique is particularly suitable for rural mains and trunk mains where the absence of fittings prevents the use of normal sounding techniques and bar holes can be made easily. The technique can also be used in urban areas but the problems and cost of producing and reinstating the bar holes in roadways make it less attractive.

8.29 Over the years a variety of substances has been tried for leak location purposes including radioactive tracers, carbon tetrachloride and freon. Until recently the most common tracer used for potable water mains was nitrous oxide gas. The method, which was developed by the Water



Fig. 14. WRC Leak noise correlator

Research Association, has been used successfully for a number of years but unfortunately the infra-red analyser used for detecting the presence of nitrous oxide is no longer commercially available. The method is, however, offered as a service by a commercial contractor.

8.30 Within the last few years a new tracer gas and detector has been proposed which has produced good results for locating leaks in potable water mains. The tracer gas used is sulphur hexafluoride (SF_6) and this has a number of advantages.

- (a) Sulphur hexafluoride is very much less soluble in water than nitrous oxide and readily comes out of the solution at the leak site, where it diffuses through the soil as a gas. This results in only shallow bar holes being required.
- (b) Sulphur hexafluoride can be detected in much smaller quantities than nitrous oxide and hence a smaller quantity of gas need be injected into the main.
- (c) The sulphur hexafluoride detector is small, light and easy to use.
- (d) Sulphur hexafluoride is a colourless, odourless, non-toxic gas and has been approved in the United Kingdom for use in distribution systems.

8.31 A brief description of the method is given below but full details of the method and the equipment used, together with a step-by-step procedure for its use are given in WRC publication TR.80 *Location of leaks in pressure pipelines using sulphur hexafluoride as a tracer.*

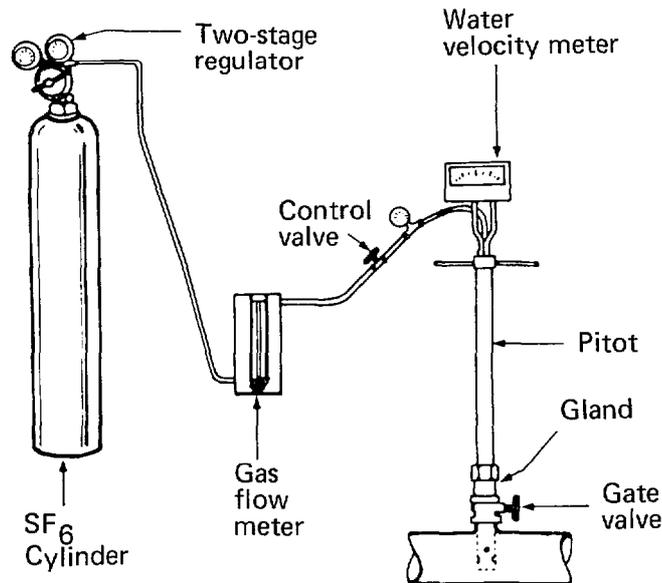


Fig. 15. General arrangement of equipment for gas injection

8.32 Sulphur hexafluoride gas is injected into the mains so as to produce a concentration about 7 mg/l. The injection equipment is shown in Figure 15. A tap or hydrant downstream of the suspected leak is sampled to ensure that the gas has passed the site of the suspected leak. Bar holes about 150 mm deep and about 25 mm in diameter are made in the surface above the line of the pipe and with a space between holes of approximately the same as the depth of the pipeline. At the site of the leak, the gas-water solution leaving the main experiences a reduction in pressure and since it is only slightly soluble at atmospheric pressure SF₆ comes out of solution. It diffuses through the soil and collects in the bottom of the bar holes. The content of each bar hole is sampled in turn using a hand-held detector. The presence of the gas is indicated by a meter on the back of the detector.

Other techniques

8.33 If a leak is known to exist and the normal sounding techniques have failed and neither the leak noise correlator nor the SF₆ technique is available, then the alternatives left to the inspector are few in number, very inefficient and often extremely expensive.

Cut and cap

8.34 The main is isolated from all other connections and shut at some downstream valve. Water is supplied into this isolated section of main via a meter. The main is then cut and capped in the centre. If the flow continues the leak lies between the meter and the end cap. If the flow ceases the leak is downstream of the centre capping. This process is repeated, each time halving the length of the main containing the leak until its position is located.

Trial excavation

8.35 Excavations are made along the line of the main at approximately three-metre intervals searching for the presence of water. In the past it has been common to drive a bar horizontally along the line of the main, searching for signs of water. This can however be dangerous and it is not recommended unless it is known that no electricity cables exist within the area.

Wait and see

8.36 Leave the leak running in the hope that eventually sufficient water will be lost that it becomes apparent on the surface of the ground or that it starts to produce a detectable noise.

9. LEAKAGE FROM SERVICE RESERVOIRS

Introduction

9.01 Results of the field trials, reported in Part 2 of this report, have shown that, in general, leakage from service reservoirs is small and consequently regular monitoring of service reservoir leakage cannot be economically justified in terms of the water that might be saved. There are, however, factors other than economic ones which require a reservoir to be inspected. The more important of these are structural safety and water quality. Also if water is leaking from the reservoir at some given level, water could leak back into the reservoir when the level is drawn down thus introducing contamination.

9.02 It is important that every service reservoir should have regular inspections of structural condition, cleanliness and watertightness. It would therefore be extremely advantageous to develop a procedure whereby reservoirs were periodically tested for water tightness, drained, cleaned and washed down and visually inspected.

9.03 It has been found that high levels of leakage can result from a service reservoir overflowing due to absent or faulty level controls. A simple method to determine whether a reservoir has overflowed is to put a match box, handful of sand or a foam swab in the overflow pipe to act as a tell-tale.

Measurement of leakage

9.04 The most reliable method for the measurement of leakage from a service reservoir is to isolate the reservoir from supply and to measure the change in level over some suitable time period. As all measurements are of changes in level, the accuracy of individual measurements is of little consequence; of more importance is the discrimination i.e. the smallest change that can be detected.

9.05 In many cases it will be possible to isolate the reservoir for 24 hours or more and consequently a leakage measurement accurate to a centimetre (ie a depth reading to 5mm), is sufficient to produce a measurement of the leakage with an error of 0.25 per cent of capacity or less. A discrimination better than this is unnecessary as this level of leakage will normally be considered insignificant.

9.06 If it is only possible to isolate the reservoir for a few hours the discrimination of the measurement becomes more important. Depth readings of ± 0.3 mm are required for a duration of two hours. This may be impractical in many instances owing to a surface 'swell' which may take several hours to disappear. A stilling tube could help to reduce this problem with some items of equipment. If reservoirs have a dividing wall then it will normally be possible to isolate each half separately for a suitable time period.

9.07 Measurement of reservoir level may also be required for the estimation of total leakage within a supply and distribution system. Again the discrimination of the level recorder is of prime importance and whilst the rate of fall will depend upon the particular system under consideration, rates of fall as low as 15 mm per hour are possible. This will normally require readings to be taken to within 0.25 mm or possibly 0.1 mm especially if it is necessary to measure average flow rates over periods less than one hour.

Equipment

9.08 The equipment suitable for the measurement of reservoir levels falls into several basic types; these are detailed below in order of increasing sophistication and cost. A brief discussion of the suitability of each of these types of equipment for the above purposes is included and a list of relevant manufacturers is given in Appendix C.

Sight gauges

9.09 A simple and cheap method of measuring reservoir level consists of an external sight tube with a graduated scale. For a permanent installation a drain valve is fitted in order to reduce scaling; a float marker will improve observation if scaling is a problem. Sight gauges installed in reservoir outlet pipes are affected by the flow in the pipe and consequently are unsuitable for measuring minimum night flow. These gauges are relatively simple to manufacture.

Typical discrimination: to 1 mm

Advantages: (a) simple method
(b) easy to manufacture and install
(c) little maintenance
(d) inexpensive – approximate cost is £250

Disadvantages: (a) non-recording
(b) unsuitable for measuring minimum night flow

Water level sensors

9.10 This family of devices consists of a water level sensor connected to a graduated scale. A variety of sensors are available, the most common of which is the hook gauge which relies upon a change in reflected light as the point of the hook breaks the water surface from below. A similar instrument is the point gauge which breaks the water surface from above. More sophisticated electric sensors produce an audible signal or light a bulb when a circuit is established by the shorter of two probes contacting the water surface. These have the advantage that it is not necessary to see the water surface.

9.11 The graduated scale, at its simplest, consists of a measuring tape; this is unsuitable for all but longer period measurements of service reservoir leakage. More accurate results are obtained with the vernier or micrometer screw arrangements of some devices.

Typical discrimination: 1mm – with measuring tape
0.2mm – with vernier

Advantages: (a) sensitive to small changes in level
(b) simple to construct
(c) accurate over wide range
(d) inexpensive – £100 to £400 depending upon sophistication.

Disadvantages: (a) non-recording
(b) accuracy dependent upon the operator:

Float gauges

9.12 This equipment is in common use throughout the water industry for routine level monitoring and consists of a float connected by a cable to a pulley. The pulley operates a mechanism which positions a pen on a recording drum in direct proportion to the motion of the float. It is unlikely that existing equipment will be sufficiently accurate for measurements of leakage; however, by interchanging the float, pulley and the gears that control the recording drum, a 1:1 recording ratio and reduced time scale can be obtained.

Typical discrimination: 1mm (1:1 recording ratio)

Advantages: (a) in common use
(b) recording instrument
(c) inexpensive for recording instrument – £500 to £750.

Disadvantages: Unsuitable for use as a flow meter.

Submersible pressure and level transducers

9.13 These devices utilise pressure transducers, which are suspended beneath the water surface and record the depth of water above them. The output device can consist of a meter, a digital display or a recording unit. The discrimination of these instruments depends upon their measurement span and changes in temperature may affect the accuracy of some transducers.

One level measuring device of this type has been specifically designed for leakage control purposes. It consists of a level transducer and recorder and for unattended operation the system is equipped with time and level switches.

Typical discrimination: 0.2mm for 300mm span
0.5mm for 1 metre span

- Advantages:
- (a) easy to install
 - (b) virtually no moving parts
 - (c) continuous measurement
 - (d) can be used manually or with recorder.

Disadvantages: high cost of £500 to £1,500 depending upon output device.

Location of leakage

9.14 In all but a few exceptional cases, it is unlikely that the location of leakage from service reservoirs will be undertaken solely to reduce leakage as in general the methods and techniques available are relatively expensive. It is only possible in this report to provide a list of the available techniques and these are set out below. If it is found that water is being lost from the reservoir, it does not necessarily mean that the structure of the reservoir is leaking. It is possible that an isolating valve is letting by or the pipework leading up to the valve is leaking and these should be examined before undertaking one of the more expensive options given below.

The methods of location of service reservoir leakage include:

- (a) Drop tests at various levels.
- (b) Inspection of the underdrains, if appropriate.
- (c) Tracers inserted within the reservoir at various levels eg Indian ink, potassium permanganate, oatmeal.
- (d) Visual inspection of full reservoir by divers.
- (e) Visual inspection of empty reservoir including regular inspections whilst drying out.
- (f) Borehole tests – internal and external.
- (g) Injection of compressed air into underdrains with a few inches of water in the reservoir.
- (h) Excavation of exterior of walls.

10. TRUNK MAIN LEAKAGE

Measurement of leakage

10.01 Three ways in which trunk main leakage can be measured are:

Meter on a bypass

Heat pulse flow meter

Pairs of insertion turbine meters

10.02 The last technique, could also be applied to pairs of other meters where it is possible to measure rate of flow or velocity. It is considered that subtracting bulk meter readings at the inlet and outlet of the main is unsatisfactory for measuring leakage absolutely although they may indicate changes in leakage.

Meter on bypass

10.03 The easiest method of measuring trunk main leakage is to close two valves on the line, one upstream and one downstream. 25mm tappings are made on either side of the upstream valve and a small meter, typically a 25mm semi-positive displacement flow meter, is connected between the two tappings. Any leakage on the section under test will be registered on the meter. The advantage of this method is that it utilises equipment that will be available in any water undertaking. Disadvantages are firstly that the main has to be taken out of service and secondly, if either the upstream or the downstream valve is letting-by, a false measurement of leakage will be obtained.

10.04 The approximate position of any leakage measured can be determined by the successive closing of any sluice valves along the main in the manner of a step test. This method has the disadvantage that trunk mains normally have few, if any, sluice valves along their length and that an accurate measurement depends upon the drop tight closure of these valves. There will usually be little to be gained by moving the meter.

Heat pulse flow meter

10.05 The second method of measuring the trunk main leakage is to use the heat pulse flow meter. This is an insertion type meter, as shown in Figure 16, and will pass through any 25mm clear, straight tapping. The meter is used by isolating the trunk main at some downstream point and inserting the meter through a tapping made at some upstream point. Any flow registered by the meter will be leakage along that trunk main plus any water which is letting-by the shut valve. Inserting the meter through a tapping adjacent to, and just upstream of, the shut valve will provide a measure of water passing the valve and the difference between the two readings is the leakage along the length of the main. If it is found that leakage does exist along the main, its approximate position can be determined by closing valves. In view of the disadvantages of this method, a better technique is to insert the meter through additional tappings made along the length of the main to determine whether the leakage is upstream or downstream of this additional tapping. This is equivalent to cutting and capping but of course is very much cheaper.

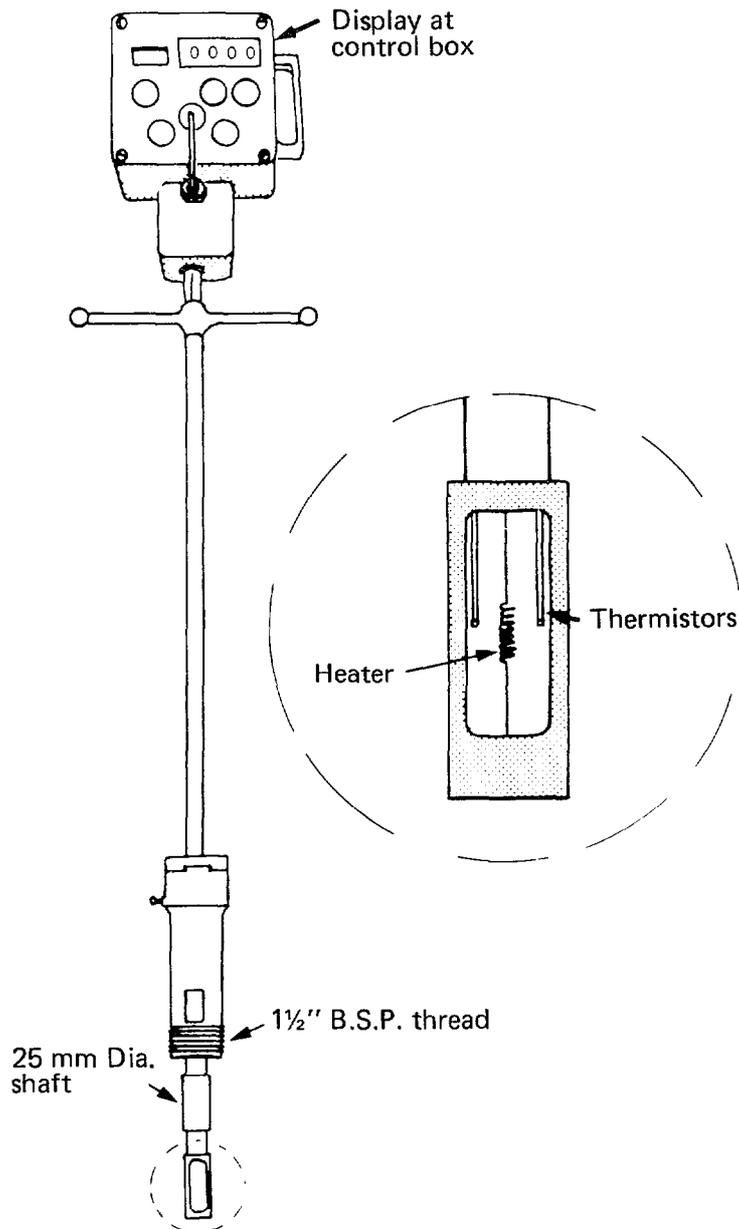


Fig. 16. Sketch of heat pulse flow meter

10.06 The meter is capable of measuring velocities in the range of 2 to 25mm per second with an accuracy of about ± 1 mm per second. The meter will, however, indicate a much higher velocity than 25mm per second but with less accuracy. For leak detection purposes this is adequate since leakage velocities greater than 25 mm per second will usually warrant further investigation. The advantages of this method of trunk main leakage measurement are:

- (a) The method accounts for any water which is 'let by' the valves.
- (b) It can be used to determine roughly the position of the leak.

10.07 The disadvantage is that the trunk main has to be isolated from supply albeit for a short period of time.

10.08 Full details of the heat pulse flow meter and a step-by-step procedure for its use are given in WRC Technical Report *Detection of leakage from trunk mains using the heat pulse flow meter*.

Pairs of insertion turbine meters

10.09 It is well known that in situations where flow meters are installed on the inlet and outlet of the trunk main, only very large leaks can be detected because of errors in the meters themselves, and often the difference between two measurements indicates a net gain along the length of the main. At first sight, the thought of using two flow measurements made with insertion meters would appear to add to this problem since problems of integrating the velocity profile to obtain mean velocity and uncertainties about the exact cross-sectional area of the pipeline at the point of measurement could increase the errors in flow measurement. These errors do not, however, affect the measurement of trunk main leakage since the two meters are not used to make flow measurements as such.

10.10 As the rate of flow through a trunk main varies, the velocity at the two measurement points also varies. Differences in the velocity at the two measurement points caused by differences in the velocity profile or cross-sectional area will vary in a velocity proportional manner, whereas the velocity differences between the two measurement points due to leakage will be independent of velocity. Consequently, by comparing upstream flow with downstream flow or upstream velocity with downstream velocity over a range of flows it is possible to determine the degree of leakage between the two measurement points. This is demonstrated in Figure 17. Manual analysis of the flow data obtained is sufficient to detect leaks producing velocities in the main equivalent to 10mm per second or greater. For detection of leaks below 10mm per second and down to a minimum of 3 mm per second it is necessary to repeat the measurement with the meters exchanged end for end and use a more sophisticated analysis of the data which will involve the use of a computer programme.

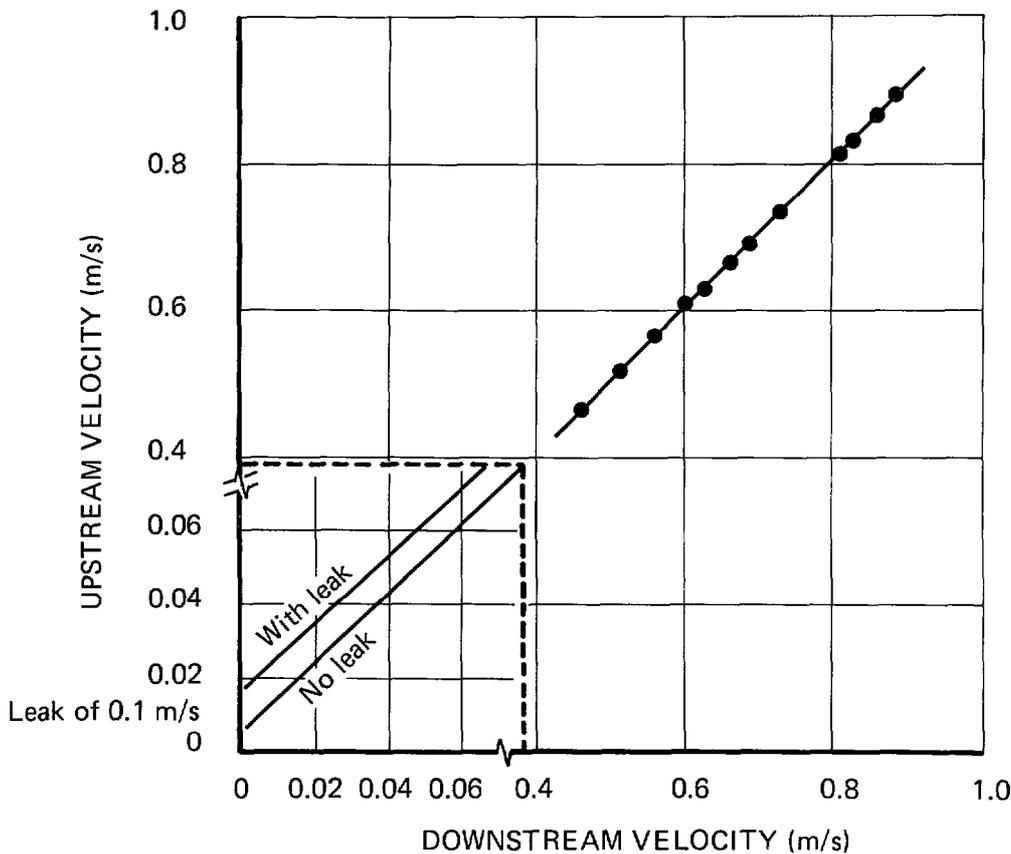


Fig. 17. Typical results of trunk main leakage measurement using pairs of insertion turbine meters

10.11 The advantage of this method of trunk main leak measurement is that it is not necessary to take the trunk main out of supply in order to make the measurement. The meters can also be inserted through additional tapplings made along the length of the main to determine roughly the position of the leak.

10.12 The disadvantage is that it requires two site visits, the first to install the meters and the second, approximately 24 hours later, to remove the meters and to collect the data.

10.13 Full details of this technique together with the equipment and the methods for analysing the data are given in WRC Technical Report *Detection of leakage from trunk mains using pairs of insertion turbine meters*.

Location of leaks on trunk mains

10.14 Each of the above methods enables the approximate position of any leakage to be determined. With the latter two techniques, which do not depend upon the position of the valves, the most effective procedure is a repeated halving of those sections of main containing sufficient leakage until lengths of main short enough for a more detailed inspection are obtained.

10.15 With all of these techniques there still remains the problem of determining the exact position of the leakage. There are several ways in which this could be undertaken as discussed below.

Walking the main

10.16 The simplest and most common way of looking for trunk main leakage is to walk the length of the main, looking for signs of water, changes in vegetation growth, illegal connections or any other tell-tale signs. Obviously the method could only be applied to trunk mains laid in open country and is of little use for mains laid under roadways.

Sounding

10.17 Sounding techniques, as discussed in Chapter 8, may be used to locate the leakage but, owing to the lack of access points on trunk mains, indirect sounding will be required predominantly. This will be more successful on mains laid under roadways; however, if the leakage has been isolated to a short enough length of main, direct sounding on the main following selective excavation may be worthwhile on some rural mains.

Pressure measurements

10.18 This method is only practicable for mains laid on sloping ground. The residual static pressure at the lower end of the isolated main will indicate the level of the point of leakage and therefore its approximate position.

Sulphur hexafluoride

10.19 The use of the sulphur hexafluoride gas tracer technique is a much more positive method of determining the position of trunk main leakage. However, since the effort required to sink barholes is fairly high, particularly if the main is under the roadway, it is important that the approximate position of the leak be established by using one of the methods outlined above. The sulphur hexafluoride technique is described in Section 8.28.

Hydrophones

10.20 The use of hydrophones ie underwater microphones sensitive to low levels of sound is currently being investigated by the Water Research Centre.

10.21 It is known that leak noises do not travel very far in large diameter and/or non-metallic pipes, when sounding on the pipe surface. It is possible that hydrophones placed in the water column, at hydrants or special tapplings, will enable the sound to be detected over longer distances.

Remote sensing

10.22 During 1977 a preliminary investigation into the use of remote sensing techniques for location of leaks was undertaken jointly by the Water Research Centre and Plessey Radar Limited.

Two remote sensing techniques were investigated.

- (a) Thermal infra-red line scan; a technique that forms an image based on differences in temperature.
- (b) Multi-band photography; a technique for detecting very small differences in colour.

10.23 The remote sensing equipment was mounted in an auto-gyro and flown at heights varying from 250 feet to 1000 feet over a series of artificial leaks. The results obtained were inconclusive, although generally the infra-red line scan indicated the leak better than the multi-band photography. It was found that successful location of the leak depended upon such factors as:

- (a) the leaking water reaching the ground surface.
- (b) the weather — whether clear or cloudy skies.
- (c) the type of vegetation.
- (d) whether the surrounding ground was wet or dry.
- (e) the position of shadows cast by surrounding trees or buildings.

10.24 It was found that the presence of surface anomalies made it possible to detect the pipeline from infra-red images even though the pipes had been laid up to 30 years previously. The technique could therefore be used for pipe location in rural areas. Figure 18 shows a typical thermal line scan image with the position of leak and main clearly visible.

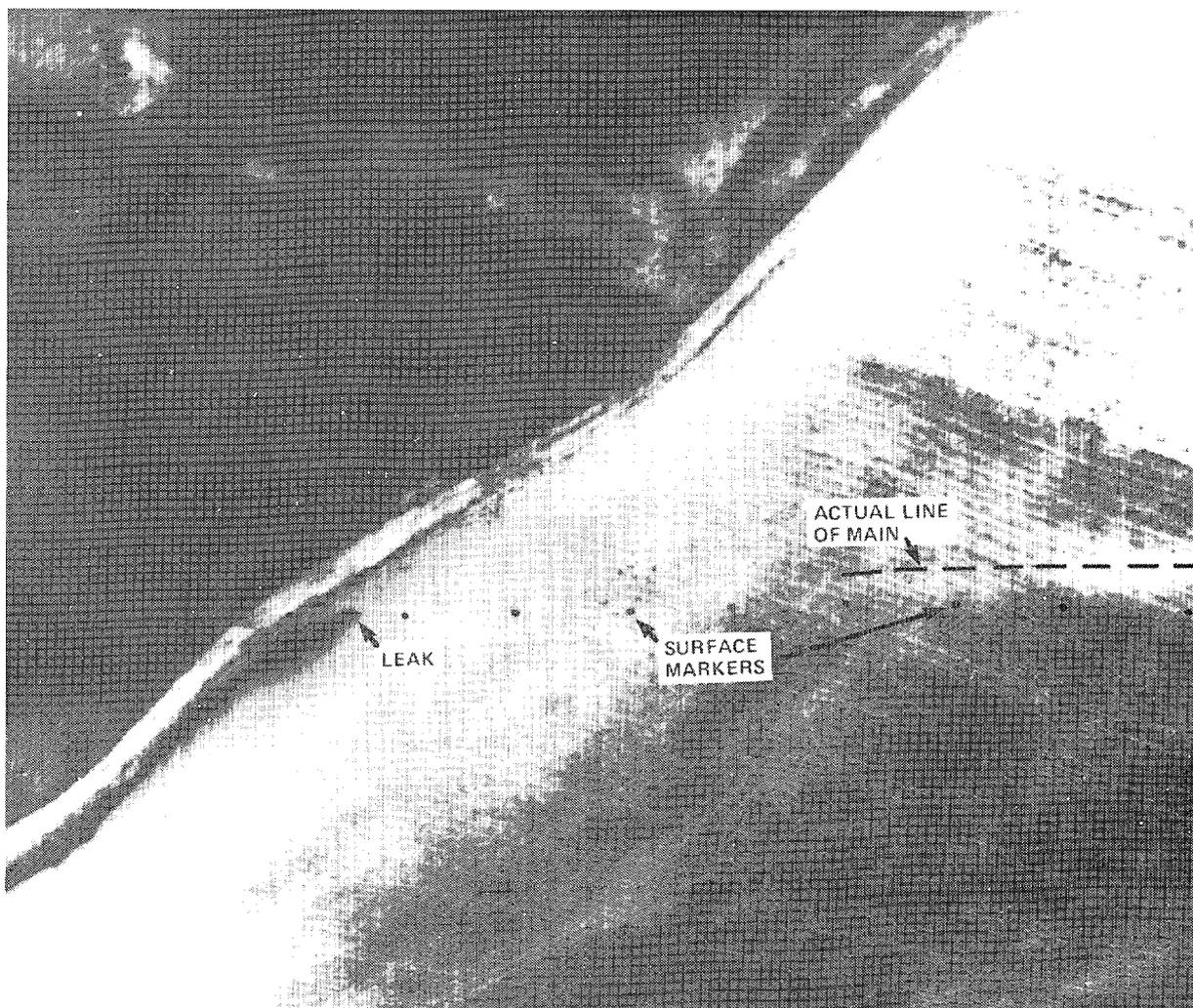


Fig. 18. Thermal line scan image

10.25 It is likely that leaks from pipelines laid in open ground could be detected remotely using the infra-red line scan provided that sufficient of the leaking water reaches the surface to form a damp patch or produce an anomaly in the vegetation growth, the weather is clear and dry on the day of the flight and on the preceding two or three days and the site is clear of shadows. The technique is, however, expensive and is unlikely to be justified for leak detection purposes unless a flight is being made for another purpose.

11. PIPE LOCATORS

Introduction

11.01 All existing pipe locators used by the water industry come under the general heading of 'low radio frequency instruments' and can only be used for locating metallic pipelines. All of the locators work by causing an alternating current to flow in the pipe and detecting the magnetic field thus produced. The alternating current may be caused to flow in the pipeline by either induction or conduction.

11.02 Induction is probably the most convenient method, because it is not necessary to have access to the pipeline at any point. Pipe locating equipment used inductively can usually be used in one of two modes.

- (a) On handle mode – the receiver and transmitter are joined rigidly by means of a long handle.
- (b) Off handle mode – the transmitter is placed on the ground above the line of the pipeline and the receiver is used separately.

11.03 Equipment used to make the current flow in the pipeline by conduction can also be used in two forms:

- (a) Earthstake coupling – the transmitter is directly connected between a fitting on the pipeline and an earthstake driven into the ground at some distance from the pipe to be located.
- (b) Direct connection – the transmitter is connected by wires to two access points on the pipeline, the section between which is to be traced.

Discrimination

11.04 The major problem, shared by all pipe location equipment, is that of discrimination between closely spaced mains and services. The degree of discrimination will depend on the mode of operation. For instruments used inductively, it is likely that discrimination between two parallel pipelines will only be achieved where the separation exceeds 1.25 to 1.5 times the depth, for the off handle mode and approximately 1 times the depth for the on handle mode. With conductive coupling, discrimination is likely to be better than 1 times depth if direct coupling is used.

Accuracy of location

11.05 The sharpness of response of pipe location instruments to buried pipelines will depend on the depth and the mode of operation. Inductively coupled instruments used in the on handle mode give a slightly sharper response than the off handle mode. The location accuracy obtained with instruments used in the conductive mode will in most cases be better than instruments used inductively although the position of the connecting wires can move the apparent position of the pipeline.

11.06 Off handle instruments and instruments used in conductive mode can be made to respond more sharply to a buried pipeline by holding the receiver coil vertically instead of horizontally and looking for a null instead of a maximum. This gives a resolution to within a few centimetres for a single pipe but since the null position is more seriously affected by adjacent services, tees, right angled bends etc, than is the peak position, more caution is needed where the null mode is used.

Use of equipment

11.07 Inductively coupled instruments are much easier to use than conductively coupled ones since it is not necessary to have direct access to the pipeline nor run out lengths of cable or drive in earthstakes. An on handle instrument is more difficult to use than an off handle instrument

since small changes in orientation of the device alter both transmitter and receiver positions relative to the pipe and cause large changes in the response of the instrument. This will limit the better discrimination ability of the instrument.

11.08 With the on handle instrument, elimination of the direct transmitter field is performed by critical adjustment of the receiver coil orientation. This is difficult, because direct pick up is easily confused with the response from the ground. In the off handle mode separation between the transmitter and the receiver is much greater, consequently direct pick up is minimised.

11.09 Use of the conductively coupled instruments is sometimes made difficult by the need to have earthstakes or run out long lengths of cable. Finding a suitable position to drive in an earthstake can sometimes be very difficult in urban areas although use can sometimes be made of metal lamp-posts or manhole covers. When the direct connection mode of operation is used it is important to have the return wire situated as far away as possible from the main it is intended to trace.

11.10 For ease of use, the various equipment and techniques available could be ordered as follows:

- (a) Inductively coupled off handle mode.
- (b) Inductively coupled on handle mode.
- (c) Conductively coupled with an earthstake.
- (d) Conductively coupled with connection to both ends of the pipeline.

11.11 Unfortunately, for better discrimination and location accuracy the reverse of that list is probably correct.

Existing equipment used by the water industry

11.12 Table 9 shows the pipe tracing equipment currently used by the industry. The first five instruments listed in Table 9 account for 80 per cent of the location equipment and of these the first can only be used in a conductive coupling mode, the second can be used conductively or inductively in the off handle mode, the third and fourth are unknown and thought to be out of production, and the remainder can be used inductively on or off handle and can also be used conductively.

11.13 It would appear that there is possibly some scope for improving the equipment currently used for pipe tracing to take advantage of recent developments in electronics. It would, however, be a waste of time to purchase new and possibly more sophisticated methods of tracing pipes without giving adequate training to the personnel responsible for using this equipment.

Table 9. Pipe locators in common use

Cintel
Terroscope
Sharman
Hattersley Davidson
Fisher M Scope
Sewerin (Zuurbier)
Metrotech
Goldak
Unilec
Releaver

Future developments

11.14 A number of improved methods for locating metallic and non-metallic pipes are currently under investigation. The majority of this work is being undertaken either directly or co-ordinated by the British Gas Engineering Research Station. The methods under investigation include an

improved inductively coupled off handle instrument for locating metallic pipelines, a microwave technique which would be suitable for both metallic and non-metallic pipelines and a sonic method which would also be suitable for metallic and non-metallic pipelines.

12. TELEMETRY FOR LEAKAGE CONTROL

Introduction

12.01 A telemetry system has the potential to provide two benefits. These are:

1. reduction of manpower leading to a more efficient operation
2. provision of more data leading to a greater overall efficiency in the leakage control procedures.

12.02 Installation of a telemetry system for leakage control purposes should therefore lead to greater overall efficiency either because of the reduced number of man hours or a lower level of leakage or both.

12.03 A number of water undertakings have installed, or are planning to install, telemetry systems which will be used either entirely or partially for leakage control purposes. Some of these undertakings have taken different approaches to the problems of leakage control telemetry systems and these are discussed briefly below.

Measurement of total inflow

12.04 Flow meters are installed at each input and service reservoir within the supply system and all measurements are relayed to a central control room. Records of both flow rate and total quantity can be made. This type of telemetry system is usually installed for the management of sources and pumps but is also used for leakage control purposes. The system is particularly useful where a number of pumped sources exists and it is possible to alter pumping schedules. Its effectiveness for leakage control depends upon the size of the areas which can be monitored; these are normally much larger than waste meter districts or district meter areas. The system allows large bursts to be detected almost immediately because of a sudden increase in flow rate from one or more of the sources or reservoirs. Analysis of night flow data enables the occurrence of small or medium size bursts to be detected two or three days after their occurrence. Significant increases in the general level of leakage can also be seen from analysis of minimum night flow. The system is insensitive to small changes in leakage and provides little information on the likely leak position.

Telemetering of district meter measurements

12.05 This method involves the installation of district meters, but with all meter readings capable of being fed back to a central control. The information obtained from the meters is used in a similar way to that described in 6.02, 6.03 and 6.04 but, because of the greater availability of flow data, such as integrated hourly quantities and instantaneous flow rates, it is possible to obtain a much better understanding of the system and any changes that may have occurred. The data fed back to the central control would probably be too great to analyse manually, and a small on-line computer would be required.

12.06 As yet there are no computer telemetered district metering systems in existence within the United Kingdom. A few pilot schemes are planned but detailed costs and benefits of these schemes will not be available until 1981. It is not possible, therefore, to determine whether full telemetering of a district metering system could be economically justified.

Automatic waste metering

12.07 The third approach is to automate the method of waste metering described in Chapter 7. The technique involves the installation of some remotely controlled valves and telemetering of night flow rates. With this approach it would be possible to isolate districts, take open readings and perform tests all from a central control point. Not every valve used for the waste metering exercise needs to be remotely controlled since some can be shut manually during the day prior to the test and opened the following day after the test. The number of remotely controlled valves required can therefore be kept to quite a small number.

12.08 The results obtained from this type of system could also be fed into a mini computer for automatic analysis and comparison with previous measurements. This type of system is being installed by one undertaking but full cost benefit data is not yet available.

Summary

12.09 Other methods of telemetering or automating the leakage control procedure could be envisaged. From the technical point of view there are few limitations and almost any leakage control function could be undertaken remotely. The major consideration in any scheme must be the costs of setting up and operating and the likely benefits that would be obtained. These matters are the subject of further work which is currently being planned by WRC and these will be reported in the future. At present the Working Group is unable to give any guidance as to whether a telemetry system for leakage control purposes could be worthwhile and if so which approach is likely to be the most efficient.

APPENDIX A

GLOSSARY OF TERMS

area: a part or sub-division of a supply and distribution system of unspecified size or characteristic.

communication pipe: that part of a service pipe which runs from a main to, and including, a stopcock at or as close as is reasonably practicable to the boundary of the street in which the main is laid.

consumer: a person supplied, or about to be supplied, with water by a water supply undertaking.

consumption: a volume of water taken from a water supply main into a consumer's installation.

demand: the volume of water which has to be put into a supply and distribution system to satisfy the requirements of consumers plus leakage and other waste which may be incurred in the process.

distribution main: a pipe laid by the water supply undertaking for the purpose of giving a general supply of water, as distinct from a supply to individual consumers, and including any apparatus used in connection with such a pipe.

district: an area of a supply and distribution system (but usually of a distribution system) which is or can be specifically defined, eg by the closure of valves, and in which the quantities of water entering and leaving the area are metered.

district meter: see meter — district.

inspection: physical investigation to locate leaks by sounding and metering methods eg step tests.

leak detection: the process of detecting and locating leaks.

leakage: that part of waste which leaks or escapes or is lost other than by a deliberate or controllable action.

meter combination: a meter installation consisting of two or more devices, usually of different types used preferentially such that the best characteristic of each device is used at that flow range at which it is most accurate.

meter - district: a device for measuring the quantity of water passing into or leaving a district.

meter - source: a device for measuring the quantity of water entering a supply and distribution system from source works.

meter - waste: a device capable of measuring and recording the range of rates of flow passing into a waste district overnight.

metered consumption: quantity of water registered on consumers' meters.

Note: this quantity will include waste and/or leakage occurring on the consumers' premises and meter error.

minimum night flow: the minimum rate of supply of water into any area during the night.

net night flow: the difference between minimum night flow and metered consumption.

night line: see minimum night flow.

pipe locator: portable electrical or electronic instrument specifically designed for use in the field to assist in locating buried pipes.

pressure control: the reduction of hydraulic pressure to, or the maintenance of pressure at, a predetermined desired range of pressures within defined zones.

property: building premises or structure occupied by a consumer as separately identified for billing purposes.

section: a sub-division or "step" in a waste district.

service pipe: so much of any pipe for supplying water from a main to any premises as is subject to water pressure from that main, or would be so subject but for the closing of some tap.

service reservoir: a water-retaining structure hydraulically linked into a supply and distribution system to provide storage capacity to meet diurnal variations in demand and to provide reserve supplies of water for emergency purposes.

sounding – direct: a method of searching for leaks in which trained inspectors listen with a stethoscope or electronic leak detector applied directly on to a main, valve or stopcock for the characteristic noise of escaping water. It may be carried out at night when both ambient noise and consumption are at a minimum.

sounding – indirect: a method of searching for leaks, similar to direct sounding but with the stethoscope or electronic leak detector in contact with the ground surface. The method is dependent upon sound being transmitted through soil, backfill, road material etc.

sounding – stop tap, stop cock: see sounding – direct. Particularly used to detect leakage from a consumer's installations.

sounding – surface: see sounding – indirect.

sounding – valve and hydrant: a form of direct sounding applied initially to the undertaking's valves and hydrants.

step tests: a method of enhancing the effectiveness of waste metering whereby successive valve closures are made to reduce the size of the waste district temporarily whilst simultaneous measures of rate of flow are being made.

supply: amount of water made available to satisfy demand.

supply and distribution system: an arrangement of apparatus, installations and works operated by a water supply undertaking between the point of abstraction from a source and a consumer's installation.

supply pipe: so much of any service pipe as is not a communication pipe.

system: an arrangement of apparatus, installations and works operated by the water supply undertaking.

trunk main: a main with few branches constructed for conveying relatively large volumes of water.

undertaking: see water supply undertaking.

unmetered consumption: volume of water taken by consumers other than through metered connections.

valve inspections: see step tests.

waste: that water which, having been obtained from a source and put into a water supply and distribution system and consumers' installations, leaks or is allowed to escape or is taken therefrom for no useful purpose.

waste district: a qualified form of district, the inflow to which is or is capable of being measured through a waste meter and in which tests can be carried out such that leakage can be traced to relatively small sections.

waste inspector: an employee or other person skilled in the practical work involved in identifying causes of waste and, in particular, locating leakage.

waste meter: see meter — waste.

water unaccounted for: that water which is the difference between the total put into a supply and distribution system and the water accounted for.

water supply undertaking: a statutory organisation with the responsibility of providing a public water supply.

zone: an area of a supply and distribution system which is or can be specifically defined by the closure of valves or other physical constraint within which the hydraulic pressure of the public water supply is reduced to, maintained at or increased to a preferred limited operational range.

APPENDIX B

WASTE METER OPERATIONS

Detailed checks on an individual waste district

B.01 The following information will need to be checked on site and recorded.

1. Valve condition
 - (a) Is each valve shown on the distribution plan easily found and is access readily available, eg road re-surfacing may have obscured it, vehicles may be habitually parked over it?
 - (b) Is each valve at the setting indicated on the distribution plan, eg normally closed or open?
 - (c) Can it be operated, eg is there mud or silt covering spindle, will normal valve keys fit, is valve seized?
 - (d) Is valve closure clockwise or anti-clockwise?
 - (e) Can the valve be fully closed without loss of water past the gate?
 - (f) Relevant details, including valve numbering, should be recorded on the district plan. Where necessary, repairs should be carried out.
2. Details of consumers' meter locations.
3. Special requirements of night consumers, eg hospitals, kidney machines or factories on shift work.
4. Location and effect of PRVs and any other special flow controls.

5. Number of houses per street, or per length of main between step valves (optional).
6. Other special circumstances, eg are there any sprinkler systems with low pressure alarms?

Administrative arrangements before a waste meter operation

B.02

1. Prepare drawings of the district for site use to include relevant information from Section B.01; (See Figure B1).
2. Prepare programmes for step-test procedures.
3. Prepare work schedules for waste inspectors which would typically include timing instructions for closure of district boundary valves, setting-up waste meter, commencement of night line or step-test operation, timing and procedures for restoring normal supply to the district. (See Figure B2).

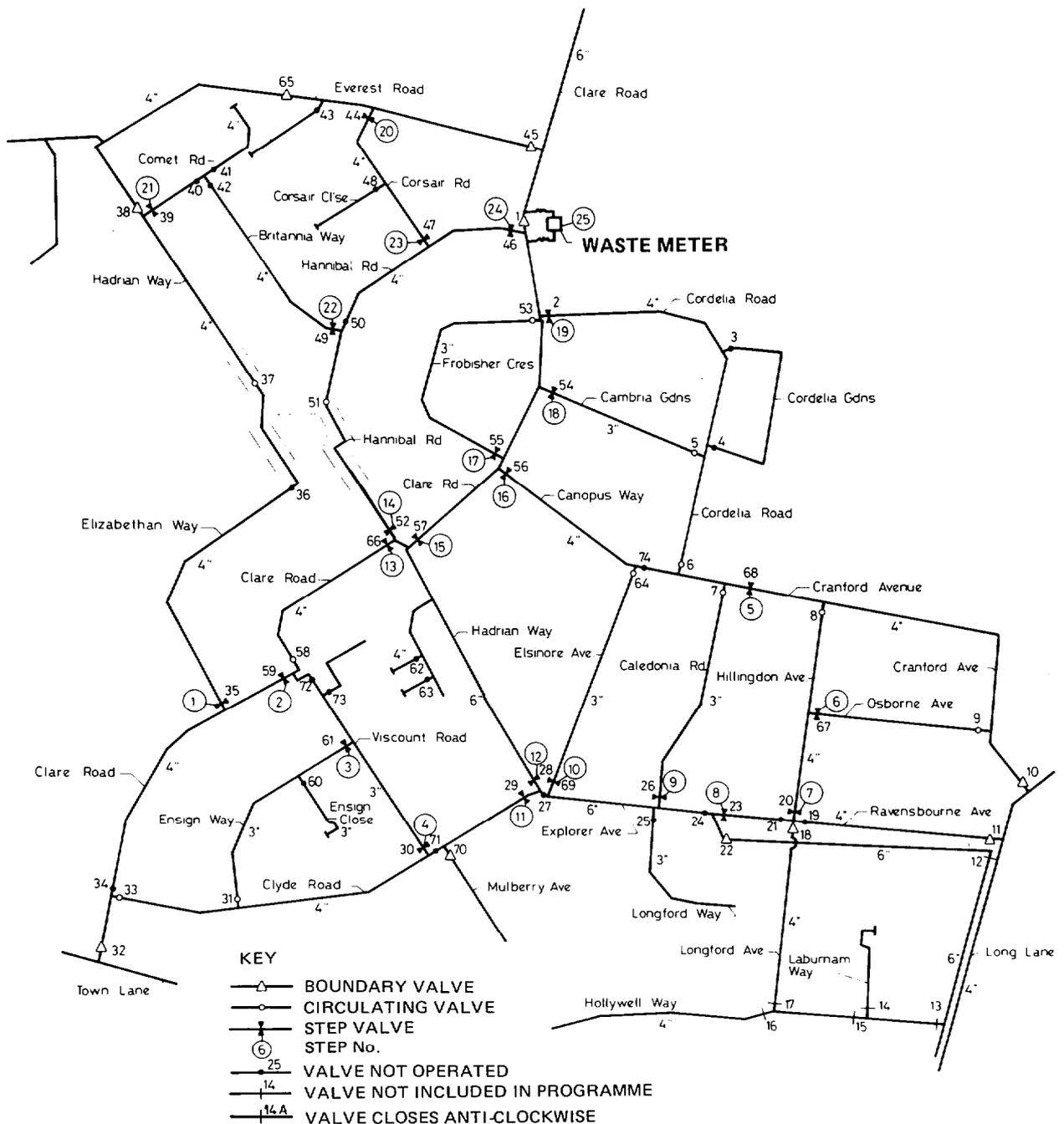


Fig. B1. Plan of waste district

4. Inform
 - (a) inspectors of the test and provide them with necessary site plans, programmes and schedules of work;
 - (b) undertaking's night staff;
 - (c) undertaking's staff associated with the running of the district but who may not be directly involved with leakage control operations;
 - (d) night consumers who require warning of shut-down;
 - (e) fire brigade;
 - (f) police, for road safety reasons and because householders may report the presence of groups of men;
5. Check the accuracy of the waste meter by flow-test (occasionally).
6. Check the accuracy of the meter timing clock.

Equipment

- B.03 Each inspector's inventory for waste meter surveys by night should include the following essential items:
- Torches
 - Watches
 - Valve keys and bars
 - Valve cover lifters
 - Stopcock keys
 - Pressure gauge or hydrant flow gauge for fixing on fire hydrants
 - Fluorescent waistcoats or jackets
- B.04 Vans should be fitted with:
- Flashing beacons (or hazard warning lights)
 - Interior map lights
 - Two-way radio
 - Spare 12-volt heavy duty car battery
- B.05 The following items should be available at the meter site:
- The waste meter and its ancillaries including charts, chart drum, clock, pen-assembly.
 - Amber lights
 - Barriers
 - Portable working lights
 - Shelter
 - Hose ramps
 - Standpipes
 - Fire hoses for mobile waste meters
 - Disinfectant
 - Foam swab for disinfecting (optional)

Use of a fixed meter to determine the net night flow

- B.06 *Daytime preparation*
1. Close all boundary valves except one or two – as required to provide an adequate supply – check for tightness, see item 13.
 2. Go to the meter taking equipment listed in Section B.05.
 3. Open the meter pit and remove the meter cover.
 4. Wind up the waste meter clock and place it in position on the meter.
 5. Number and check the chart, then fix it to the drum.

District: E34

Date:

Notes:

Op. No.	Valve No.	Valve type	Location of valve	Closing time		Opening time		Comments
				Est.	Actual	Est.	Actual	
1	30	BV		DAY		DAY		
2	44	BV		DAY		DAY		
3	43	CV		DAY		DAY		
4	40	BV		DAY		DAY		
5	37	CV		DAY		DAY		
6	31	CV		DAY		DAY		
7	42	BV		AFTER 10pm		BEFORE 7am		
8	38	BV		AFTER 10pm		BEFORE 7am		
9	39	BV		AFTER 10pm		BEFORE 7am		
10	2	ST1						
11	5	ST2						
12	4	ST3						
13	9	ST4						
14	15	ST5						
15	16	ST6						
16	12	ST7						
17	10	ST8						
18	18	ST9						
19	19	ST10						
20	25	ST11						
21	28	ST12						
22	26	ST13						
23	32	ST14						
24	34	ST15						

Fig. B2. Step test programme

6. Fix the drum and ensure that the clock has correct gearing for the required run.
7. Adjust the fitting of the pen assembly to the datum.
8. Crack open the meter valves.
9. Vent the meter at the air release valve.
10. Note whether the pen is moving easily and making a clear line on the chart. If not, the gland packing is probably too tight.
11. Replace the meter cover and pit cover.

Night time work

12. Shut remaining boundary valves.
13. Check boundary valves. This is normally achieved by sounding but a more positive method is given in Figure B3.
14. Open meter valves fully.
15. Close meter by-pass valve.
16. Record readings on trade consumers' meters.

Completing the run

B.07 On the following day the routine is as follows:

1. Record readings on trade consumers' meters.
2. Open the meter pit and take off the meter cover.
3. Open the by-pass valve.
4. Close the meter valves – the pen should return to zero.
5. Check the zero on the chart by rotating the drum.
6. Remove the pen.
7. Remove the drum.
8. Remove the clock.
9. Replace the meter cover and the pit cover.
10. Open all boundary valves. (Note that in some districts it may be necessary to open one or two boundary valves to supply the morning peak.)
11. Refer the chart to the supervisor.

All operations must be carried out in the above order.

Analysis of night line

B.08 Inspection of the chart will indicate the level and duration of night flows into the district and by taking account of metered trade consumption the net night flow can be determined and should be recorded. Based on this information the decision to proceed with a step-test can be made.

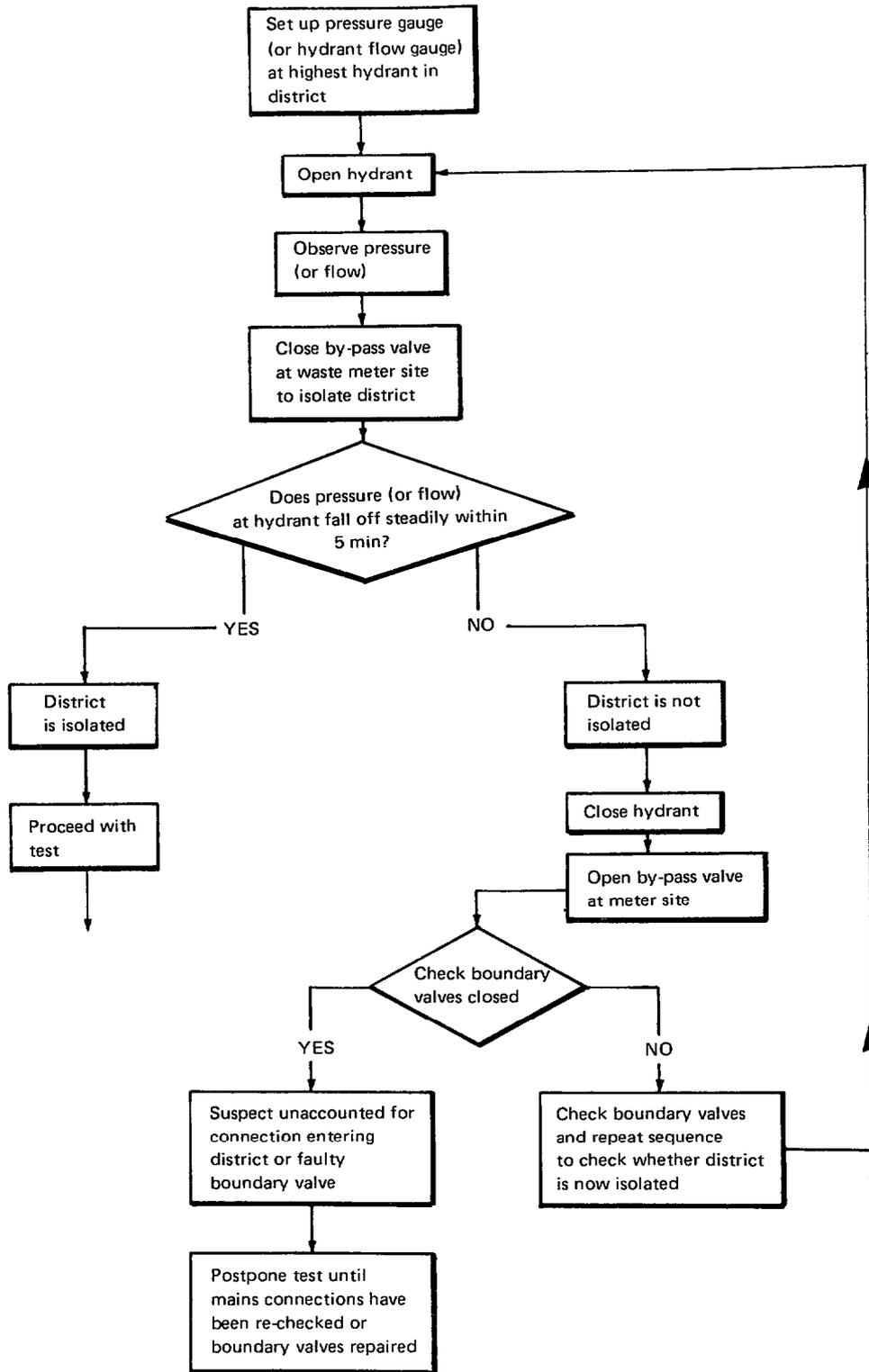


Fig. B3. Boundary valve checking procedure

Use of a fixed meter for a step-test

B.09 Daytime preparation

1. Close the boundary valves and circulating valves according to the work schedule (Section B.06) leaving one or two open.
2. Go to the meter site during daylight, bringing the equipment listed in Section B.05. Meter charts will need to be 6-hour for a Deacon meter or 3-hour for a Kent meter.

3. Check that the district boundary valves are closed (as item (13) in Section B.06).
4. Set up the meter,
 - (i) open the meter pit and remove the cover from the meter,
 - (ii) wind up the clock, then install it,
 - (iii) number and check the chart, then fix it to the drum, but do not fit the pen at this stage,
 - (iv) replace meter and pit covers.

Night preparation (30 minutes prior to step-test)

B.10

1. Close remaining boundary valves.
2. Synchronize all watches.
3. Open meter pit and fit pen.
4. Zero the meter by setting the pen adjustment, then set the chart for the correct time.
5. Open the meter valves.
6. Shut the by-pass valve.
7. Remove air at the air vent.
8. Replace the meter cover.

Step-test

B.11

1. Start the step-test at a pre-arranged time indicated by the previous night line chart. Before commencing the step-test it should be confirmed that night flow conditions have been established.
2. Close the valves according to the programme at pre-determined intervals.
3. Check the step and circulating valves for water tightness by sounding.
4. Note time of valve closures on the step-test programme.
5. The last valve to be closed is a meter valve.
6. Check chart timing when all valves are closed.
7. Re-open the by-pass valve (unless a reverse step-test is to be carried out).
8. Re-open the numbered step valves.
9. Re-open the circulating valves and boundary valves.
10. Return to the meter and remove the pen assembly, drum, chart and clock.
11. Replace the covers.
12. Refer the chart to the supervisor.

Analysis of step-test

B.12 Inspection of the chart will indicate the sections of the district in which the largest flows are occurring. By taking account of housing density and/or trade flows those areas with highest leakage can be identified.

Use of mobile meter

B.13 The night line and step-test procedures are essentially the same as given in B.06 to B.11 but the following factors and procedures have to be taken into account when a mobile meter is to be used.

Site of hydrant points

B.14 When choosing a site for a mobile meter the following points should be borne in mind.

1. The site should be chosen so that it causes little inconvenience to pedestrians and road users.
2. Ready access should be available to two hydrants which have a valve between them.
3. Sites which would involve hoses laid across main roads should be avoided. It may be acceptable to have hoses across minor roads with the hoses protected by ramps and warning signs. Where hoses have to be laid across footpaths or driveways, ramps, warning signs and lights should be provided.
4. The site chosen should be such that one or two operators can manoeuvre the equipment into position; a steep slope or a muddy area would be unsuitable.
5. There are obvious advantages to be gained from working in a place lit by all-night street lighting.
6. In areas with a high incidence of criminal damage, the equipment should be positioned so that it remains within the public view, or preferably waterworks staff should be in attendance throughout the operation.
7. It may be necessary to install a new hydrant and/or valve where metering is to be carried out regularly at the site. Convenience of setting up should be considered when positioning the new hydrant.
8. Where a hydrant with a loose jumper is used downstream of the meter it will be necessary to shut down to remove the hydrant jumper and to control the hydrant with a valve in the standpipe.

Hygiene

B.15 When using mobile waste meters, care must be taken to avoid contaminating the mains through fire hydrants.

B.16 This contamination could arise from unsterile equipment or from the bowls of fire hydrants, and the following precautions are recommended.

1. Hoses which are new, have been in store, or have been contaminated should be flushed through, filled with water containing not less than 20 mg/litre of chlorine and flushed out after a minimum period of two hours.
2. When hoses are not in use the ends should be capped or the two end couplings joined.
3. Couplings joining two hoses should be raised on blocks to prevent possible contamination from puddles of dirty water and soil.
4. The couplings on the trailer should be capped when not in use.
5. The standpipe should be kept clean and preferably capped when not in use.
6. Hydrants should be flushed out until they run clean.

Setting up

B.17 The major problem in setting up the equipment for the first time is the choice of meter position and hose lengths. It is best to avoid the difficulty of having to 'snake' hoses, since under

full mains pressure the hoses cannot accept curves of much less than 5ft radius. This problem is minimised by having available hoses of different lengths or, where hydrants have to be installed, by positioning hydrants to suit the hose lengths.

B.18 Site procedure should be as follows:

1. Set up any road signs necessary for the protection of the men working on the equipment.
2. Disinfect the hydrants and standpipes as detailed above. During the disinfection contact time, operations 3 to 8 can be carried out.
3. Pace out the area and decide on hose lengths and meter positions.
4. Position the meter trailer.
5. Connect up the hoses to meter and standpipes. Lay the hoses along the ground in the positions at which they will be used, adjusting the standpipe swivel joints accordingly.
6. Check the hose positions with regard to pedestrians and road users and check that the hoses do not curve more sharply than a 5ft radius. Adjust the meter position and/or hose lengths as necessary.
7. Adjust the meter on levelling jacks, first at the rear to level the trailer laterally, and finally by means of the jockey wheel. It has been found from experience that it is advisable to secure the jockey wheel by placing it in an upturned hydrant box cover. If the meter is set up on soft ground then the rear jacks should have pads placed beneath them.
8. Adjust pen to zero on meter chart.
9. Remove the hoses and flush the hydrant bowls to waste to complete disinfection.
10. Replace the hoses and pressurize the system by cracking open both hydrants, and releasing air from the system at the meter airbleed. The hydrants can now be closed.
11. The system is now ready for use. When the boundary valves are closed and checked the system can be operated by fully opening the hydrants and closing the bypass valve.

B.19 If the site has been used for mobile waste metering before, or if the hydrants have been installed specifically for the purpose of waste metering, steps 3 and 6 are omitted.

B.20 When the above system has been set up for the first time and proved satisfactory there will be a considerable saving in time on future occasions if a record sketch is made of the layout.

APPENDIX C

LIST OF MANUFACTURERS AND SUPPLIERS

- 1. Pressure reducing valves**
- Neptune Glenfield Ltd.,
Low Glencairn Street,
Kilmarnock, Scotland.
- Abbott Birks and Co. Ltd.,
East Portway,
Andover,
Hants SP10 3NJ.
- Guest and Chrimes,
PO Box 9,
Don Street,
Rotherham.
- Instruments and Gauges,
Hedley Street,
Maidstone, Kent.
- J. Blakeborough and Sons Ltd.,
PO Box 11,
Brighouse, HD6 1NH.
- (ii) Electronic detectors*
- Terroscope
Abbott Birks and Co. Ltd.,
East Portway,
Andover,
Hants SP10 3NJ.
- 2. District meters**
- Kent Meters Ltd.,
Pondswicks Road,
Luton.
- Sewerin Aquaphone
General Descaling Co. Ltd.,
Retford Road,
Worksop.
- Frost Meters,
The Manchester Water Meter Co. Ltd.,
Mancunian Way,
Ardwick,
Manchester M12 6HJ.
- Metrotech
Seton Cotterill,
4 Ruddlesway,
Windsor, Berks.
- Neptune Measurement,
PO Box 2,
Dobcross,
Oldham, Lancs.
- Fisher
E. Pass and Co. Ltd.,
Holland Street,
Denton,
Manchester.
- Guest and Chrimes,
PO Box 9,
Don Street,
Rotherham.
- 3. Waste meters**
- Kent Meters Ltd.,
Pondswicks Road,
Luton.
- Action Electronics Development Ltd.,
171 Queen Victoria Street,
London EC4.
- Palatine Engineering Ltd.,
Hawthorn Road,
Bootle,
Liverpool 20.
- Seba Dynatronic
Kent Meters Ltd.,
Pondswicks Road,
Luton.
- Quadrina Ltd.,
Bridge Road,
Letchworth,
Herts SG6 4EU.
- (iii) Leak noise correlator*
- Plessey EAE,
284/5 Southtown Road,
Great Yarmouth,
Norfolk NR31 0JB.
- 4. Leak detectors**
- (i) Stethoscopes*
- Palatine Engineering Ltd.,
Hawthorn Road,
Bootle,
Liverpool 20.
- (iv) SF₆ gas tracing equipment*
- A. I. Industrial Ltd.,
London Road,
Pampisford,
Cambridge.

5. Reservoir level measuring equipment

(i) Sight gauges

Seetol Gauge,
Seetru,
43 Corn Street,
Bristol BS1 1MX.

(ii) Water level sensors

Palatine Engineering Co. Ltd.,
491 Hawthorne Road,
Bootle.

A. Ott,
Agent: Smail Sons' Co. Ltd.,
129 Whitefield Road,
Glasgow G51 2SF.

Diptone
4 Markethill Road,
East Kilbride,
Glasgow G74 4AA.

(iii) Float gauges

R. W. Munro Ltd.,
Cline Road,
Bounds Green,
London N11 2LY.

A. Ott,
Agent: Smail Sons' Co. Ltd.,
129 Whitefield Road,
Glasgow G51 2SF.

Sparling Envirotech Ltd.,
Victoria Road,
Burgess Hill, RH15 9LL.

Leopold and Stevens,
Agent: G. K. Instruments,
Commerce Way,
Leighton Buzzard.

(iv) Submersible pressure and level transducers

K. D. G. Instruments Ltd.,
Fleming Way,
Crawley,
West Sussex RH10 2QE.

Tekflo,
Albany Road,
Granby Industrial Estate,
Weymouth,
Dorset DT4 9TH.

Druck Ltd.,
Fir Tree Lane,
Groby,
Leicestershire LE6 0FM.

Churchill Controls,
Headley Road East,
Woodley,
Reading,
Berks RG5 4TR.

6. Trunk main leakage measuring equipment

(i) Bypass meters

Kent Meters	
Frost Meters	Addresses
Neptune	as above
Guest and Chrimes	

(ii) Heat pulse flow meter

Water Research Centre

(iii) Insertion turbine meters

Quadrina Limited
Bridge Road,
Letchworth,
Herts SG6 4EU.

7. Pipe locators

Terroscope
Abbott Birks and Co. Ltd.,
East Portway,
Andover,
Hants SP10 3NJ.

Sewerin
General Descaling Co. Ltd.,
Retford Road,
Worksop.

Metrotech Unital
Seaton Cotterill,
(as above)

Goldak
Action Electronic Developments,
171 Queen Victoria Street,
London EC4.

Fisher M-Scope
E. Pass and Co. Ltd.,
Holland Street,
Denton,
Manchester M34 3QH.

Cintel
Instruments and Gauges,
Hedley Street,
Maidstone, Kent.

Biccotest
Biccotest Instruments,
Delamare Road,
Cheshunt, Herts EN8 9TG.

Seba Dynatronic
Kent Meters Limited,
(as above)

APPENDIX D

DETERMINATION OF LEAKAGE LEVELS

Net night flow

A procedure is detailed below for the determination of net night flow using, where possible, facilities which exist in any well run system. Satisfactory results have been obtained from several field trials of this procedure.

Preparatory work

1. Study plans of the system to determine:
 - (i) The limits of the area to be measured
 - (ii) Positions of closed valves.
 - (iii) Positions of valves which need to be closed.
 - (iv) Positions of existing district or waste meters which may be used to establish boundaries.
2. Establish sources which can be used to supply the area overnight, ie existing source works or service reservoirs. Determine the accuracy with which the likely night flow rates can be measured at these sources using existing meters or reservoir level measuring instruments.

Note: Existing source meters such as Venturi meters will normally be unsuitable at these low flow rates.

3. Determine the number of unmetered properties in the study area.
4. Determine from meter records and surveys:
 - (a) Large metered users at night. These meters will need to be read during the test.
 - (b) Metered users that use water at night but with sufficient storage to be turned off.
 - (c) Metered consumers unlikely to use a significant quantity of water at night.
5. Determine the cross-sectional area of any reservoirs to be used to measure consumption and install level measuring equipment. Check or preferably calibrate any source or district meters to be used and check all closed valves. Check accessibility of consumers meters and clean dial glasses.

Note: Hook gauges and other water level sensors have been used successfully in the field trials.
6. Draw up forms to record results and brief staff so that their roles are established. Supervision teams will be needed for emergencies and to coordinate the programme.

The night test

7. Isolate the study area and turn off all sources and reservoirs not used in the test.

Notes: (a) Friday and Saturday nights are normally unsuitable owing to late night use.
(b) Reservoirs which are to be used should be filled during the day and turned off before midnight to allow any surface swell to subside.
8. Turn off all metered consumers in section 4b.
9. Record or read reservoir levels and/or source meters at quarter hour intervals commencing at midnight. This gives the minimum night flow.
10. Read meters of consumers in section 4a and any boundary meters between 12.30 and 2.30 am and record the time when read. Read for the second time in the same order between 2.30 am and 4.30 am. The larger metered consumers should be read hourly.

Notes: (a) One team of meter readers can normally read between 10 and 15 meters per hour.
(b) Hotels and restaurants etc should be read after 1.30 a.m.
(c) Unlike normal meter reading, all digits should be recorded.
(d) Safety considerations may dictate the use of a two-man team.

11. Return study area to normal operations.

Calculations

12. Calculate the net night flow in the distribution system from the equation;

$$\text{nnf} = s' - m' - l$$

where s' = sum of all input flow rates (the minimum night flow).

This is the minimum flow rate recorded over an hourly or half hourly period determined in 9 above.

m' = night flow rate of all metered consumers.

This is the sum of all metered consumption recorded, expressed as a flow rate plus an allowance for all consumption in section 4c.

l = leakage from trunk mains and service reservoirs which can be measured separately.

Note: The nnf is the value required for the procedure described in Part 2.

Estimation of total leakage

It may be necessary for an undertaking to calculate the total level of leakage within a system for purposes other than leakage control and this can be achieved by calculating the unaccounted for night flow from the equation,

$$u' = s' - (m' + a'n')$$

where

u' = unknown or unaccounted for night flow rate

a' = average domestic night flow rate per property

n' = number of properties supplied

and s' and m' are determined as in the procedure above.

The value of a' cannot be measured directly but the results of the field trials (and other exercises) have shown that night flow rates of less than 2 l/prop/hr can be achieved in areas where all detectable leakage has been eliminated. It is suggested therefore that this figure be taken as a maximum for a' but that lower values be used where local knowledge indicates that they would be appropriate.

The total daily leakage can then be calculated by the method described in 5.07 and 5.08, making allowances for the fact that pressures at night are likely to be higher than those encountered during the day. It is recommended that the leakage is expressed in terms of litres per hour or cubic metres per day, or for comparative purposes, in terms of litres per property per hour and not as a percentage of some measure of total quantity. (See sections 3.23 to 3.27).