THE INTERNATIONAL APPLICATION OF THE BABE CONCEPTS – FROM FEASIBILITY STUDIES TO PERFORMANCE TARGET BASED NRW REDUCTION CONTRACTS

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Abstract

Until recently, the practice of controlling leakage from water supply and distribution networks could have been considered more an art than a science. In 1991 the UK's National Leakage Control Initiative was set up to address the problem of leakage control in a more structured manner. BABE (Burst and Background Estimation), a conceptual holistic model of leakage, was developed and designed for world-wide application. In 1994, the FAVAD (Fixed and Variable Area Discharges) concept was introduced to rationally explain the diverse and complex relationships between pressure and leakage rate in distribution systems. Bristol Water Consultancy Services (BWCS) have been applying these concepts internationally since 1995 and practical examples of their application in Greece and Malaysia are presented.

Introduction - BABE Concepts

BABE - Bursts And Background Estimates - is a set of concepts applied as component-based computer models which, for the first time, provide organisations responsible for water supply and leakage control consultants with user-friendly tools for making a fully-integrated assessment of all of the components of leakage control - technical and economic. The BABE and FAVAD concepts are used to assist in strategic assessments, in leakage management operations and planning and design:-

- at an operational level – to plan, prioritise and manage a leakage monitoring, control and repair programme to locate and repair unreported leaks and bursts;
- 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 programme of leakage control;
- at a planning level – to phase network restructuring and rehabilitation programmes;
- 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 initially calibrated for UK conditions, and are widely used there in various forms by almost all of the privatised water companies serving England and Wales. Since 1995, BWCS has utilised BABE in several World Bank, European Development

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Bank and GTZ funded projects. It has now been applied to widely different supply and distribution characteristics - Samarkand and Bukhara (Uzbekistan), Dushanbe (Tajikistan), Dubrovnik (Croatia), Amman (Jordan), Riyadh (Saudi Arabia), Cartagena (Colombia), Kuala Lumpur (Malaysia) are a few examples. The BABE Software, integrated with an economics package and calibrated to local conditions, permits an assessment of leakage management approaches to determine that which will be most appropriate and effective for a given distribution system. It aids the selection of the most appropriate leakage control methods and levels of activity, management of system pressures, metering, and the effect of changes to the water network operators' policies and service levels.

Non-Revenue Water Analysis using BABE

Defining Non-Revenue Water

One of the internationally recognised problems in comparing Non-Revenue (NRW) levels from country to country is to understand what a particular organisation defines as NRW or as it is often referred to – Unaccounted for Water. The IWA has recognised this discrepancy in terminology around the world and has developed a standardised method for defining the elements of the Annual Water Balance (Ref. 2). The IWA methodology for Annual Water Balance divides the System Input into two basic components, Authorised Consumption and Water Losses, as represented in Figure 1 below. The individual components that make up the whole are further defined within the IWA reference (Ref. 2). Application of the IWA methodology is essential in assessing correctly the NRW situation and enabling a comparison with other networks internationally.

<table>
<tr><td rowspan="8">System Input</td><td rowspan="5">Authorised Consumption</td><td rowspan="3">Billed Authorised Consumption</td><td>Billed Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td>Billed Metered Authorised Consumption</td></tr>
<tr><td>Billed Unmetered Authorised Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Authorised Consumption</td><td rowspan="5">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Authorised Consumption</td></tr>
<tr><td rowspan="3">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorised Consumption (including theft of water)</td></tr>
<tr><td>Metering Inaccuracies</td></tr>
<tr><td colspan="2">Real Losses</td></tr>
</table>

Figure 1: IWA Standardised Components of the Annual Water Audit

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BABE Components of Real Losses

The Bursts And Background Estimation **(BABE)** concept divides real, physical losses into a number of components and defines basic assumptions about each component such that the total level of losses for any system can be determined. According to **BAB**E, the physical loss from the system can be considered to occur on each of the following elements of the system:

- the primary distribution or trunk main system
- the secondary distribution system
- service connections to individual customers

In addition to these components, the losses are further sub-divided according to whether the losses are detectable with active leakage control or not and whether they are located by active leakage control or reported by others. These components are described as:

- background leakage (undetectable leaks)
- unreported bursts (those detected by active leakage control)
- reported bursts (those reported by customers or others)

Typically, losses with individual flow rates of less than 400 to 500 litres per hour are not detectable with normal leak detection techniques and collectively form the background leakage component. Background leaks tend to be leaking pipe joints, leaking fittings and very small corrosion holes in metal pipes. Although individually they have low flow rates, they tend to have long duration of existence and collectively can form a substantial proportion of the total physical losses.

Reported bursts tend to have higher flow rates but short duration. They will usually have a "nuisance" value such that consumers are affected or are highly visible. The short duration is usually a function of their visibility or nuisance value and the speed at which the water undertaking responds to this type of leak.

Unreported bursts tend to be of medium flow rate with a duration that is dependent upon the active leakage control policy. These types of burst are occurring continuously in the distribution system at a rate dependent upon system pressure, method of operation, ground conditions and infrastructure condition.

If the active leakage control policy is to carry out leak detection survey across the whole system on an annual basis, then some leaks will be up to one year old, having just occurred after the last survey, whilst some will be no more than a few days old. The average duration of an unreported burst will be half of the interval of the survey, in this case six months. If the frequency of survey is increased to twice yearly, the average duration of an unreported burst will be reduced to 3 months. The annual volume of water lost from unreported bursts would be halved but the annual cost of the survey would be doubled. An economic balance would be reached when the cost of survey equals the cost of water saved. This demonstrates how the concepts combine the technical aspects of physical loss control with the economics of the cost of water.

The calculated values of BABE Components are derived independently of the Annual Water Balance Calculation. They are used in conjunction with the Physical Losses derived from the Annual Water Balance to estimate the level of excess or currently undetected losses, i.e. those losses that are not being detected and repaired with the current active leakage control policy.

In order to reduce physical loss with an economically justified strategy of leakage management options, it is necessary to employ the BABE concepts and develop a model of the level of physical losses for each of the relevant components. Each alternative leakage management action will impact on each of the physical loss components with differing results and with differing associated costs. By applying a number of scenarios for physical loss reduction, the actions with the highest economic benefit can be determined and prioritised in the overall strategy accordingly.

The Importance of Pressure Management

The flow rate of any leak is dependent on the size of the leak orifice and the pressure that is applied to the system. Leakage is therefore pressure dependent and reductions in system pressure to optimal levels can lead to reductions in leakage levels. The management of system pressure is yet another, and arguably the most important, tool for active leakage control. The relationship between leakage and pressure is, however, not straightforward. The FAVAD (Fixed and Variable Area Discharges) concept is applied within BABE to describe the relationship between pressure and each of the components of leakage. In FAVAD, bursts are assumed to be fixed size holes and the flow rate through a burst is proportional to pressure with a power law exponent of 0.5 (square root relationship). Background leaks at joints and fittings are now known not to be fixed in size but are in fact variable or expanding paths. FAVAD states that the size of orifice, that is the cross sectional area, for these leaks varies with pressure. This introduces another pressure term into the general equation such that the flow rate through a background leak is proportional to pressure with a power law exponent of 1.5.

Background leakage is thus shown to be more sensitive to pressure reduction than leakage arising from bursts. A particular problem of traditional leak detection and repair activities is that whilst they may result in the removal of unreported bursts from a system, they do not remove the background leakage. By definition, background leakage is that leakage that cannot be detected by traditional leak sounding techniques and is generally uneconomic to repair. Consequently, all calculations of the water balance using the BABE concepts should incorporate corrections for pressure according to the FAVAD principles.

International Applications of BABE Concepts
BABE Consultancy for DEYACh (Chania, Crete)

BWCS were commissioned by the Municipal Enterprise for Water and Sanitation of Chania (DEYACH) to undertake a detailed technical assessment of existing demand, consumption and water system networks – particularly in the context of water losses - within the city of Chania, Crete (Greece). The analysis was based on several weeks of field study including the measurement of flow and pressure data and the use of BABE techniques and methodologies to assess the network system.

Annual Water Balance and Physical Losses – Chania

The town of Chania is a medium sized town with an estimated population of 75,000 people and an estimated network length of 210.5 kilometres. Supply is continuous to an estimated 14,375 connections at an average pressure of 45 metres. Output from the water production facilities is metered and the recorded Total System Input for 1998 of 10.19 Mm^3/year. DEYACh imposes compulsory universal metering for all categories of consumers (except the fire brigade) and all metered consumption is derived from billing records. DEYACh have completed extensive research into the level of meter under- registration and estimate this to be approximately 14% of the true metered consumption.

Using these calculations, an updated 1998 Annual Water Balance (see Table 1) according to IWA methodology was established.

	FY1998 (Mm^3)
System Input	**10.190**
Authorised Consumption	
Billed Water Exported	0.000
Billed Metered	4.991
Billed Unmetered	0.000
Unbilled Metered	0.152
Unbilled Unmetered	0.053
	5.197
Water Losses	**4.992**
Apparent Losses	
Meter Inaccuracies	1.347
Unauthorised Consumption	0.101
	1.448
Real Losses	**3.543**

Table 1: Chania 1998 Annual Water Balance (summary only)

Annual Physical Losses of 3.543 Mm^3 is equivalent to 675 litres/connection/day compared with Bristol Water's loss of 90 litres/connection/day. Further confidence in this assessment was obtained from actual night flow analysis conducted on two large areas of the distribution network (Table 2). The weighted average for these two zones is 600 litres per connection per day, very similar to the Annual Water Balance figure and providing confidence that the values obtained are realistic and representative of the actual levels of leakage.

Zone	Physical Losses from Night Flow Analysis (m3/d)	Number of Connections	Physical Losses (l/conn/d)
Model 1 area	3,214	5,854	549
Model 2 area	3,178	4,804	662
Weighted Average	**6,392**	**10,658**	**600**

Table 2: Chania Night Flow Analysis

A summary of the total annual loss from the BABE components is summarised in Table 3. It is interesting to note that the largest component of Physical Loss is that attributed to Background Leakage. This is commonly found in urban distribution systems where Background Leakage from service connections constitutes the greatest element.

BABE Components	Annual Volume (Mm^3/year)
Losses from Background Leakage	2.227
Losses from Reported Bursts	0.389
Losses from Unreported Bursts	0.000
Total Physical Loss according to BABE calculation	**2.616**

Table 3: Physical Loss according to BABE calculation (Chania - 1998)

It should be noted that Background Leakage cannot be reduced by implementing more Active Leakage Control or carrying out more leakage surveys. By its very definition it comprises small undetectable leaks which can be removed by infrastructure replacement (most expensive option) or reduced by implementing pressure management. In this example the Unreported Bursts are zero as in 1998 DEYACh did not conduct any leak survey work and hence did not locate any undetected leaks.

It can be seen that there is considerable difference between the Annual Water Balance estimate of Physical Losses (3.543 Mm^3/year) and the calculation of Physical Losses using the BABE Component approach (2.616 Mm^3/year). Whilst an element of the difference is due to small errors inherent in the calculation methods, a significant element of the difference is due to what is called "*Hidden Loss*". This is composed of the amount of detectable loss within the network that is not being located by the water utility due to insufficient active leakage control. This results in a backlog of undetected bursts to occur in the network. This level of loss is equivalent to 140 unreported service pipe bursts (at an average of 18.2 m^3/day) running for 365 days of the year.

The cost of physical loss reduction exercises should be related to the value of water that is likely to be saved. In this example, if it is estimated that the leak detection and repair exercise is 50 million Greek Drachma and the current value of Hidden Losses at 15 million Greek Drachma, then the payback will be 3.3.years. The remaining question is whether the saving is sustainable for a time greater than the payback period. If a lower level of Physical Loss can be sustained for an indefinite period through routine monitoring and normal Active Leakage Control then a payback period of 3.3 years is acceptable and the economic benefit of such a one-off exercise is justified.

BABE and FAVAD principles applied in Selangor Phase 2 (Malaysia)

Introduction

BWCS is currently engaged on a US$105 million project to reduce NRW across the entire State of Selangor (Malaysia) by 200 million litres/day. It is considered to be the largest performance target based NRW reduction project in South East Asia and possibly the world. A vital key to its success is the application of BABE modeling techniques to set the targets and the use of metered zones to measure the savings achieved. Using BABE principles and methods will ensure the target is achieved and the project is successful.

BABE Night Flow Analysis

Conducting Flow and Pressure measurements both before and after a NRW reduction exercise is a prerequisite to providing witnessed and documented proof of the savings achieved. It also provides compelling evidence of the capability and success of the projects objectives. Using such measured data allows an assessment of the leakage levels in each zone to be assessed and an example zone (called Zone A) is presented below.

Use of the Minimum Night Flow (usually between 03:00 and 04:00) is the most meaningful piece of data related to leakage levels as during this period as authorised consumption is at a minimum and leakage will be at its maximum percentage of the total flow. The leakage component is estimated by subtracting an assessed amount of legitimate consumption (for each customer connection) and any known significant night use. This element is termed the Net Night Flow and consists predominantly of physical losses from the network, which can be further divided into background losses and bursts using the BABE component methodology. The Net Night Flow is proportional to the average pressure in the zone and thus the leakage level throughout the day can be modulated from the Net Night Flow value according to the recorded 24-hour average pressure. This allows the Total Physical Losses to be calculated and since the Total Inflow is known, to estimate the Total Consumption.

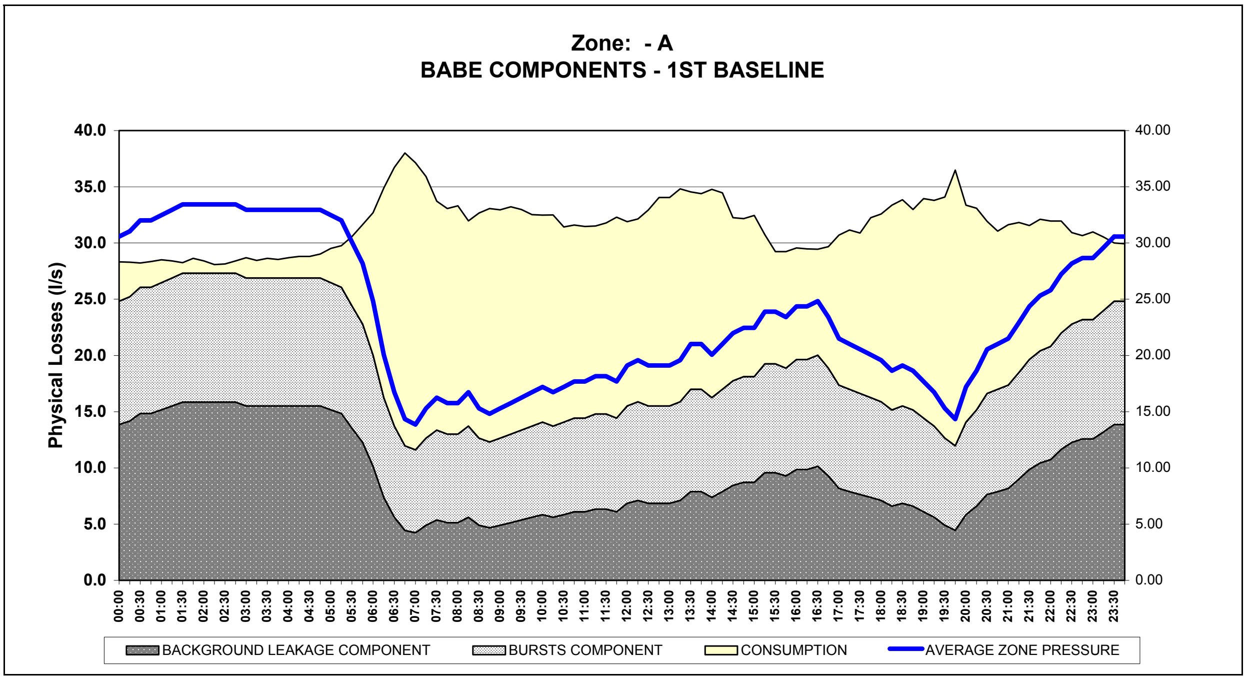

Figure 2: Zone A – BABE Components (1st Baseline)

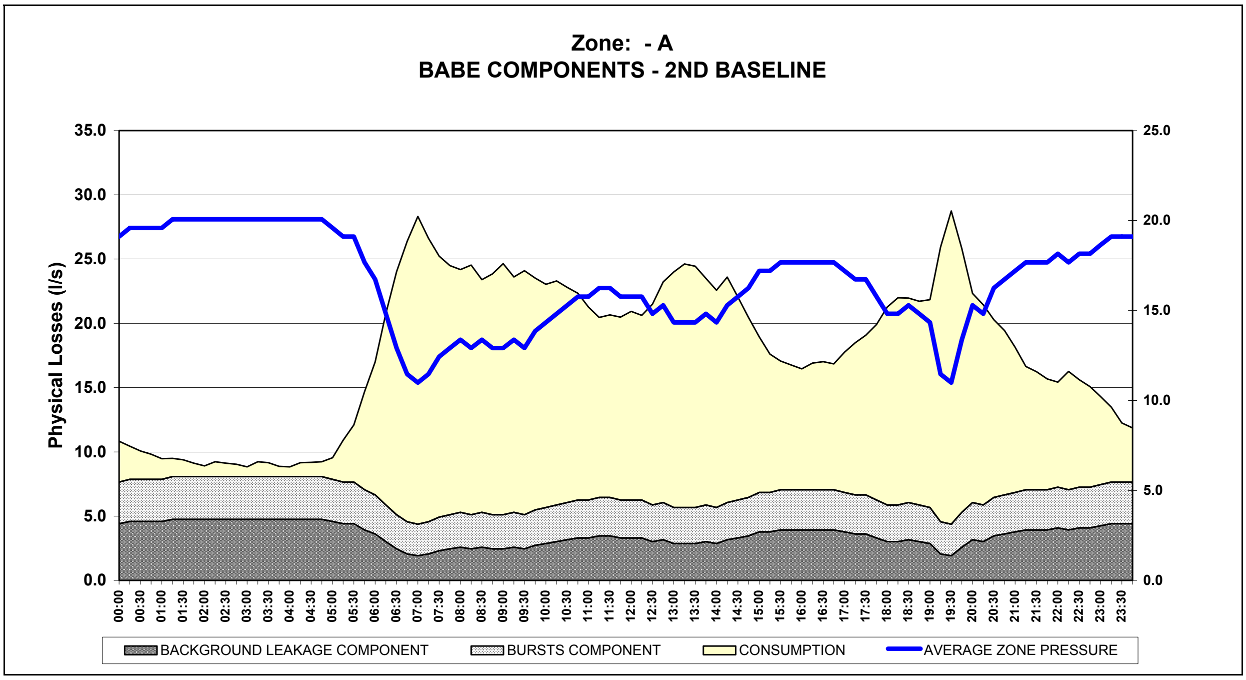

Figure 3: Zone A – BABE Components (2nd Baseline)

In Figure 2 the Total Inflow before leak detection is presented (First Baseline). This has been split into the 3 components of Background Leakage and Bursts, modulated for pressure, and Consumption. The measured data indicates a Total Inflow of 2,729 m^3/d and an Average Zone Pressure of 23 metres.

Figure 3 presents the Total Inflow after leak detection and repair (Second Baseline). The Total Inflow indicates a significant reduction to 1,559 m^3/d - a saving of 1,171 m^3/d. It should also be noted that the Average Zone Pressure has also been reduced to 16 metres using a Pressure Control Valve. An important part of the zone implementation is the ability to manage pressure within the zone, as in some cases repairing all the bursts in a zone can lead to a rise in pressure with no noticeable reduction in leakage levels. This is due to increased pressure causing a rise in Background Leakage to the detriment of any savings achieved in repairing Unreported bursts.

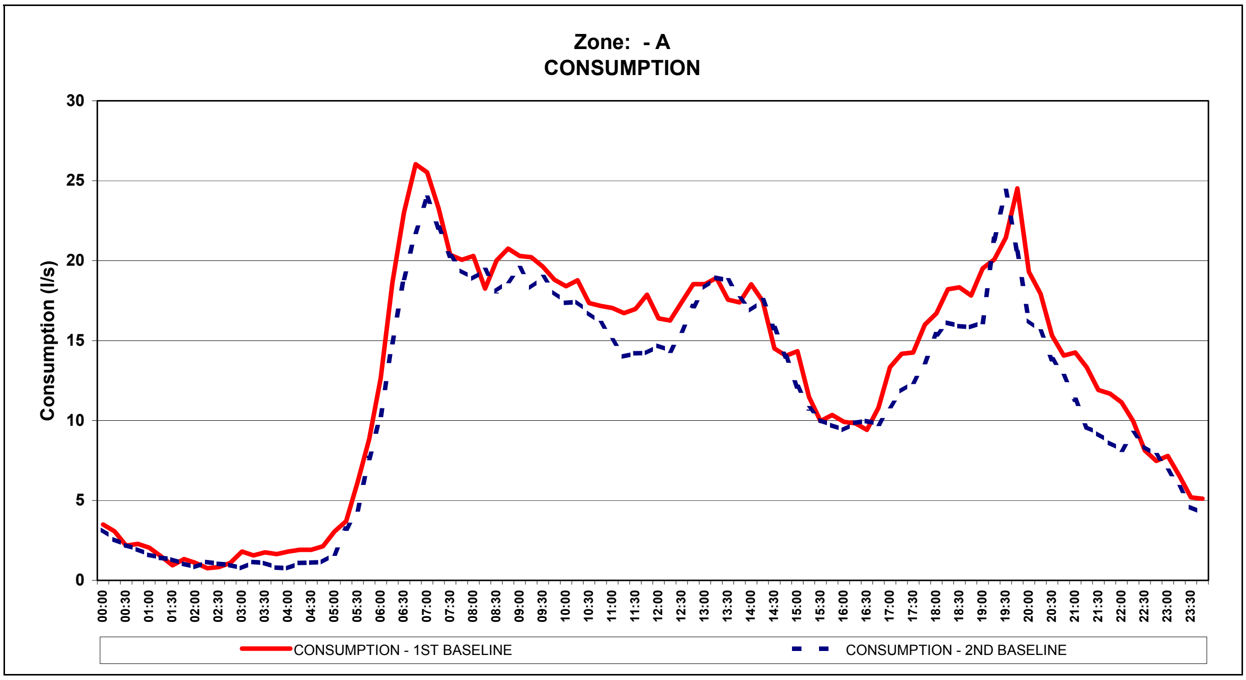

Figure 4: Zone A – Consumption (1st and 2nd Baseline)

In Figure 4 the profile of consumption is presented both before and after Leak Detection and Repair. The chart clearly demonstrates that consumption remains unchanged despite leak detection and repair works allied to pressure reduction.

Conclusions

Given the importance – and the magnitude of – system leakage, this knowledge and capability provides a better basis upon which to develop future strategy for the management of urban water and wastewater infrastructure. A number of key conclusions can be drawn:

- The Application of BABE methods and techniques works within the International context and is being actively used.
- All BABE concepts have been published and are in the public domain however it is relevant experience in their application that ensures they are successfully applied.

References

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2. *Performance Indicators for Water Supply Services*, H. Alegre, W. Hirner, J. Baptista, & R. Parena, IWA Publishing 'Manuals of Best Practice' Series, 2000. ISBN 1 900222 272