BREAKS AND BACKGROUND ESTIMATES (BABE)

The development work on the Breaks and Background Estimates (BABE) concepts for estimating physical losses was led by Allan Lambert, a Senior Consultant with BWS, early in 1992 when he was Technical Secretary to the UK National Leakage Control Initiative. The concepts were designed from the outset to:

- Use a combination of logical, individual assumptions which are combined systematically, using appropriate software;
- Be internationally applicable;
- Be capable of customization or adaptation to model any individual water distribution and its leakage characteristics.

The BABE concepts, as used in the production of their related software, are the first to model physical leakage objectively, rather than empirically, thus permitting rational planning management and operational control of strategies for their reduction. The concepts were first elaborated during the UK's National Leakage Control Initiative, which began in 1991 and they reached the point in their development where they could be applied in practice by mid-1994. The findings of this Initiative have been published in the Managing Leakage series of reports (Ref.. 1).

In all the years since they were first used, the basic programs have undergone significant further development as they have been progressively adapted to incorporate valid technical advances that have been made internationally in the leakage management sector. For example, in 1995, the concepts used for modeling Pressure Reduction and Management (PRAM) were substantially enhanced using the work of May (Ref.. 2) on Fixed and Variable Area Discharge paths (FAVAD). Further improvements have resulted from the testing and application of the concepts and models in a wide variety of situations internationally, through incorporation of advances in technology - particularly in respect to pressure/leakage relationships - and in the user-friendliness of the software design.

The BABE and PRAM concepts, and the software developed from them, are valuable management tools that assist water companies to improve their technical and financial credit-worthiness by providing the key to effective active leakage control. They assist in strategic assessments, in leakage management operations and planning and design:

- At an operational level – to plan, prioritize and manage a leakage monitoring, control and repair program to locate and repair unreported leaks and breaks;
- At planning, design and operational levels – to progressively manage operating pressures to optimum levels;
- At a strategic level – to derive a water balance and to determine an economically justifiable program of leakage control;
- At a planning level – to phase network restructuring and rehabilitation programs;
- At a managerial level – to set leakage management performance criteria for both water supply entities and for private operation of systems by private sector concessionaires and management contractors.

The concepts and programs were first calibrated for UK conditions, and are widely used there in various forms by almost all of the privatized water companies serving England and Wales. They have also been successfully applied in many other countries. Many of the principles are beginning to be used by Regulatory Authorities in the UK to set targets that water utilities should meet in respect to leakage management and in the formulation of leakage management performance targets in relation to water service management contracts.

A recent paper (Ref. 3) outlines the BABE concepts, and refers to recent applications in countries with continuous supply, mostly to properties with plumbing systems subject to mains pressure. In Amman, Jordan, the concepts have been successfully applied for the first time to a long-duration, intermittent supply situation by the consultants, where they have also used them to assist in the formulation of the basis for a national leakage management study. Experience in Jordan, West Bank, the Bahamas and Santa Cruz, Bolivia are described in the Case Studies at the end of an Infrastructure Note drafted for the World Bank (Ref.. 6).

Some of the principal factors that drive the concepts and software are described below, including:

- A definition of background leaks and breaks;
- Reported and unreported breaks;
- Passive and active leakage control;
- Awareness, location and repair times;
- Burst flow rates;
- The fundamental importance of pressure to leakage management;
- The night-day factor;
- The use of marginal costs in economic assessments.

Water service undertakings around the world attribute different meanings to the terminology used to describe their respective systems, their active leakage control activity and the components of their annual water balance. To avoid misinterpretation of terminology used in this work, Appendix F (see Volume 3) reports the main terms used and their definition as applied in the work.

THE BABE CONCEPTS AND THEIR APPLICATION

Definition of Background Leaks and Breaks

The Breaks and Background Estimates (BABE) concepts can be used to calculate, from first principles, up to 18 components of losses in different parts of the distribution system, and on customer's pipework. The system consits of:

- Transmission mains (typically > 12in);
- Service reservoirs ;
- Distribution mains ;
- Connections from the main to the customer's meter or, in absence of a meter, to the point that customer or property manager becomes responsible for pipework and plumbing, normally at the property boundary;
- Losses on the customer's own pressurized pipework;
- Plumbing inside customer's properties.

Losses are categorized as:

- *Breaks*, both reported and unreported, being individual events for which the rate of loss is greater than 2gpm at 5 bar (12.5 psi) pressure
- *Background leaks*, being individual events for which the rate of loss is less than 2 gpm at 5 bar (12.5 psi) pressure.

To give an idea of the flow represented by 2 gpm, water would typically flow from a garden hose under low pressure at this rate, or a typical 2 gallon bucket would be filled in about a minute.

This categorization is based on the generally accepted minimum rate of loss which can be detected by pipe sounding techniques - which is itself influenced by depth of cover to the pipe, pipe material and water temperature. The detectable rate of loss is considered to be 2 gpm where pipes are buried with a normal minimum cover of about 3 feet and metal pipe materials are used. Background losses are individual events that will continue to flow undetected by an active leakage control program unless either detected by chance or until they gradually worsen to the point that they can be detected.

Further categorization of physical loss events refers to whether a leakage event is reported or unreported:

- *Reported breaks* are those events that are brought to the attention of the water utility by the general public or the water supply organization's own personnel. A break or a leak that, under urban conditions, manifests itself at the surface will normally be reported to the water supply organization whether or not it causes a nuisance such as flooding.
- *Unreported breaks* are those that are located by Leak Detection teams as part of their normal everyday active leakage control duties. These breaks go undetected without some form of active leakage control.

- *Hidden losses*, in a BABE analysis, are composed of two elements – *undetected breaks* and *closing error*.

Left undetected, hidden breaks continue to accumulate and deteriorate. Dependent upon the permeability and nature of the soil in which the pipe is laid, the water lost may continue to percolate away into the ground and feed the water table or infiltrate a drainage system. There will always be some hidden losses as it will be impossible to find all the breaks in a system at any one time, the number remaining undetected being a function of the intensity and success of the active leakage control program. Eventually, the flow from an undetected break may become so great that it becomes visible at the surface and is reported.

Although the BABE analysis provides a close approximation to the magnitude of the different elements that constitute the water balance, there is almost always an unexplained amount of water – this is called the closing error. Increasing knowledge of the various components in each situation should lead to the closing error being gradually diminished.

The total leakage from undetected breaks and hidden losses is generally significantly greater than from reported breaks as, virtually by definition, they run for much longer periods - certainly at least until action is taken by which they are detected. Breaks that show at the surface are almost invariably reported quickly and repaired within a short time because of their nuisance value.

Passive and Active Leakage Control Policies

Passive leakage control. When a water service organization responds to reports of accidental damages, breaks and leaks visible at the surface and reported to them by the general public or their personnel, this is termed passive leakage control. This form of leakage management is the most commonly practiced by water service providers.

For reported breaks and accidental damage, the key factors limiting the total water lost from them is the time taken to make a repair and the quality of workmanship and materials used in making the repair.

Active leakage control. In order to locate unreported breaks, it is necessary to use leak detection techniques and to carry out a campaign that applies them to the network continuously. The conduct of such a program is termed active leakage control. One of the major benefits of the BABE concepts is that they can assist the management of a water utility to plan and execute the most economically justifiable active leakage program for a water distribution system.

Awareness, Location and Repair Times

The length of time for which an unreported break runs is split, in the BABE concepts, into three separate time components - awareness, location and repair - the duration of each of which is separately estimated and modeled:

- *Awareness:* - the length of time taken from a leak first occurring – whether it is reported or unreported - to the time when the water utility organization first becomes aware that a leak exists. For reported breaks, this duration is usually very short while for unreported breaks, it is a function of the active leakage control policy.

- *Location:* - having become aware of a break within a limited area, the time to locate it will also be dependent upon the intensity of activity devoted to location but should generally be a matter of a few days - or less if detection consists solely of sounding.

- *Repair:* - this is also generally quite a short period since the water utility has made a considerable investment in "awareness" and "location", it would be illogical to permit a break to continue once detected.

Reported breaks have extremely short combined awareness, location and repair times - varying typically in the range of only a few hours up to a week – and therefore the amount of water lost is relatively contained. The time taken by the public to report a break will depend upon the degree of inconvenience caused but would not generally be more than 5 days and the break, once reported, is repaired within 2 days.

However, unreported breaks, which can only be detected through active leakage control, run for much longer periods and, although the rate of leakage may be less than for reported breaks, the amount of water lost can be considerable. Consider, as a demonstration of this concept, a case where the leakage detection technique adopted is the regular sounding of the system, followed by rapid repair of all located breaks. If the system is completely sounded once a year then the average duration for which an unreported break will run on that system will be a half year, or approximately 185 days. This is derived from the sum of the average time taken to become aware of the break, i.e. half a year in this example, plus one day each to locate and then to repair the break. Doubling the intensity of active leakage control effort, i.e. completely sounding the system every 6 months instead of every year, would reduce the duration for which the burst runs to an average of about 95 days, halving the water lost. However, conversely, a reduction in activity to sounding the system every two years would allow breaks to run for an average of 365 days before their location and repair, doubling the losses resulting from sounding the complete system annually.

This illustrates why the detection of unreported breaks can be of such importance to a water service provider.

Clearly, these various intensities of sounding carry differing levels of cost – personnel, equipment and materials - to implement and these costs must be compared with the value of the water that would be either saved by a higher intensity of active leakage control activity or lost due to a lower level of activity. BABE software used for economic overviews of leakage management strategy permits the balancing of cost and benefit in order that an economically justifiable intensity of detection activity may be selected, whatever the method of active leakage control.

Night flow measurement techniques to achieve awareness of breaks, combined with step testing to locate individual breaks, are more efficient than regular sounding alone. Night flow measurements require two conditions – a sectorized system, with sectors generally of not more than 3000 connections, preferably far less, and a fully-pressurized system. The BABE concepts and programs assist in the selection of the most economically justifiable active leakage management policy by comparing the cost of each alternative with the value of water saved using marginal cost.

Break Flow Rates

Typical break flow rates used in the BABE programs, and reported in gpm at 5 bar pressure (12.5 psi), are taken from internationally published data (UK and Germany) for different pipe sizes and materials.

All the BABE programs contain the means to adjust these flow rates, at a standard pressure of 5 bar, according to the pressures at which the portion of the distribution system under study is being operated.

Pressure – Its Fundamental Importance to Leakage Management

The most important driving factor influencing losses, whatever the infrastructure condition, is undoubtedly pressure.

The pressure under which a system operates affects every leak in the distribution pipe network, including customers pipes pressured by the network.

Pressure and leakage flow rates. There are two main types of discharge paths for leaks and breaks - fixed area and variable area. Holes and breaks in the walls of metal pipes and discharges from open-ended plumbing are examples of fixed area paths, while examples of expanding paths are splits in the walls of plastic pipes and leaks at joints and fittings. Losses from fixed area leakage paths vary according to the square root of the system pressure, while discharges from variable area paths vary according to pressure to the power of 1.5 or 2.5. As there will be a mixture of fixed and variable area leaks in any distribution system, loss rates vary with pressure to a power that lies between the limits of 0.5 and 2.5. Recent re-analysis of apparently diverse research data from Japan and the UK has shown that this factor typically has a value of 1.15 for large distribution systems containing mixtures of pipe materials, a value which has been found to be common in many countries studied by the Company.

Most networks contain a mixture of pipe materials and joints and the characteristics of the leaks from these combine to produce an average N1 value of approximating 1 +/-20%. Until a water utility has carried out specific tests on their system, it is recommended that an N1 value of 1 be used to model the water loss situation.

Pressure and frequency of break occurrence. Pressure not only affects the rate at which losses flow from the system, it can also have a major effect on the frequency with which new leaks and breaks occur. Recent examination of break records and pressure in the UK has shown that mains break frequency may vary according to the cube of the pressure, i.e. doubling the pressure will cause an eight-fold increase in the rate of occurrence of mains breaks. Conversely, reducing system pressure will significantly reduce burst frequency. To retain the benefit of reduced numbers of breaks, a reduction in pressure must be maintained at all times. Unfortunately, if pressure is allowed to rise even temporarily, all the breaks that would have occurred at the higher pressure will then take place.

Pressure and system stress. Frequent changes in operating pressure, inducing surges, also stresses pipes far more than a relatively steady pressure. Where pressures in distribution systems are subject to frequent daily valve operations, such as occur with intermittent supply, there is an increasing weight of evidence that the resulting frequent stresses and pressure surges produce frequencies of breaks many times those which would be experienced under a steady pressure regime. This is reflected in the BABE models by the actual recorded frequency of breaks.

Pressure and reduction of background losses. Most importantly, reduction of excess system pressure is a very effective way of reducing background losses that, by definition, are undetectable. The importance of pressure management to this factor can hardly be over-emphasized because it has been demonstrated that, typically, 70 to 80% of breaks occur on connection pipes, which are frequently within the "background loss" category due to the large number of joints and fittings.

It follows that reduction of excess system pressure is frequently the single most effective action that can be taken when practicing active leakage control. Reduction in system pressures can often have the added benefit of lower power costs due to reduced pump energy consumption.

Therefore, not only does pressure affect every point of leakage from the system, it also affects the frequency at which breaks occur. In order to take full account of pressure and its importance to leakage reduction, the BABE software include the following relationships which have been derived from observation of practice and verified internationally:

- Break flow rates proportional to pressure to a power between 0.5 to 1.5, depending upon the pipe materials and predominant types of failure;
- Background losses proportional to pressure, generally to the power of between 1 and 1.5.

Night-Day Factor

Pressure in a water distribution system varies with demands through the 24-hour day. For systems served by gravity from reservoirs, pressure is normally highest at night, between 02.00 and 04.00 am, when consumption is at its lowest. Pressure is lowest when consumption is highest, generally around the principal meal times.

The minimum flow, measured over one hour during the night when flow is at its lowest, is generally used in the BABE programs as the initial basis for calculating losses from the system. If pressure is highest at that time, it would be incorrect to multiply the rate of flow measured at this time by 24 to obtain the losses over a day, so the loss rate at night (in gal/hour) is multiplied by a "Night-Day Factor" of less than 24.

The Night-Day Factor is automatically calculated from the pressure profile in the pressure management software, and can be more than 24 hours for pumped systems or where sophisticated pressure control is practiced.

Use of Marginal Costs in Economic Assessments

All the customized BABE programs provide not only a technical assessment of potential savings in physical losses by pressure management or active leakage control, but also a rapid economic appraisal of the associated cost savings. Such economic calculations use the marginal cost of water. The marginal cost of water [per 1,000 gallons] is, simply, how much money a water utility would save if the physical losses were reduced by 1,000 gallons.

In any particular appraisal of savings, several considerations will apply in deciding which marginal cost should be entered in the program; however, as all such entries are default values, they can be easily changed for sensitivity testing purposes.

Marginal costs can be considered as either:

- Short term operation costs, e.g. pumping costs from sources or in distribution;
- Short term operation costs plus deferred capital cost, if the water saved would be sufficient to defer capital investment in new source works, pumping stations etc;
- Bulk supply cost, if the water saved would reduce bulk supply charges;
- Price charged to customers, if the water saved could be sold.

Non-Revebue Water (NRW) consists of two principal components:

- Real, or physical, loss of water – leakage;
- Apparent, or commercial, loss – water unregistered on customer meters due to their inaccuracy, water stolen by unauthorized users and authorized but unmetered use by water operations or public institutions.

The reduction of physical losses "creates" new water, it is water that is now available to be consumed for the first time. Saving of apparent losses does not result in additional resource. Therefore savings in physical losses, in effect substitute for the provision of additional resource or, at worst, delay investment in bringing additional resource to the supply area.

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