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Component Based Analysis for Management of Leakage in Potable Water Supply Systems

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EXECUTIVE SUMMARY

Understanding and managing leakage in potable water distribution systems has always posed interesting and often difficult problems to the water supply authority. Many approaches to this issue have been developed in different parts of the world, some of which have been very innovative and successful. In many cases, however, the lack of a standard approach to the problem has resulted in failure and the waste of valuable resources.

To address this problem, a National Leakage Initiative was established in the UK in 1991 by the Water Services Association and the Water Companies Association to update and review the guidelines concerning leakage control that had been in use since 1980. It was agreed by all organisations involved in potable water supply that the guidelines required updating in view of the considerable progress that had been made over the previous ten-year period. It was agreed that all water suppliers would adopt a straightforward and pragmatic approach to leakage levels which was eventually achieved through the development of various techniques that became known as the Burst and Background Estimate (BABE) procedures. The BABE procedures were developed over a period of approximately 4 years by a group of specialists selected from several of the major water supply companies based in England and Wales. The techniques have since been adopted and adapted in many parts of the world to the extent that they are known and used in most developed and developing countries. While the term BABE is still well known and recognised in many countries, the methodology has continued to develop well beyond the original Burst and Background Estimates Techniques with the result that it is often referred to simply as Component Based Leakage Management.

In order to promote and encourage efficient use of the available water resources in South Africa, the South African Water Research Commission (WRC) initiated and supported numerous projects. Although some very comprehensive and sophisticated software was already available both internationally and locally, it was considered too expensive for many of the smaller municipalities in South Africa with the result that the WRC concentrated on providing low cost software solutions to help water suppliers in managing their unaccounted-for water. Five models have been developed that can now obtained directly from the WRC either free of charge or at a nominal cost. The four models developed by the author are discussed in the paper and include:

- SANFLOW: Background Night Flow Analysis Model (completed 1999)
- ECONOLEAK: Economics of Leakage Model (completed 2001)
- PRESMAC: Pressure Management Model (Completed 2001)
- BENCHLEAK: Benchmarking of Leakage Model (completed 2002)

INTRODUCTION

Within the last few years there has been a growing realisation that the rapidly increasing water demands throughout South Africa are not sustainable. As a result of this realisation, there has been a significant change of emphasis away from the traditional approach of developing new water transfer schemes to one of Integrated Resource Planning in which water conservation is often regarded as a top priority. New supply schemes are not excluded from future planning, but they will now be developed only in cases where it can be shown that the existing water resources are being used efficiently. Several recent studies have shown that major proposed augmentation schemes can be postponed by many years if the growth in demand can be trimmed by only a few percent – a target that is certainly achievable in most systems. The savings associated with delaying a new water transfer scheme are so large that the measures needed to achieve the delay are not only environmentally attractive but also very cost effective.

New legislation introduced by the South African government provides real incentives for more efficient water use (or penalties for inefficient use) and will gradually result in stricter control of Non-Revenue Water throughout the country.

In order to support the government legislation and encourage efficient use of the available water resources in South Africa, the Water Research Commission (WRC) has initiated and supported numerous projects over the past 6 years. Although some very comprehensive and sophisticated software is already available both internationally and locally, it is often out of reach of many of the smaller municipalities who cannot afford to purchase such packages. The WRC has therefore concentrated on providing low cost software solutions to assist water suppliers in understanding and managing their Non-Revenue Water.

The new models are all based on the Burst and Background Estimate (BABE) methodology which was first developed for the UK Water Industry in the early 1990's (UK Water Industry, 1994). The BABE philosophy has since been accepted and adopted in many parts of the world as it provides a simple and pragmatic approach to understanding and managing the complex and often confusing problem of leakage from water distribution systems. The approach has been so successful that it is increasingly being recommended by many international water associations as the most systematic and pragmatic approach to Leakage Management.

The BABE approach was first introduced to South Africa in 1994 through a series of courses and seminars presented countrywide by the author and Mr A Lambert (founder of BABE) at the request of the Water Research Commission. The methodology and concepts have since been widely accepted by most water suppliers throughout the country and have been incorporated to a large degree in the Code of Practice for the management of potable water in distribution systems (SABS, 1999).

The BABE concepts are most effective when applied in conjunction with the following:

- Fixed Area Variable Area Discharges (FAVAD) principles (May, 1994);
- Unavoidable Annual Real Losses (UARL) principles and
- The Infrastructure Leakage Index (ILI) from Lambert et. al., 1999.

In the development of the BABE techniques, it was initially agreed that the following four principle issues concerning leakage management (see **Figure 1**) should be addressed:

- Logging and analysis of Minimum Night Flows;
- Economics of leakage and leakage control;
- Pressure Management;
- Benchmarking of Leakage and Auditing of Non-Revenue Water

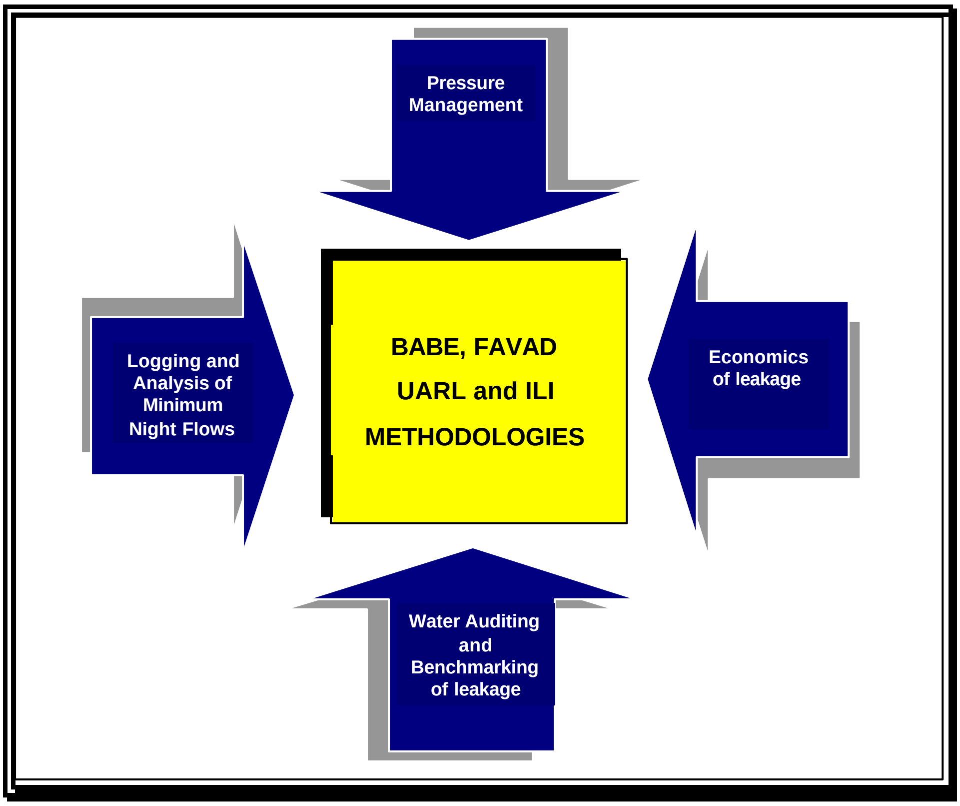

Figure 1: Four Main Elements of the BABE Methodology

In order to address the four key components of the BABE methodology, four models were developed over a period of approximately four years as shown in **Figure 2.**

Each model is a small self-contained program which addresses one specific issue. It was decided to adopt this simple and straightforward approach in order to avoid confusion and allow water suppliers to use one or all of the models as they consider appropriate.

All four models are available through the Water Research Commission and details of the models are provided in **Table 1** for reference purposes. The various manuals accompanying the software can be obtained directly from the WRC website on www.wrc.org.za.

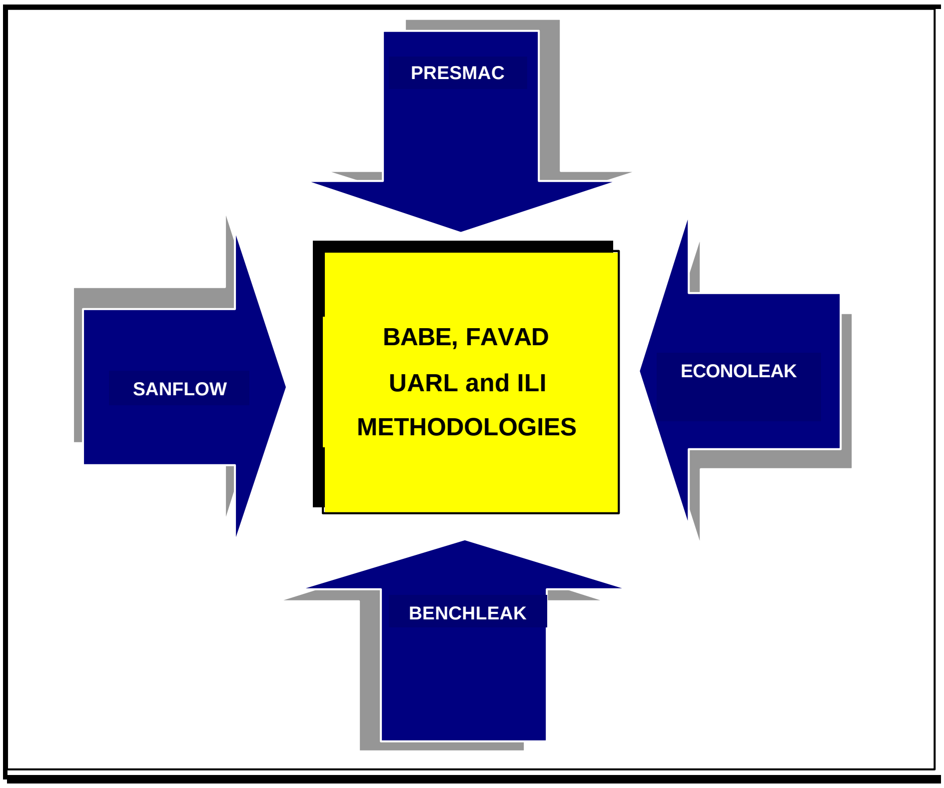

Figure 2: Models Developed through the WRC

Table 1: Details of the various WRC BABE-based models

Model	Details	ISBN Reference	WRC Reference	Released
SANFLOW	Model designed to provide an indication of the unexplained burst leakage in a zone from the analysis of the minimum night flow.	1 86845 490 8	TT 109/99	1999
PRESMAC	Model designed to estimate the potential for Pressure Management in a pressure zone based on logged flow and pressures over a representative 24-hour period.	1 86845 772 2	TT 152/01	2001
BENCHLEAK	Model designed to establish the levels of non-revenue water in a water utility or zone metered area based on the latest IWA recommendations regarding the Minimum Level of Leakage.	1 86845 773 7	TT 159/01	2001
ECONOLEAK	Model to evaluate the most appropriate frequency for undertaking Active Leakage Control	1 86845 832 6	TT 169/02	2002

It should be noted, that while the BABE methodology addresses certain key issues regarding the management of leakage and non-revenue water, it does not address the many social and environmental issues that are also very important. Water suppliers should therefore ensure that they consider both the social and environmental issues as well as the technical issues since the success of a project will depend on both sets of issues being addressed properly.

SANFLOW: BACKGROUND NIGHT FLOW ANALYSIS MODEL

Measurement of minimum night-flow into a zone-metered area (ZMA) is possibly one of the simplest and most valuable actions that a water supplier can take in order to identify whether or not they have a serious leakage problem.

A typical normal inflow to a ZMA is shown in **Figure 3** (UK Water Industry, 1994), from which the minimum night-flow can be identified as the lowest flow entering the zone at any time. In most zones the minimum night flow occurs sometime between midnight and 4 am. In order to evaluate the level of leakage in a particular zone from the inflow, as shown in **Figure 3**, the minimum night-flow is split into various components in accordance with the general BABE principles. **Figure 4** shows the different components making up the minimum night-flow and these are fully explained in the SANFLOW user guide (Mckenzie, 1999).

The analysis of background night flows is a simple exercise and the SANFLOW model provides a quick and effective aid to water suppliers in this regard. The program was designed specifically to assist water suppliers in identifying likely problem areas with respect to leakage and, conversely, also those areas that do not have a serious leakage problem.

The model is based directly on the BABE principles and is written in DELPHI for the Windows operating system.

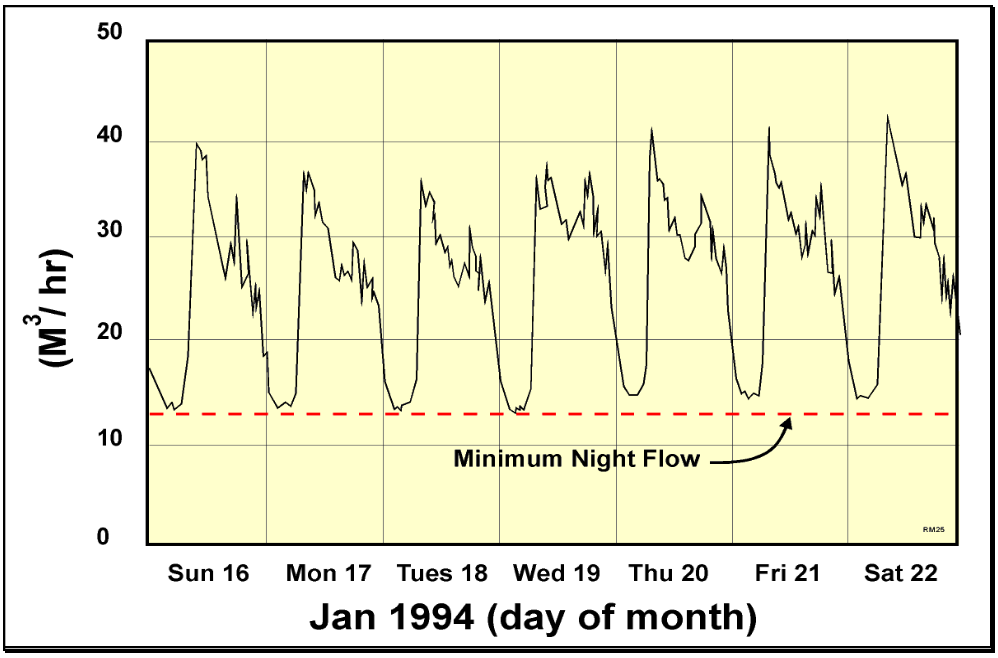

Figure 3: Example of inflow to a ZMA showing the minimum night flow

The SANFLOW Model includes several additional features which were not originally available on any of the overseas versions. In particular, it includes the ability to undertake sensitivity analyses based on basic risk management principles in order to provide a likely distribution for the number of bursts in a zone (or district). This feature enables the user to set an upper and lower limit on each parameter used in the model. The selection of single parameter values has often been criticised as too subjective, with the result that different users may obtain different results from the same initial data. By using the sensitivity analysis feature of the model, however, this potential problem can be addressed. It should be noted that the most recent versions of many BABE-based models now incorporate either sensitivity limits or error limits which help to provide the user with greater confidence in the results when using the models. It seems likely that all future models will be developed with this capability to address any concerns from users and water suppliers when using data that can be considered to be subjective in nature.

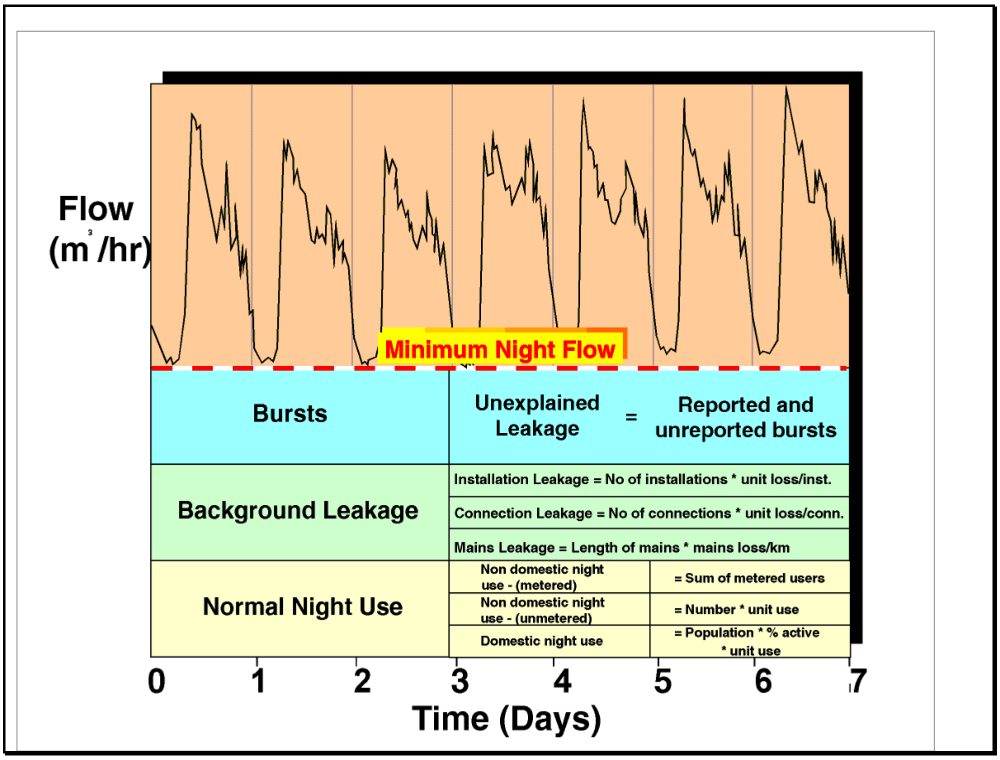

Figure 4: Components making up the minimum night-flow

ECONOLEAK: ECONOMICS OF LEAKAGE MODEL

The economics of leakage control is becoming a very important issue since most water supply utilities in South Africa are operating on limited budgets. The water suppliers are often unable to provide proper motivation to carry out expensive rehabilitation or leak detection programmes. The approach used in the ECONOLEAK Model is one of several approaches which can be considered. It appears that there is no general consensus at present on the "standard" methodology to be applied to economics of leakage. The approach adopted may not address all issues regarding the economics of leakage. It does, however, help water suppliers to understand the various issues that should be considered and taken into account when attempting to establish the economic level of leakage for a particular water supply system. In this regard, it has proved to be very useful and helps to develop a better understanding of the economic issues regarding among water suppliers throughout South Africa.

The ECONOLEAK Model enables a water supplier to identify when it is necessary to intervene through active leakage control. In other words, the program will assist water suppliers in identifying when they should send a leak-detection and repair crew into an area to find unreported bursts.

In order to use the model, the water supplier is required to gather the information indicated in **Table 2**. It should be noted, that if the information is not readily available from the water supplier's records, the default values provided in the User Guide can be used until more reliable information is obtained (Mckenzie, 2002).

The model uses the basic information described in **Table 2** to provide the water supplier with an indication of when they should intervene in a particular zone and also how much funding should be allocated to leakage detection and repair per annum.

Table 2: Basic information required to use the ECONOLEAK Model.

Description	Units	Default value
Number of service connections	Number	-
Length of transmission mains	km	-
Length of distribution mains	km	-
Average system pressure	m	-
Unavoidable connection losses at 50 m of pressure	Litres/connection/hr	1.25
Unavoidable mains losses at 50 m of pressure	Litres/km/hr	20
Leakage from service reservoirs	As % of volume per day	0.1
Leakage through mains burst	m^3/hr at 50m pressure	12.0
Leakage from connection pipe burst	m^3/hr at 50m pressure	1.6
Average running time of mains burst	Days	0.5
Average running time of connection pipe burst	Days	10
Average cost of repairing mains burst	Rand	3 000
Average cost of repairing connection pipe burst	Rand	2 000
Monthly water supplied to the zone or district	Kilo litres	-
Estimated monthly real losses	Kilo litres	-
Purchase price of water from bulk supplier	Rand/m^3	
Selling price of water	Rand/m^3	
Frequency of service connection bursts per 1000 connections at 50 m of pressure	Bursts /1000 conn/yr	2.5
Annual frequency of mains bursts per km of mains at 50 m of pressure	Number/km of mains/yr	0.15
Pressure leakage exponent for flow through mains and connection leaks	-	0.7
Power exponent for calculating number of mains leaks for different pressures (cubic relationship is normally adopted)	-	3
Cost of basic sounding per km of mains	Rand/km mains	700
Cost of leak noise correlator per km of mains	Rand/km mains	1400
% of mains requiring leak noise correlator to detect leaks	%	20

PRESMAC: PRESSURE MANAGEMENT MODEL

In the continual battle to reduce leakage from potable water distribution systems, the influence of pressure is often overlooked. Planners design potable water distribution systems to provide a certain minimum level of service (usually in the order of 25 m of pressure) throughout the day at the most critical point in the system. The critical point is generally either the highest point in the system or the point most distant from the source although it may be a combination of the two depending upon local topography.

The pressure at the critical point will depend upon the pressure at the inlet point minus the friction losses occurring between the inlet and the critical point. The friction losses will be highest during periods of peak demand; typically during the breakfast period and again during the early evening period when most consumers are using water for washing, cooking, gardening etc. After the evening peak, the pressure throughout the system will gradually increase due to reduced friction losses and in certain cases also the filling up of local storage reservoirs.

Since the systems are designed to supply the minimum level of pressure at the critical point during the peak demand periods, it is clear that the pressure will increase during the periods of low demand. The pressures in potable water distribution systems are therefore significantly higher than required much of the time, particularly during the night when most of the consumers are asleep. Since losses and leakage from a system are highly dependant upon pressure, it is also clear that leakage rates will be highest during the periods when few, if any, consumers wish to use water.

Although there is no simple solution to the complex problem of excess pressure in a water distribution system, considerable research and development has taken place over the past decade. This has resulted in the creation of various techniques and equipment that can help to control pressure and thus reduce leakage.

Following the development of the Burst and Background Estimate (BABE) procedures in the early 1990's, various computer models were developed in the UK to assist water suppliers in assessing the reduction in leakage that could be achieved through various forms of Pressure Management. These software solutions were developed in parallel with several new pressure controllers that are able to modulate the pressure at a pressure-reducing valve (PRV) according to time (time-modulation) or demand (flow-modulation). By using such controllers it became possible to reduce the pressure during periods of low demand and thus reduce leakage without adversely affecting the level of service to the consumers. For the first time, both software and hardware solutions could be used together to tackle pressure in potable water distribution systems.

Although the pressure management software developed in the UK is available commercially to companies and consultants throughout the world, it is not designed specifically for South African conditions, nor is it supported by any organisation in South Africa. In addition, the UK software is relatively expensive in terms of the local currency and although the potential savings can be very significant, many of the smaller municipalities are unable to budget for such software without demonstrating the savings in advance – clearly a cart and horse situation.

To overcome these problems the WRC commissioned the development of a pressure management model (Mckenzie, 2001). PRESMAC is based on the same BABE principles as the existing UK models (see Lambert, 1997 and May, 1994) and was modified to suit South African conditions where necessary. The new South African model is a full Windows package written in DELPHI as opposed to the UK models that were originally based on EXCEL. The model can be used to assess the likely savings (in monetary terms) of various pressure reduction options (fixed outlet and time–modulated PRV's) in a selected zone metered area. The analysis is undertaken in a relatively simple and pragmatic manner allowing the user to gauge the potential for pressure management very quickly and effectively without requiring a full detailed pipe network analysis. Although the methodology is based on a number of simplifications and assumptions, in practice the predicted savings are generally within 10% to 20% of those actually achieved (erring on the conservative side).

Although the technology to implement Advanced Pressure Control is readily available and the concepts are well understood, limited legitimate results are currently available with the result that few South African water services providers have sufficient confidence to motivate and support the necessary capital investment.

To address the confidence issue, the Water Research Commission commissioned a study to undertake a series of Pilot Studies and to document the results. The pilot studies have since been documented (Wegelin et al., 2002) to provide information on Advanced Pressure Control so that water suppliers considering Pressure Management can evaluate the potential savings and associated problems.

When selecting the pilot areas, care was taken to select a range of different conditions so that the results were not simply weighted to the one or two extreme cases where massive savings can be achieved. Instead, the areas selected represent a fair cross-section of the type of areas that will be encountered in most water supply systems. Some of the areas are ideally suited to Advanced Pressure Control while others are not. The following eight pilot projects were eventually selected to illustrate the effects of pressure management in South Africa:

- City of Tshwane (Pretoria) – Valhalla high level zone;
- City of Tshwane (Pretoria) – Meintjieskop;
- Rand Water ODI – Slovoville (Mabopane);
- City of Johannesburg – Slovoville;
- City of Johannesburg – Tshepisong;
- City of Tygerberg – Zone C (Khayelitsha);
- City of Oostenberg – Wallacedene;
- City of East London – Mdantsane PRV6.

The key findings from the Pilot Studies can be summarised as follows:

- The average zone pressure for the eight selected zones was 58m, with minimum and maximum values of 13m and 102m respectively. This is higher than the international norm of approximately 45m.
- Pressure reducing valves require regular maintenance and checking if they are to serve effectively in any water distribution system. Three of the existing seven PRV installations were not operational when the project commenced. This resulted in large water losses, excessive zone pressures and high frequency of pipe bursts.
- Proper sizing of the meter and pressure-reducing valve should always be undertaken before any form of pressure management is implemented to ensure effective operation.
- The average minimum night flow to average daily demand relationship for the eight selected zones was found to be 66%, indicating very high levels of leakage in the pilot zones. A typical value of between 10% and 30% is expected for a well-managed system in the South African environment. Internationally the norm for a well-managed zone is between 10% and 20%, although as previously mentioned, percentages can be misleading and the overall water use for the system must therefore be taken into consideration.

Some of the results from the Pilot Projects are summarised in **Tables 3 and 4.**

Table 3: Summary of inlet pressure and leakage reduction

Zone name	Inlet pressure (m) [(1)]			Minimum night flow (m^3/h)			N1 value
	Before	After	Reduction	Before	After	Reduction	
Valhalla	45	36	9	14	11	3	2.5
Meintjieskop	80	70	10	63	53	10	1.0
Slovoville (ODI)	83	20	63	42	9	33	2.0
Slovoville (Jhb)	100	34	66	34	11	23	1.3
Tshepisong	92	63	29	82	46	36	1.4
Wallacedene	47	20	27	83	52	31	1.0
Khayelitsha	44	21	23	321	180	141	0.8
Mdantsane	52	40	12	14	13	1	0.75
Average/Total	**68**	**38**	**30**	**653**	**375**	**278**	**1.3**

Notes: (1) Inlet pressure at time of minimum night flow

Table.4 : Summary of reduction in zone inflow (m^3/annum)

Zone name	Inflow without pressure management	Reduced distribution losses	Reduced consumption	Total reduction	Inflow with pressure management
Valhalla	592 395	6 903	368	7 271	585 124
Meintjieskop	1 307 795	24 317	827	25 145	1 282 650
Slovoville (ODI)	439 460	192 051	4 455	196 506	242 954
Slovoville (Jhb)	361 715	127 690	4 257	131 947	229 768
Tshepisong	1 411 090	212 930	11 892	224 822	1 186 268
Wallacedene	1 133 453	58 832	2 101	60 934	1 072 519
Khayelitsha	3 295 220	202 864	-6 135	196 729	3 098 491
Mdantsane	191 625	4 698	81	4 780	186 845
Average	**8 732 753**	**830 285**	**17 846**	**848 134**	**7 884 619**

It should be noted that the results are based on actual logged flows and pressures and are therefore based on factual data. The reductions in leakage vary significantly from area to area and clearly highlight the message that pressure management can be very effective under certain conditions and relatively ineffective in other areas. It should also be noted that the Pilot Studies could not assess the influence of the pressure management activities on the burst frequency in the areas. In some cases the savings achieved from the reduction in the number of bursts can exceed the savings in current leakage. Unfortunately this could not be investigated due to the limited scope and budget for the study.

BENCHLEAK: CALCULATION AND BENCHMARKING OF REAL LOSSES

One specific problem which surfaces regularly concerns the manner in which water suppliers calculate and express their levels of leakage. Although it is still common practice to express leakage as a percentage of the water supplied into a particular system or zone, this simple performance indicator can be very misleading.

To demonstrate the problems associated with percentage values, a very simple example can be used. In this example a distribution system experiences leakage of 10 000 m^3/day. This system is analysed for a range of different consumers as shown in **Table 5** (Lambert et al., 1998).

From **Table 5** it can be clearly seen that although the real losses are identical in all cases, the percentage losses vary considerably.

Table 5: Example to demonstrate problems with percentage losses*

Per capita consumption (litres/head/day)	Daily consumption (m^3/day)	Real losses (m^3/day)	Distribution input (m^3/day)	Percentage losses
25 (Standpipe)	6 250	10 000	16 250	62
50 (Jordan)	12 500	10 000	22 500	44
100 (Czech Rep)	25 000	10 000	35 000	27
150 (UK, France)	37 500	10 000	47 500	21
300 (Japan)	75 000	10 000	85 000	12
400 (USA)	100 000	10 000	110 000	9

A project was initiated by the WRC to look into the problem of comparing leakage levels in the various supply systems throughout South Africa. A standardised approach to leakage benchmarking was developed through the project and incorporated in the BENCHLEAK Model.

The approach adopted in the benchmarking project was based upon the most recent work by Allan Lambert (1999) and was developed by the authors in close co-operation with and support from Mr Lambert. The approach developed through the WRC has been very successful and has already been adapted for use in many other parts of the world. Numerous organisations have now developed their own versions of BENCHLEAK which they are using to provide first order estimates of the non-revenue water and real losses in their water supply systems.

Full details of the Benchmarking procedure are provided in various papers presented at international conferences. In summary, however, the basic approach includes the use of the new Performance Indicator called the Infrastructure Leakage Index (Lambert, et.al., 1999) (ILI) which is a simple ratio of the current annual real losses (CARL) divided by the unavoidable annual real losses (UARL).

ILI = CARL / UARL

The unavoidable annual real losses (UARL) can be easily assessed for any given system as long as the number of connections, length of mains and average operating pressure are known. Details of all the calculations are provided in the BENCHLEAK User Guide which is available from the WRC together with the model.

In South Africa it has been very difficult to compare results from one system with those from another system due to the fact that the Water Suppliers tended to use their own definitions of Real Losses and Unaccounted-for Water etc. The BENCHLEAK Model therefore uses the IWA standardised 'best practice' terminology to describe the basic elements making up the water balance for a water supply system. By adopting this standard approach to the water balance, it is now possible to compare results from different systems in a meaningful manner and also compare the results from South African water suppliers with those from other water suppliers worldwide. The terminology is depicted in **Figure 5**.

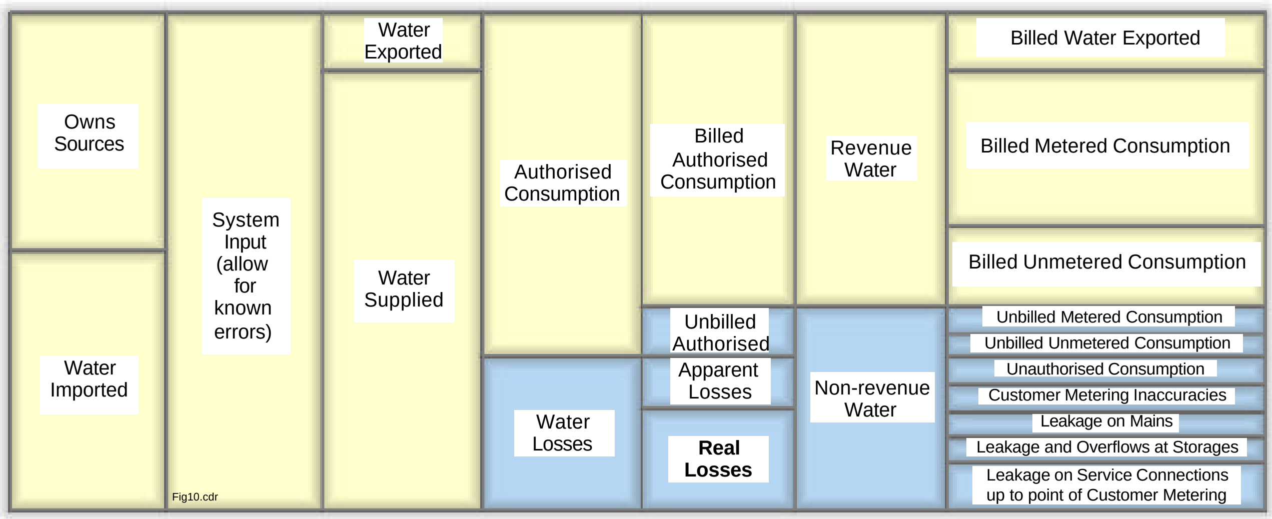

Figure 5: Main components of the water supply water balance

Full descriptions of all elements shown in **Figure 5** are provided in the BENCHLEAK User Guide (Mckenzie and Lambert, 2001) which is available together with the software from the WRC website.

Following the development of the BENCHLEAK Model, it was used to assess the annual values of non-revenue water and real losses in approximately 50 water supply systems throughout South Africa. The results were screened for errors and eventually the figures from 35 systems were documented in the WRC report.

It is interesting to note that the ILI values for the South African systems range from 1.0 to approximately 20 with an average value in the order of 7. This can be compared to ILI values calculated by the IWA LeakageTask Force for 27 supply systems in 19 countries which range from 1.0 to 10 with an average value of 4.2.

For South African conditions it would be unusual to achieve an ILI value of below 2.0. Values in the order of 5.0 are relatively common and represent systems in a reasonable condition.

While there is still some debate concerning the use of the ILI as a key performance indicator by certain water conservation specialists, the fact remains that it provides a useful indication of the leakage problem in an area in a manner which can be easily understood, particularly in developing countries. While it may not be completely foolproof, it has been used with considerable success in identifying key problem areas in large reticulation systems and, as far as the Clients are concerned that is exactly what they wanted to achieve. At the end of the day, the results speak for themselves and until something better can be placed on the table, the ILI will be used to assist water suppliers to manage their leakage problems.

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