Recent Developments in Application of 'Bursts and Background Estimates' Concepts for Leakage Management

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Abstract

During the UK 'national leakage control initiative', which was carried out in 1991–94, Welsh Water formulated a conceptual model of leakage management which was intended for international application.

This paper explains how the concepts of 'bursts and background estimates' (BABE) have been calibrated and extended to cover financial/economic analysis and pressure management, using specialist software for practical application and following the methodologies in the recent water industry 'Managing Leakage' reports. Examples of applications of BABE software and concepts, in the UK and internationally, are also described.

Key words: **Economics; leakage; losses; night flows; pressure management.**

Introduction

International publications on leakage control exhibit diverse views on how to calculate, express and manage losses, with little consistency in terminology or techniques. Following the publication of Report 26[1], UK water companies developed the use of night-flow measurements more intensively than perhaps any other country, but relatively few companies attempted to carry out annual water balances in a systematic manner prior to privatization. Also, individual countries' perception of pressure management varied widely.

In 1991, the 'national leakage control initiative' (NLCI) was set up jointly by the Water Services Association and the Water Companies Association to review and update guidance to the UK water industry. As the research of the NLCI project groups proceeded during 1992, the need for consistency (between all the technical concepts being developed) was recognized. Accordingly, the NLCI Steering Group began to develop an internationally applicable conceptual model of losses, which could be used to link the outputs of the nine NLCI project groups.

The results of the NLCI's work were published in 1994[2] as the 'Managing Leakage' series of reports (shown in the 'outer wheel' of Fig. 1). Several of the reports make explicit reference to the first BABE model which was written as a spreadsheet and used (a) to estimate components of annual losses and (b) to undertake calculations of economic leakage levels (Report C). National data published in Report E now supersede the provisional parameter values which were originally suggested[3].

The concepts and software have continued to develop, and there are now three software programs (designed for specific purposes and end-users) which are being used, nationally and internationally, for a systematic component-based approach to a wide range of leakage management problems.

Development of Concepts and Software (1993–95)

Progress in 1993

The first development of the conceptual model was directed towards estimating individual components of annual losses from first principles which would be internationally applicable. The approach was similar to that used in estimating evapotranspiration losses from natural catchment areas, i.e.

(i) Categorize the various components of losses;
(ii) Specify equations for each component using relevant parameters; and
(iii) Calculate components of losses based on local data and nationally acceptable parameter values.

The initial model specified fifteen components of losses, consisting of three categories in each of five locations:

Categories
Background losses
Reported bursts/overflows
Unreported bursts/overflows

Locations
Trunk mains
Service reservoirs
Distribution mains
Communication pipes
Customers' supply pipes

Background losses are the aggregation of small sources of leakage whose individual flow rate is less than $0.5\ m^3/h$. These can be expected to run continuously, as it is generally uneconomic and impractical to eliminate them. 'Bursts' are larger individual events with flow rates exceeding $0.5\ m^3/h$, which have variable durations. The basis of calculating the annual volume of losses from bursts is shown in Fig. 2.

This paper was presented at a meeting of the North Western and North Wales Branch, held in Chester on 11 January 1995.

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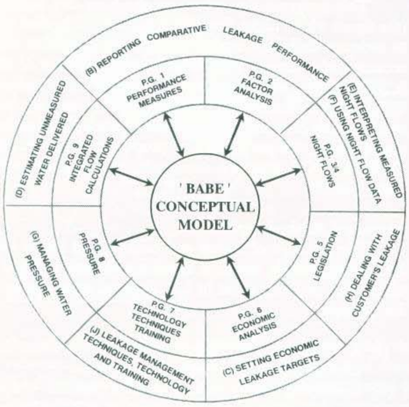

Fig. 1. Technical consistency
('Inner Wheel': National Leakage Control Initiative Project Groups 'Outer Wheel': Managing Leakage Series of Reports, October 1994)

An important innovation in BABE was the conceptual division of average burst duration into three components (awareness, location and repair times). This enables any leakage management policy, or standards of service, to be rationally modelled in terms of its effect on the average duration of reported and unreported bursts (which, in turn, affects the average volume of losses per burst). Fig. 3 shows how the average volume of losses per burst is dependent on both flow rate *and* duration; moderate bursts on service pipes running for many days can lose greater volumes than mains bursts with high flow rates for shorter periods.

Initial calculations, using approximate figures for burst frequencies and flow rates, were sufficiently promising for the NLCI to commission the Welsh Water Group of Companies to develop appropriate software (in Excel spreadsheet format) during 1993. In May 1993, the program only calculated components of annual losses and night flows[3], and during the summer of 1993 the Excel program was extended to provide facilities for:

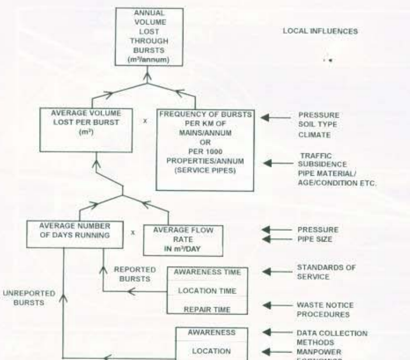

Fig. 2. Factors influencing losses from bursts

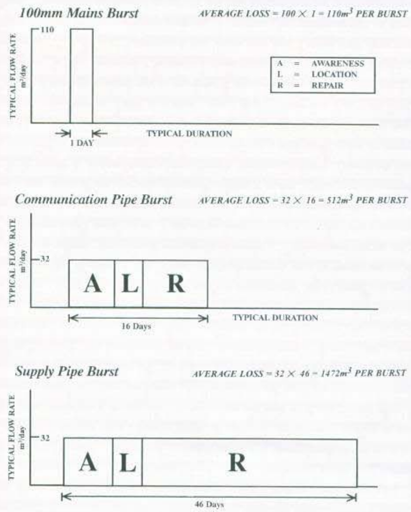

Fig. 3. Effect of duration on losses from reported bursts

(a) Annual water balance (using OFWAT July Returns data) with sensitivity testing of water-balance components;
(b) Calculating manpower cost vs losses relationships for particular active leakage-control methods, e.g. regular sounding and continual night-flow monitoring; and
(c) Derivation of relationships between manpower cost, marginal cost of water supplied and pressure, to fix an economic level of manpower input for a particular leakage-control method in a particular supply area.

The Excel versions of BABE were issued through the NLCI to all water companies in England and Wales during 1993, and were also purchased by the National Rivers Authority and specialist consultants. Most water companies accepted invitations to join a User Group, to steer future software developments by Welsh Water.

Progress in 1994

In the BABE models, flow rates of background losses (per km of main, and per service) are specified at a particular 'standard' pressure, then adjusted for different pressures using a 'pressure correction factor'. In the first Excel model, the 'standard' UK pressure was assumed to be 40 m, and the empirical 'leakage index' relationship from Report 26[1] was used to define a single pressure correction factor.

During 1994, it became evident that the weighted average night pressure in the UK was approximately 50 m, and the nationally derived flow rates published in 'Managing Leakage' for background losses (Table 4.1, Report E) and reported/unreported bursts (Appendix D, Report E) are therefore specified at a standard pressure of 50 m.

Also during 1994, May[4] published the concept that individual leakage paths in a distribution system could be considered as either 'fixed' or 'expanding', with pressure/flow relationships to the power 0.5 and 1.5 respectively. Therefore, in any particular distribution system at any time, the pressure/loss rate relationship would vary with the proportion of 'fixed' and 'expanding' leakage paths. This explanation reconciles observed variations in data used to derive the Report 26 'leakage index' and the 'square root' relationship for flow through fixed orifices. Fig. 4 shows the pressure correction factors for the Report 26 leakage index (Line A), fixed leakage paths (Line B) and expanding leakage paths (Line C).

During the summer of 1994, the BABE software was upgraded and rewritten as three individual programs (as described below), designed for particular end-users, whilst taking account of the above developments and comments received from the user group. When 'Managing Leakage' was published in October 1994, the updated BABE programs provided purpose-built software for implementing the methodologies in the reports. Copies have since been purchased and used by most UK water undertakers, and by specialist consultants and the National Rivers Authority.

Progress in 1995

Pressure Management

The 1994 version of the BABE Pressure Management Program was designed simply to apply the Managing Leakage Report G (Appendix E) methodology for estimating reductions in daily volume of losses arising from pressure management. A substantially upgraded program (UKPMVB), with many additional enhancements, was completed in June 1995 and is described later in the paper.

This program also calculates the hour-day factors (the figure which night-flow losses must be multiplied by to estimate daily and annual losses), and questions the accuracy of assuming a 'standard' hour-day factor of 20 h, particularly where pressure control by flow modulation has been introduced. The program can now also be used to study economic interactions between (a) pressure management, (b) percentage of properties metered, (c) OFWAT DG2 pressure standards, and (d) metered supply tariffs.

Standard Methodologies

The concept of bursts and background losses are being increasingly used to develop standard methodologies for problem areas in UK demand management, for example:

(i) A recommended procedure for assessing losses on unmeasured underground supply pipes;
(ii) Specifying active leakage-control policies which are equivalent to external metering of households, in terms of controlling supply pipe losses;
(iii) A 'standards of service' approach to the setting of leakage targets, based on average durations of different categories of bursts; and
(iv) The National Rivers Authority is increasingly using BABE in connection with assessments of abstraction licence applications.

Brief Description of Current Models

Annual Model UKADB

This is a program, written in Microsoft Access, which is designed for use by engineers, planners or economists in supply areas exceeding 10 000 properties. It is used for retrospective annual water balances, investigating policy issues, identifying economic leakage levels and allocating adequate revenue resources to implement an agreed policy.

In a traditional UK annual water balance (Fig. 5),

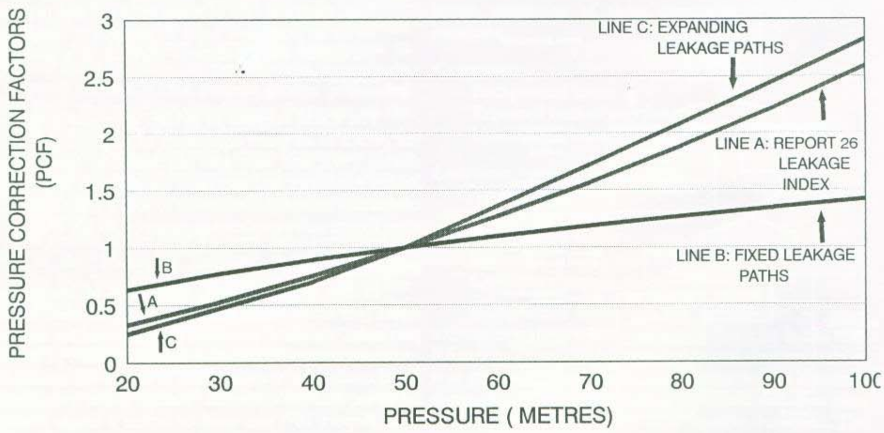

Fig. 4. Pressure correction factors for flow rates of background leaks and bursts

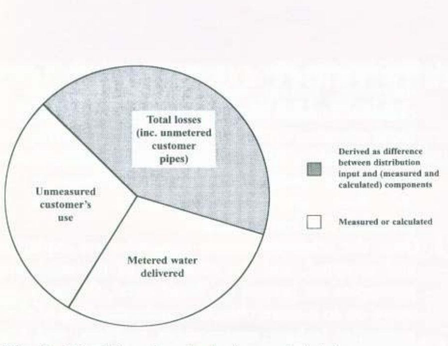

Fig. 5. Traditional water balance: total losses calculated by difference

the water delivered to metered customers and the estimated unmeasured customer use is deducted from the distribution input, and the difference is attributed to losses (some of which are on unmeasured customers' pipes) – but without any understanding of how, where and why those losses are occurring.

With the BABE annual water balance (Fig. 6), the components of losses (calculated from basic infrastructure data, recorded bursts frequencies and modelled company policies) are added to the components of metered water delivered and unmeasured customer use. When the total is compared with the distribution input, there will usually be a balancing error. Sensitivity testing is then used in the model to indicate if the balancing error is too large to be attributed to the modelling assumptions.

A small (2–3%) balancing error is normally acceptable, but a large balancing error indicates the presence of an anomaly – usually an unsuspected backlog of unreported bursts which have accumulated over a number of years. Backlogs, which can be dealt with on a 'one-off' basis, require separate consideration from ongoing management of losses associated with year-on-year burst frequencies. The modelling process is similar to the building of a network analysis model, where

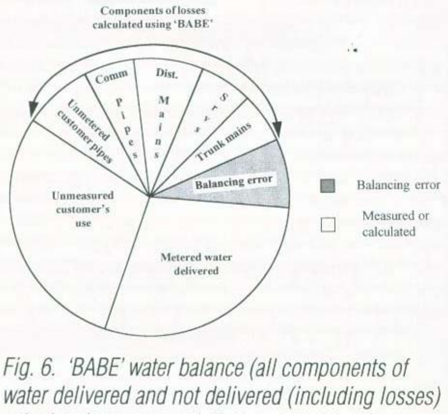

Fig. 6. 'BABE' water balance (all components of water delivered and not delivered (including losses) calculated or measured; then compared with distribution input, and balancing error calculated)

predicted flows and pressures in a network are compared with actual measurements to detect large anomalies.

The 'components of losses and annual water balance' section of program UKADB includes items such as (a) separation of supply pipe losses into 'underground' and 'plumbing' components, (b) multiple pressure/flow relationships (e.g. Fig. 4), (c) optional entry of burst numbers or burst frequency, (d) performance measures and scaling factors recommended in Managing Leakage Report B, and (e) sensitivity tests.

The second (optional) section of the annual model is used to assemble fixed and variable costs of operating leakage policies, and to calculate the economic leakage level on a 'total cost' basis (for example, Appendix B2-2 and Figs. B2.3 and B2.4 in Managing Leakage, Report C). The recent development of a curve-fitting program also allows the results of the 'total cost' BABE models to be expressed as a marginal cost curve (as in Fig 1.1 of Managing Leakage Report C).

Background night flows program UKBNFI

Managing Leakage Report F identifies several parameters which influence night flows, and highlights the problems associated with setting target night flows based on only one parameter (e.g. l/prop. h, or l/km. h).

UKBNFI is a short program, written in Microsoft Visual Basic, which uses local and national data to predict the expected 'background' night flow (in m^3/h) into each separate district if there are no 'bursts' (individual events >0.5 m^3/h). The program can also be used for checking the sizing of district meters for reliable minimum night-flow measurement, and using 'best achieved' night flows to assess the relative propensity to background losses of the infrastructure in each district. The program is designed to assist operations leakage teams in week-by-week prioritizing of efforts on locating unreported bursts. If the measured night flow in any district exceeds the background night flow, the excess is categorized (week-by-week) as a number of equivalent service pipe bursts (ESPB's, equal to 1.6 m^3/h at 50 m pressure). If a supervisor has numerous districts of different sizes, burst-location work can be effectively prioritized in urban areas by calculating properties per ESPB, or by km mains per ESPB in rural areas. Overall performance (of burst location *and* repair) can be monitored weekly by comparing total ESPBs for all the districts in the supply area with the 'economic' number of ESPBs determined from an annual UKADB model.

Pressure management model (UKPMVB)

This program, written in Microsoft Visual Basic, is designed for use by technicians or supervisors at local offices, to quickly assess the savings which would arise from introducing pressure management (or refining existing pressure management) in an individual district. The methodology to calculate changes in daily volume of losses, which applies to both fixed outlet and flow modulating pressure-reducing valves, is based on the 'managing pressure' and 'using night-flow data' reports in the 'Managing Leakage' series. However, full technical and economic appraisal of pressure management also requires consideration of such matters as (a) effect on customers' consumption and metered income, (b) effect on burst frequency and repair costs, (c) diagnosis of fixed and expanding leakage paths, (d) valve sizing, and (e) profiling of flow modulating valves, and these are included in the program.

International Aspects

Since late 1993, there has been increasing international interest in the BABE concepts and software, with numerous presentations, papers, demonstrations and test applications. Because the concepts were designed to be internationally applicable, no fundamental problems have so far been identified when applying BABE in other countries. Early in 1994, the versatility of the BABE concepts was demonstrated when the original BABE Excel model was customized for use by leakage contractors in Canada and the USA.

Papers on BABE at international symposia in Jamaica[5], Cyprus[6] and Japan[7], were followed by presentations to the World Bank by Acer Consultants Ltd. in April 1995. The models were used by Bahamas Water and Sewerage Corporation[8] to review and refine their active leakage-control policy, through a World Bank funded project, and further projects associated with the World Bank are under active consideration. The software has been used by Welsh Water International in the Czech Republic, and in Italy and France for diagnosing problems and recommending solutions. Haiste Kirkpatrick International (Carl Bro Group) as lead partner, together with Yorkshire Water, are evaluating the BABE programs for inclusion in an EC project[9] being undertaken in Germany, Greece, Ireland, Portugal and Spain. German and French customized versions are also under active consideration.

Customization issues tend to relate to local terminology and preferred units, seasonal influence of climate, data availability, and assessing the influence of particular features which could influence background losses (e.g. hydrant types, service-pipe responsibility) or night use (e.g. cistern size). Enquiries and experience to date have not identified any other leakage management models or commercially available software, in the UK or elsewhere, as comprehensive as the current BABE programs.

Conclusions

1. Considering the recent impact of computer modelling in so many fields of water engineering, it is perhaps surprising that conceptual leakage management models have not been previously developed and tested. Most of the individual components already existed, but had not been systematically combined, calibrated or presented as user-friendly software.
2. The UK National Leakage Control Initiative provided the stimulus, and a source of representative data, for calibrating and testing the models in UK conditions. Using the BABE models, recommended methodologies in the 'Managing Leakage' reports can be applied speedily and reliably.
3. As with Network Analysis Models (introduced 15–20 years ago), it will take time for the full potential of the BABE models to be realized, and a period of continual development and enhancement can be anticipated.
4. The concepts offer a systematic approach to more diagnostic leakage management and analysis of complex demand management issues. This helps to focus attention on key areas for future research, and the software is designed to accommodate technical advances or results of other published research (e.g. the fixed and expanding paths concept of pressure/flow relationships).
5. Once the relatively simple principles are explained and accepted, and the reliability of the modelling principles are proved by 'blind tests', the users can move on to a more objective understanding of their particular leakage management problem, and how best to tackle it.
6. The models have been designed to be internationally applicable, and no significant technical customization problems have yet been identified.

Acknowledgements

The authors wish to thank colleagues from the UK water industry (too numerous to mention individually) for their support and interest in the development and application of BABE models. The views expressed in this paper are their own.

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