Accounting for Losses: The Bursts and Background Concept

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ABSTRACT

Losses of treated water occur through leakage and overflows from the pressurized pipes and fittings in water undertakers' distribution systems and customers' private supply pipes. The UK National Leakage Control Initiative was formed in 1991 to update previous published work on leakage control policy and practice in the UK.

Although some published technical relationships exist, there has been no overall methodology which attempts to provide a component-based estimate of annual losses in different parts of the distribution system for any particular combination of local circumstances, i.e. pressure, burst frequency, burst flow rate, number of properties, length of mains, method of leakage control, standards of service, and waste notice service/enforcement policy.

The 'bursts and background estimate' spreadsheet-based methodology is designed to provide such estimates. It links 'night-flow' and 'annual losses' concepts, and can be used for a variety of purposes. These include (a) assessment of the likely incidence of losses for different leakage control and waste notice policies, (b) identification (from night flows) of districts in which there are unreported bursts, and (c) assessment of economic target levels for leakage control. The substantial element of annual losses from service pipes, and the considerable influence of pressure on annual losses, are also discussed.

Key words: Bursts; leakage control; losses; net night flows.

INTRODUCTION

Point of Delivery

Since privatization in 1989, the Office of Water Services (OFWAT) has introduced the concept of 'water delivered' to customers. Companies in England and Wales are now required to submit audited and certified annual calculations of distribution input and water delivered. The water balance diagram (Fig. 1) from the National Leakage Control Initiative (NLCI) Draft Glossary of Terms[1], which now defines standard UK leakage terminology, identifies that distribution losses are calculated as the difference between the metered input to a distribution system (DI, in Ml/d) and the water delivered (measured and unmeasured) to customers, after allowing for distribution operational use (DOU) (e.g. flushing mains).

Water 'delivered' (at the point where the customer's private pipework commences) consists principally of measured and unmeasured use by customers and unmeasured supply pipe losses (both underground and plumbing losses). The term 'consumption' (not shown in Fig. 1) includes plumbing losses and customer use, and represents what would be measured by an internal household meter. Customer use excludes all supply pipe losses, whether underground or on the above-ground plumbing system

Annual Losses and Night Flows

The transition to thinking in terms of *annual* losses poses particular challenges in the UK, as Report 26[2] strongly steered a generation of UK leakage practitioners and planners to consider leakage almost exclusively in terms of night flow rates, rather than as a calculation of annual losses as in West Germany[3]. Each method has its respective mertis. 'Annual losses' are used for the retrospective assessment of overall performance and long-term demand forecasting. 'Night flows' are used by practitioners responsible for leakage control and prioritization of leakage control activites. Any conceptual model therefore needs to be able to link night flows with annual losses in a consistent manner.

Need for an Overview Methodology

'Paying for Growth'[4] states that before the National Rivers Authority (NRA) will consider granting a major new abstraction licence, an assessment should be carried out by a water company of the relative merits of demand management measures, in particular metering and leakage control. Yet there is currently no standard methodology to undertake such assessments. In the same report OFWAT expresses a wish to secure 'effective leakage control policies and realistic estimates of distribution losses', yet there is no methodology for estimating the components of annual distribution losses; at present only the gross total is crudely inferred as the arithmetical difference between distribution input (measured) and water delivered (a component-based calculation in which around two-thirds is estimated (Fig. 1). Weimer [3], referring to

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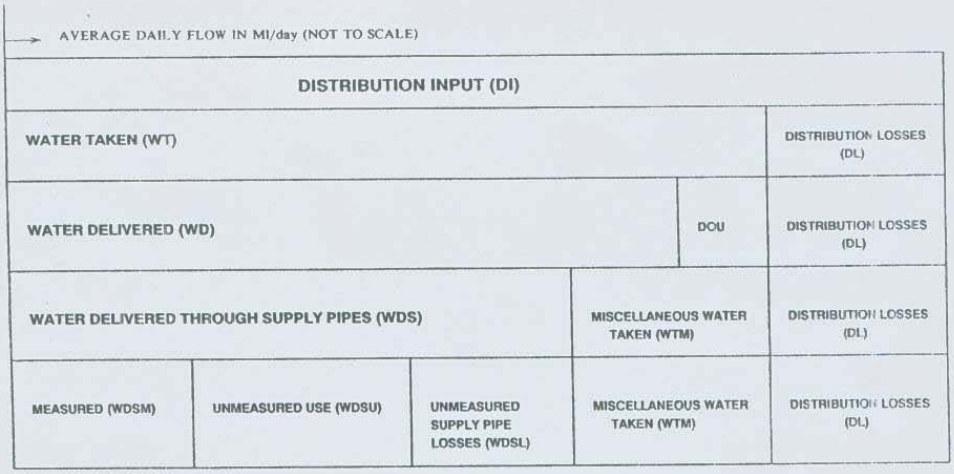

Fig. 1. Annual water balance: simplified breakdown of distribution input

fully metered situations, considers that 'the annual water balance can initially only be taken as a guide . . . as the calculations are susceptible to errors . . . analyses' show this uncertainty in the calculated annual losses to be ±46%'.

The recent OFWAT report 'Cost of Water Delivered to Customers 1991–92'[5] states that 'the estimation of (annual) supply pipe leakage poses particular difficulties; and also states that 'variation in distribution losses can be entirely reasonable' but 'no evidence has been provided that actual supply pipe leakage differs significantly across companies' despite the fact that supply pipe losses occur on the same pressurized service pipes as communication pipe losses (which are of course part of the distribution losses).

Losses From Infrastructure Components of Distribution Systems

Distribution losses in Fig. 1 are the sum of losses from four different parts of the distribution system – trunk mains, service reservoirs, distribution mains and communication pipes. The combinations of these assets in individual companies and supply areas are widely variable, as are the variations of pressure which are known to affect leakage significantly[2].

Differences in burst frequencies, flow rates and durations of bursts must also logically cause variations in annual losses. The duration of reported bursts will be related to standards of service, repair policies and waste notice policies, and the duration of unreported bursts will also be related to the method of active leakage control being practised.

Component-Based Conceptual Models for Distribution Losses

In 1980, recommendation no. 4 of Report 26[2] stated that 'no further work should be carried out at present to investigate the mechanisms of leakage and its points of occurrence', as 'investigations did not reveal any 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'.

This recommendation recognized the difficulty of such work. However, in 1993 there appears to be no alternative but to attempt such estimates. A wealth of factual data is available, derived from new technology since 1980. Also, the achievable accuracy in respect of estimating individual components of annual distribution losses and supply pipe losses should always be considered in relation to the achievable accuracy in estimating the other major components of the 'water balance' (Fig. 1), ('water delivered' and 'distribution input'), and Weimer's comment[3] that the gross annual difference may be in error by ±46% even where there is complete metering of customers.

The bursts and background estimate (BABE) approach uses a component-based spreadsheet model[6] which can use a combination of data from three distinct sources:

(i) 'Standard' components (e.g. pressure correction factors, average burst flow rates);
(ii) Auditable local data (e.g. infrastructure data, recorded frequencies of bursts); and
(iii) Company policies (standard of service, leakage control method, waste notices) expressed in terms of their influence on the average number of days for which bursts will run.

TABLE I. Summary Sheet: Estimated Annual Losses (Ml/d) for a Sample Area at 70 m Average Night Zone Pressure, with Continual Night Flow Monitoring, using Provisional Values for Welsh Water

Infrastructure component	Background losses	Bursts/Overflows		Total	%
		Reported	Unreported		
Trunk mains	0.55	0.01	0.00	0.56	4
Service reservoirs	0.07	0.00	0.15	0.22	2
Distribution mains	1.32	0.11	0.65	2.08	15
Communication pipes	2.89	0.42	2.47	5.78	45
Total (distribution system)	4.83	0.54	3.27	8.64	67
Supply pipes	1.42	1.21	1.60	4.24	33
Total (including supply pipe)	6.25	1.75	4.87	12.88	100

Conceptual component-based models are used in hydrology and water resources for balancing the input to catchment areas (precipitation) with the outputs (river flow, groundwater) and the annual losses through evapotranspiration. The general approach is therefore consistent with methodologies already used by OFWAT (in relation to water delivered) and the NRA in relation to assessment of availability of natural water resources.

BURSTS AND BACKGROUND CONCEPT

Sample Calculation

The principles used in BABE can be briefly explained by rêference to a sample calculation of annual losses in Ml/d. Table I shows this calculation for an actual supply area of 90 000 population, with 41 500 properties, 50 km of trunk mains, 907 km of distribution mains, and average night zone pressure of about 70 m. Continual night-flow monitoring (178 districts) with weekly data collection is the current leakage control method.

The following sections of the paper describe the basis of the calculations used to derive the figures in Table I which are also given in bar-chart form in Fig. 2.

Background Leaks and Bursts (Reported and Unreported)

Report 26[2] outlines the 'queue' theory of rate of outbreak and repair of leaks. Technical report TR154[7] identifies that many of these leaks are self-evident and are therefore identified and repaired without recourse to inspection. However, not all self-evident leaks are reported to companies and because auditable data from company work planning systems must be used, the terminology 'reported' and 'unreported' is used in the BABE concept.

The volume lost (m^3) from an individual leak or burst can be simply calculated as the average flow rate (m^3/d) times the duration (d) for which the leak or burst runs. However, the range of flow rates from leaks or bursts is immense; from around 10 l/h on a dripping tap, to 10 000 l/h or more for a major mains burst.

Individual points of loss have therefore been categorized as 'background' losses (Table I) unless

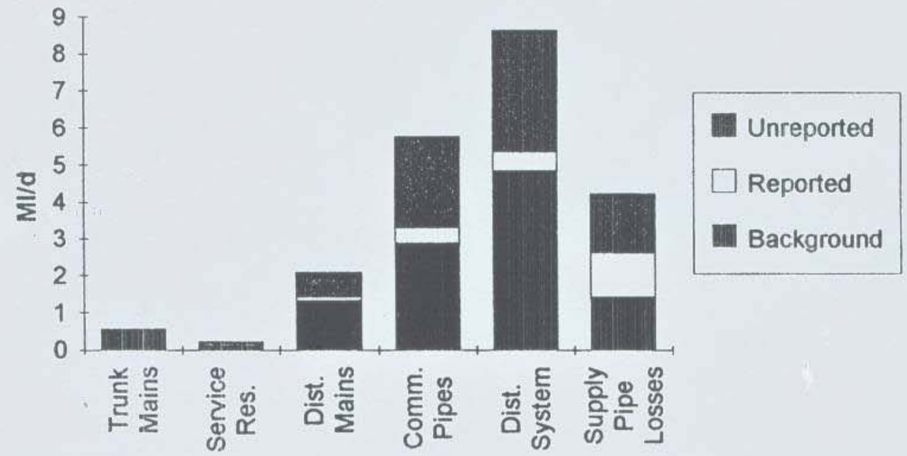

Fig. 2. Bar chart of annual losses (from Table I)

TABLE II. Formula for Background Net Night Flows: Explanation of Terms used and Provisional Values (Welsh Water)

Term	Explanation	Assumed value
L/N	Average mains length per property (m)	From local data
C_1	Background loss on distribution mains (l/km of mains/h) at 40 m average zone night pressure (AZNP) and 60 min sampling period (S)	.035
C_2	Background loss on service pipes (l/property/h) at 40 m AZNP and 60 min sampling period (S)	2.5
PCF	Pressure correction factor related to Leakage Index at 40 m AZNP $= LI_{(AZNP)}/LI_{(40)}$ where $LI = .5 \times AZNP + .0042 \times AZNP^2$ and AZNP = Average zone night pressure (m)	Equation derived from Report 26 Leakage Index Graph from local data
SCF	Sampling period correction factor of the form $SCF = 1/\{A + B/(C + S)\}$	A = .95 B = 6.0 C = 60 S = 60
NFCUA	Assessed customer night flow use (l/property/h) for S = 60 min	1.5

the flow rate is large enough to exceed a measurable and auditable threshold value, in which case it is categorized as a 'burst'. For the calculation shown the threshold value used for pipework is 500 l/h. This is about half the rate at which a hosepipe would run at a pressure of 40 m.

In practice, this effectively means that almost all losses from fittings on mains and services (air valves, hydrants, stop taps, dripping taps, cisterns, etc.) fall within the 'background' category. In the case of service reservoirs, background losses represent leakage from the structure, and overflows are the equivalent of 'bursts'.

Duration is also strongly influenced by whether the loss is a background loss (leak), or a burst reported to the company and promptly repaired, or an unreported burst which runs until it is identified and repaired by active leakage control.

Estimates of Background Losses

Distribution Mains and Services

The rate of flow of background losses can be assessed from night flow measurements in districts where it is believed that all bursts (>500 l/h individually) have been temporarily shut off or repaired. As background losses are likely to be related to numbers of fittings, length of mains (L km) is used as a surrogate for the number of fittings on mains, and number of billed properties (N) as a surrogate for the number of fittings on services. A two-part formula relating night flows to L and N for rural areas was developed by Lambert and Morrison[8]

However, leakage is known to be strongly influenced by pressure[2], and reported night flows are influenced by the sampling duration period (NLCI standard 60 min, but actual data is collected by different companies over periods from a few minutes to several hours). The BABE conceptual model therefore incorporates a four-part formula for net night flow (NFN) of the form:

$$\begin{aligned} &NFN &&= \{C_1 \times L/N + C_2\} \times PCF \times SCF \\ &(l/property/h) &&+ NFCUA \times SCF \end{aligned} \quad (1)$$

The terms in this equation, and the assumed values for the calculation are shown in Table II. The sampling correction factor only affects the night flow equation to a small degree (±3%) and does not influence the annual loss calculation. However, the pressure correction factor (PCF) derived from Report 26[2] has major significance on both night flows and annual losses, with PCF values of 0.44 at 20 m average zone night pressure (AZNP), through 1.0 at 40 m AZNP, to 2.08 at 70 m AZNP.

Equation 1 (and its graphical representation in Fig. 3 for a 1-hour sampling duration) is particularly useful for prioritizing leakage operations work in searching for unreported bursts in districts with varying combinations of L, N and AZNP. In particular, it helps to explain the persistently high NFNs (in l/property/h) in rural areas (L/N up to 100 m) with high pressures (e.g. Arscott[9]). Shore [10] quotes an average minimum night flow of 4.8 l/property/h (including trade use) for a large urban area immediately following leakage control, whereas Equation 1 (for an AZNP of 40 m and urban L/N of 10 m) predicts comparable background net night flows (excluding industrial use) of 4.4 l/property/h.

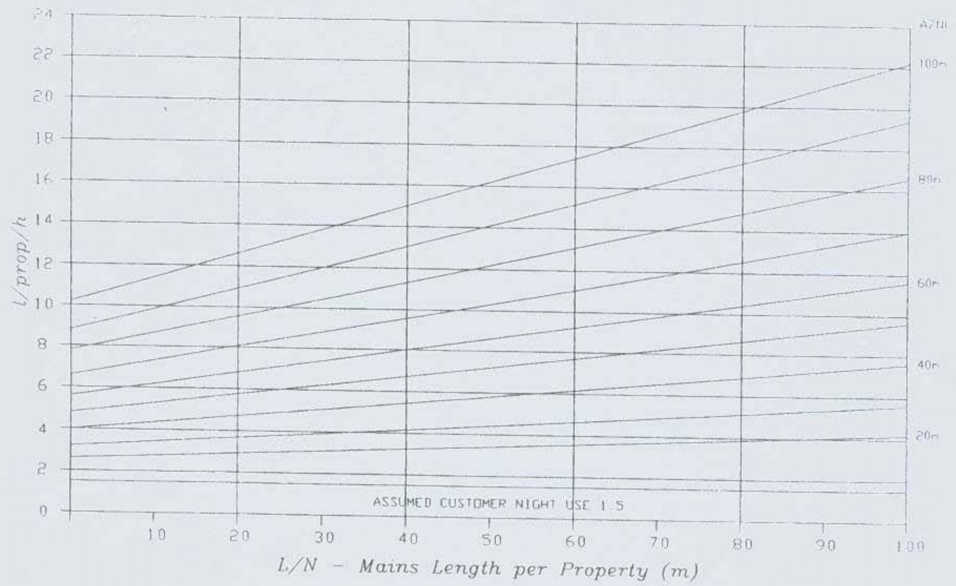

Fig. 3. Background net night flows at 60-minute sampling period

Hour to Day Conversion Factor

For the purpose of calculating daily average values of background losses in Ml/d, the night flow losses from Equation 1 (excluding the customer use NFCUA) are multiplied by T hours[2], an hour/day conversion factor which takes account of diurnal pressure variations. For the calculations shown in Table I, a T value of 20 h has been assumed for distribution mains and services.

Average Net Night Flows

It is very important to stress that Fig. 3 does *not* represent the *average* net night flows which can be achieved over a yearly period. This is because the average will be influenced by the frequency and flow rate of bursts (which cannot be eliminated) and the durations for which they run.

The 'average' net night flow graph will be of similar form to Fig. 3, but will vary (for any particular supply area) with the leakage control method used.

The BABE spreadsheet can produce average net night flow graphs (not shown in this paper). As an example of the difference between background and average NFNs, reference to Table I shows that the background losses on distribution mains and services are 5.63 Ml/d (1.32 + 2.89 + 1.42), or 136 l/property/d, equivalent to a background net night flow of 8.3 l/property/h (divide 136 by 20 h and add 1.5). However the total losses (including influence of bursts) are 12.1 Ml/d (2.08 + 5.78 + 4.24) or 291 l/property/d), giving an average NFN over the year of 16 l/property/h.

Communication Pipe/Supply Pipe Subdivision

The C_2 value for background service pipe leakage (2.5 l/property/h in Table II) needs to be subdivided between background leakage on the communication pipe (part of distribution losses) and on the supply pipe (part of water delivered). Background losses on service pipes are likely to be related more to number of fittings than to length of pipe, and the sample calculations are based on the assumption (from limited research) that background service pipe losses are split 67% to 33% between communicaiton pipes and suppy pipes. The spreadsheet can accept alternative % values.

Note that if the background supply pipe losses are considered to take place from fittings, this component of loss is part of the plumbing losses within a household and forms part of the measured or unmeasured *per capita* consumption.

Trunk Mains and Service Reservoirs

For these calculations, BABE initially gives default values of background losses based on simple formulae derived by the author from Report 26[2] and Technical Report TR154[7]. The trunk mains formula assumes 0.2 m^3/km trunk mains/year for each year of age, and the service reservoir formula is 0.33% of capacity per day. Table I shows these default background losses are not large in relation to total losses; if auditable local data show higher losses for trunk mains or service reservoirs which can be economically justified in particular cases (e.g. linked to asset management plan condition grade of service reservoirs), such data can be substituted in the spreadsheet instead.

ESTIMATES OF ANNUAL BURST LOSSES, REPORTED AND UNREPORTED

BURST LOSSES = BURST FLOW RATE × AVERAGE DURATION × FREQUENCY

All the components of burst losses in Table I (including service reservoir overflows, which are separately estimated) are calculated using this basic equation. The objective should be to derive comparably reliable estimates of all terms on the right-hand side of the equation, rather than to try to achieve extreme precision in any one (e.g. burst flow rate).

Burst Flow Rate (Q m^3/d)

This will be influenced by both pipe size and pressure. Hoch[11] quotes an average of 4.2 m^3/h for 100–150 mm dia. mains and 1.7 m^3/h for 32–80 mm service pipes. Heide[12] uses 5.8 m^3/h for mains less than 200 mm. These quoted data are not related to pressure (typically 60 m or more in Germany), and burst flow rate data related to both pipe size and pressure need to be assembled if the 'bursts' concept is to be used consistently and widely. In Table I calculations it is provisionally assumed that at 40 m AZNP the average flow rates are about:

25 m^3/d for an underground service pipe burst;
75 m^3/d for a typical distribution mains burst; and
150 m^3/d for a typical trunk mains burst

At pressures other than 40 m AZNP, the flow rates are assumed to increase or decrease according to the Report 26 Leakage Index (Table II).

Average Duration of Bursts

In Table I there are two separate items (reported and unreported bursts) for each pipework component of infrastructure (trunk mains, distribution mains, communication pipes and supply pipes). Each duration (in days) used for these calculations is considered to consist of three separately identified and estimated elements:

AWARENESS: (D_a) From start of burst to company awareness of its existence (but not necessarily its precise location)
LOCATION: (D_l) From awareness of existence to precise location
REPAIR: (D_r) From precise location to repair

Reported Bursts

A feature of repored bursts is that they are identified and repaired quickly. For reported bursts, in the sample calculation it is assumed that the total duration for reported trunk mains bursts is one day, for distribution mains 1.1. days, for communication pipes 16 days (4 + 2 + 10) and for supply pipes (involving repair organized by the customer(s), often requiring waste notice procedures) 46 days (4 + 2 + 40). If these figures are realistic, a typical reported supply pipe burst at 40 m AZNP loses 1150 m^3 (25 × 46), compared to only 82 m^3 (75 × 1.1) from a typical distribution mains burst, due to the different average running durations (Fig. 4).

Unreported Bursts

The average duration of unreported bursts is directly related to the method of active leakage control. For regular sounding once per year, the average duration (awareness and location) for an unreported burst on mains or services would be 183 days, to which the repair times (as for reported bursts) would be added.

However, with continual night flow monitoring and data collection on a once-weekly basis, the average awareness time of an unreported burst (on distribution mains or service) will be four days; with telemetry, it would be less than 0.5 days. In general awareness time can be related to data-collection methods.

The location time for continual night flow monitoring depends entirely upon the policy and economics of using skilled manpower resources to locate the burst(s). In the Table I example, the policy is to identify (from night flows) districts likely to have bursts of distribution mains magnitude (or equivalent aggregations of service pipe bursts) and to locate the bursts within seven days of awareness. This gives estimated average total durations of 12 days for unreported distribution mains bursts.

Given that there are 128 unreported mains bursts per year, and 178 districts, it can be estimated that each district will be investigated (by step test or sounding) every 507 days on average. On such investigation, any service pipe bursts in the district would also be located, so the average duration of service pipe bursts location would be 253 days (half of 507 days), giving total durations of 267 days for unreported communication pipe bursts, and 297 days for unreported supply pipe bursts.

Almost any variant of active leakage control policies (regular sounding, district metering, waste/combined metering, continual night flow monitoring) can be simulated in the BABE concept in terms of its influence on duration for which unreported bursts will run.

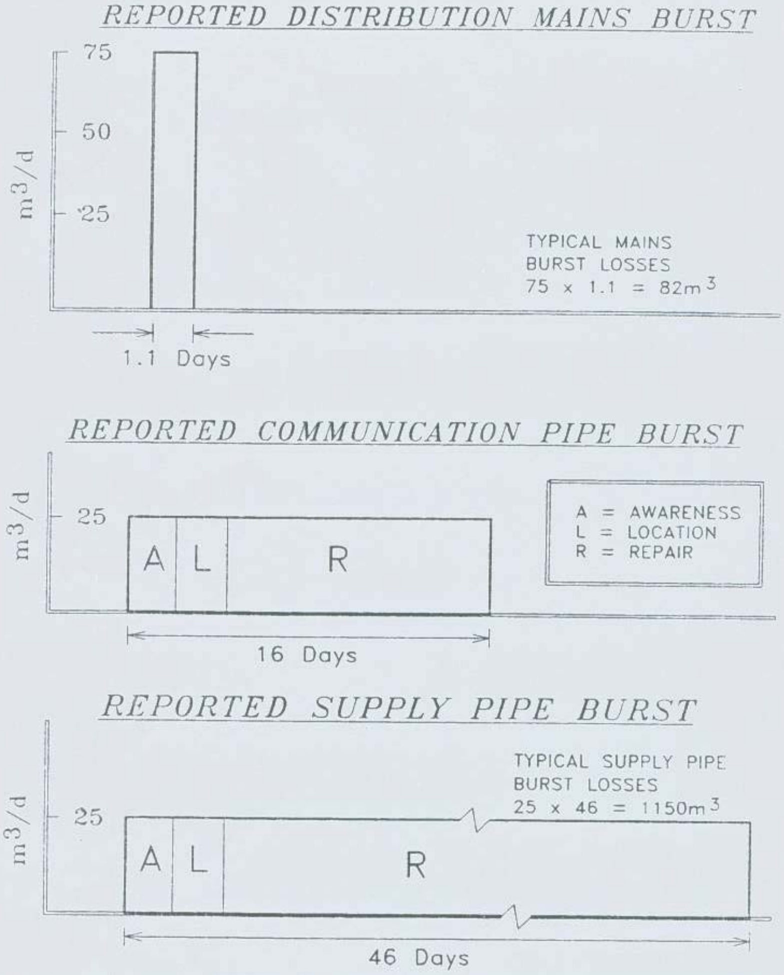

Fig. 4. Estimated durations and quantities of reported bursts at 40 m AZNP

The associated operational manpower costs for each policy can be related to the volume and value of the consequent reduction in annual losses, to derive an appropriate local economic leakage control policy. An enhanced version of BABE which will undertake these calculations is being developed. However, changes in policy for the collection of data (awareness) or use of manpower (location) will only influence the losses from *unreported* bursts in Table I, whereas pressure control will influence *all* distribution mains and service pipe losses. Changes in policy for service and enforcement of waste notices will influence losses from reported and unreported bursts on supply pipes.

Duration of Repair

The repair duration should be the same for reported and unreported bursts, for any particular infrastructure component. On trunk mains, distribution mains and communication pipes it will depend upon company standards of service. On customers' supply pipes, it will depend on the company policy for ensuring that s. 73 and s. 75 of the Water Industry Act 1991 are complied with, in particular

TABLE III. FREQUENCIES OF REPORTED AND UNREPORTED BURSTS IN SAMPLE AREA DURING 1992

Infrastructure component	Reported bursts	Unreported bursts	Total bursts	Units
Trunk mains	0.12	0	0.12	per km/year
Distribution mains	0.26	0.14	0.40	per km/year
	5.56	3.09	8.65	per 1000 props/year
Communication pipes	4.44	1.56	6.00	per 1000 props/year
Supply pipes	4.46	0.92	5.38	per 1000 props/year

through service of waste notices and ensuring repairs are carried out – a difficult area of company/customer relations.

The 40-day repair duration for supply pipes assumed in the Table I estimates represents a positive enforcement policy.

BURST FREQUENCIES

TRUNK MAINS AND DISTRIBUTION MAINS

Auditable frequencies of *reported* bursts on trunk mains, distribution mains and service pipes can be abstracted from company distribution records. Auditable frequencies of *unreported* bursts can only be determined from company records if there is an active leakage control policy; the underlying unreported burst frequency can only be determined if there is consistent application of efficient leakage control policies over a number of years.

Recorded burst frequencies will implicitly include the local influence of matters such as subsidence, traffic loading, type of soil, pipe age/condition/material, pressure, climate (severe winters/dry summers) etc. Changes in leakage control policy (reduced or increased effort) will produce changes in recorded frequencies of unreported bursts, even though the underlying frequencies may be unchanged. Public relations initiatives, to encourage customers to report leaks and bursts, can also influence the balance between reported and unreported bursts, but not the total frequency of bursts.

Bursts on mains are expressed as number per km of mains per year; bursts on communication pipes and supply pipes in terms of numbers per 1000 properties per year. The frequencies used for the BABE calculation should be based on local data and may vary from year to year. Those used for Fig. 1 are based on actual records for calendar year 1992, and are shown in Table III. The total burst frequency on distribution mains in this high pressure, comparatively rural area (0.4 per km per year) was about twice the national average. 36% of distribution mains bursts, 26% of communication pipe bursts and 17% of supply pipe bursts were unreported.

TRUNK MAINS AND SERVICE RESERVOIRS

There were no unreported trunk mains bursts located by the leakage control team in 1992, but minor intermittent overflows were identified at three small service reservoirs, which are awaiting connection to telemetry and the fitting of control valves.

WATER BALANCE AND RELIABILITY OF ANNUAL LOSS ESTIMATES

When, for any distribution system, the losses have been calculated as in Table I for the current leakage control policy, BABE allows a water balance calculation (as in Fig. 1) to be undertaken to check that the sum of all the measured, calculated and estimated components is approximately equal to the measured distribution input for the period under review. A close agreement will give confidence in the output from BABE calculations based on alternative management policies. An exact balance (or calibration) should be achievable by minor variation of one or more of the estimated parameters in the water balance. The achievable accuracy in respect of estimating annual distribution and underground supply pipe losses should always be considered in relation to the achievable accuracy in estimating the other components of the water balance (Fig. 1), particularly the water delivered components. When the estimates in Table I (excluding the background supply pipe losses, which are considered to be part of *per capita* household consumption) were added to the metered and *per capita* consumption, there was a difference of only 3.4% compared to the measured distribution input for 1992. This is an encouragingly close agreement, given the approximate nature of the estimates of average burst size and AZNP for a large area.

DISCUSSION

COMPONENTS OF ANNUAL LOSSES

Underground Supply Pipe Bursts

The total bursts component of underground supply pipe losses in Table I (2.81 Ml/d) represents 31 l/head/d (or 77 l/property/d for an average 2.5 person household). Just over half of this is attributed to unreported bursts on the supply pipes of a few properties (around 1 in 1000 properties).

Overview (see Fig. 2 and Table I)

In total, only 6% of total losses are attributed to trunk mains and service reservoirs. Despite their high frequency of bursts, distribution mains contribute only 15% of total losses, with only 5% from bursts because these are repaired promptly (whether reported or unreported). In contrast, the service pipes which experienced 11.4 bursts/1000 properties/year, account for 78% of total annual losses, because of longer average burst durations. 33% of total annual losses appear to occur on private supply pipes, with a remarkable 12% contributed by the 1-in-1000 properties with long-running unreported supply pipe bursts.

Out of the total losses of 12.87 Ml/d, only about 38% (4.87 Ml/d) are attributed to unreported bursts, which are related to active leakage control policy.

Pressure Control

Because pressure reduction reduces the flow from all leaks and bursts, it influences all the values in Table I except those for trunk mains and service reservoirs. Spreadsheet runs with alternative AZNPs can be used to demonstrate the effect of lower average zone night pressures on losses. The actual influence of reduced pressure on annual losses could be even more beneficial, as reduced pressures may result in reduced burst frequencies.

At 40 m AZNP, overall losses would be halved; background (plumbing) supply pipe losses would be reduced from 34 l/property/d to 16 l/property/d (a reduction in *per capita* consumption of 8 l/head d for an average household), and underground supply pipe bursts losses from 68 l/property/d to 33 l/property/d. Reduction of average night zone pressure to around 22 m (perhaps just achieveable in some localities in lowland areas) would halve these figures again.

However, in hilly areas, there are limitations imposed on pressure control by the need to maintain standards of service for properties in elevated locations. If a modest reduction of 10 m was achievable on average, the annual losses in Table I would fall by 2.2 Ml/d. Individual calculations for specific areas can be carried out using the BABE concept.

Performance Measures

If the distribution losses are expressed in m^3/km of mains/d (as in the OFWAT Water Delivered Report[5]), the figure is 9 m^3/km/d. If the AZNPs for the sample area were 40 or 22 m (instead of 70 m), then with the same burst frequencies and leakage control policies, the distribution losses would be reduced to 4.8 m^3/km/d or 2.7 m^3/km/d.

The total treated water losses in Table I in l/property/d (a measure recently used in the POST Report[13]) are 208 l/property/d for distribution losses and 102 l/property/d for supply pipe losses, giving a total of 310 l/property/d for treated water supplies.

Some 'What-If' Calculations for Alternative Methods of Leakage Control

Regular Sounding

With the basic data on spreadsheet, it is easy to simulate the effect on unreported bursts losses of alternative leakage control methods. For example, a return to regular sounding (once per year) would reduce service pipe losses by 1.1 Ml/d but increase distribution mains losses by 9.4 Ml/d, due to the large number of unreported mains bursts in this sample area.

As already stated, alternative leakage control policies (other than pressure control) will only affect the unreported bursts estimates.

Standards of Service

The BABE concept allows proposed changes in standards of service to be evaluated in relation to their effect on the average pressure, or the average duration for which bursts run (and hence annual losses). Of particular relevance is the service and enforcement of waste notices, including compulsory repair policies.

Relative Merits of Demand Management Measures

BABE can be used to undertake rapid comparisons of the relative merits of demand management measures, in particular metering and leakage control. For example, if all 41 500 properties were compulsorily metered (internally), and customers reduced their *per capita* consumption by 7.5% (11 l/head d) the reduction in distribution input would be 1 Ml/d. Application of the BABE spreadsheet shows that the same saving could be effected if:

(i) The overall average night zone pressure could be reduced by 4.5 m (7%), or
(ii) The average repair duration of bursts on private supply pipes could be reduced to the company standard of 10 d for communication pipe repairs, or
(iii) Customers in 30 of the 38 properties experiencing unreported supply pipe bursts had reported them.

CONCLUSIONS

1. The BABE concept represents a first attempt at a component-based approach to estimating annual losses. The reliability of the calculations can be improved if the National Leakage Control Initiative produces (for example) definitive values for average burst flow rates on different sized pipes at different pressures; or a review of the background loss data assumed in Table III.
2. Even if the BABE estimates are only approximately correct, the methodology represents a considerable advance in terms of identifying the broad issues of leakage control, when applied to the specific situations in individual supply areas. Once BABE is calibrated with locally auditable data, alternative strategies and cost implications

can be tested. Leakage policy and performance can be better related to expenditure and economic theory, leading to locally-based appraisals of the optimal combination of leakage control, metering and resource development.

3. There appears to be no justification for a standard assumption (e.g. 50 l/property/d) for underground supply pipe losses, which are attributed to bursts (reported and unreported) on less than 1% of properties per year. Depending on the local data for reported/unreported burst frequencies, pressure, and the current economic leakage control/waste notice strategy for the area in question, the average underground supply pipe losses could be less than 10, or more than 100 l/property/d. Background supply pipe losses (on plumbing) can be regarded as a small but pressure-variable component of *per capita* consumption (depending to some extent upon type of plumbing system).
4. The major influence of pressure on leakage rates has been known since Report 26 was published in 1980, yet surprisingly this factor has never previously been used in the UK as an explanatory factor for annual losses. The BABE spreadsheet approach allows for the influence of both pressure and burst frequencies (which may also be related to pressure) to be objectively considered.

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