# *ECONOLEAK*

## *ECONOMIC MODEL FOR LEAKAGE MANAGEMENT FOR WATER SUPPLIERS IN SOUTH AFRICA*

## *User Guide*

developed through

**SOUTH AFRICAN WATER RESEARCH COMMISSION**

**By**

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The publication of this report emanates from a project entitled: ***Development of an Economic Model for Evaluating Leakage in South Africa***
***(WRC Project No. 1145)***



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## PREFACE

This document incorporates the project report and the user guide to the Economic Model for Leakage Management (ECONOLEAK) which has been developed through the Water Research Commission (WRC)-funded project titled '***Development of an Economic Model for Evaluating Leakage in South Africa"***

The ECONOLEAK model represents one of several models and supporting user guides that have been developed through the WRC in order to assist water suppliers to manage and reduce their levels of unaccounted-for water. The models are supplied free-of-charge through the WRC for use within South Africa and further details can be obtained from the WRC web site on: ***http://www.wrc.org.za.*** The following user guides and models are available for downloading from the WRC website:

| Model/Software | Supporting User Guide/Document | WRC Report Number |
|---|---|---|
| **SANFLOW** | Development of a standardised approach to evaluate bursts and background losses in water distribution systems in South Africa | TT 109/99 |
| **BENCHLEAK** | Benchmarking of leakage for water suppliers in South Africa | TT 159/01 |
| **PRESMAC** | Development of a pragmatic approach to evaluate the potential savings from pressure management in potable water distribution systems in South Africa | TT 152/01 |
| **ECONOLEAK** | Economic model for leakage management for water suppliers in South Africa | TT 169/02 |

## COPYRIGHT



## TECHNICAL SUPPORT

The WRC does not provide technical support on the ECONOLEAK model and any questions or problems associated with the program should be directed to the model developers at ***ronniem@wrp.co.za*** or ***wrp@wrp.co.za***

# *Economic Model for Leakage Management (ECONOLEAK)*

## *Executive Summary*


### *The Problem*

*In many instances water distribution managers and engineers are aware that they can achieve significant savings in their water purchase account through reduced water losses due to leakage. Pay-back periods of less than a month are often quoted for certain actions, although they are seldom accompanied by valid motivation. As a result, it is often very difficult to convince the financial managers controlling the budgets to allocate the required funding for specific leakage-reduction activities.*

*Water loss and leakage reduction in a water distribution system can be achieved by various measures including retro-fitting, metering, pressure management, active leakage control, mains replacement, etc. The major problem facing the water distribution managers is to determine which measures are the most beneficial and how much can be saved in real terms from each measure. Before embarking upon one or other of the various approaches, it is important to analyse the leakage properly and to identify and quantify the major problem areas. After the problems have been identified and quantified, the most appropriate leakage reduction measures should then be determined and accompanied by sound financial motivation.*

#### *Purpose of the model*

The ECONOLEAK model is not designed to address the economic issues associated with all of the various types of leakage-reduction activities mentioned above. Instead, it is aimed specifically at determining when a water supplier should invest in active leakage control for a specific zone metered area. The model will compliment the existing WRC SANFLOW, PRESMAC and BENCHLEAK models which together provide water suppliers with four key tools to assist them with their leakage management. It must be noted that the overall concepts of the ECONOLEAK Model are based on the Burst and Background Estimate procedures which were first developed for the UK water industry in the mid 1990's. The model will assist water suppliers to gain a better understanding of the main factors influencing the economics of leakage control and enable them to identify the most cost-effective methods of reducing their system leakages.

The ECONOLEAK Model requires considerable factual system data in order to assess the economics of leakage in a water supply system. Unfortunately very few water suppliers in South Africa have access to the necessary data. While this is regarded as a problem in the short term, it does create an awareness of what information is required which, in turn, may encourage water suppliers to start capturing and processing the necessary data. In this regard, the model is very useful in creating awareness of some key information that all water suppliers should be capturing and monitoring on a continuous basis.

#### *Background to BABE*

*In 1991, a National Leakage Initiative was established in the UK 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. As a result of new water legislation, it became necessary for all water suppliers to demonstrate to the regulators that they fully understood their position on leakage. This did not imply that all water suppliers had to demonstrate the lowest achievable leakage levels, but simply that they were applying correct and appropriate economic and resource principles. To this end, it was agreed that all water suppliers would adopt a straightforward and pragmatic approach to leakage levels. This was 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 group was instructed to develop a systematic and pragmatic approach to leakage management that could be applied equally well to all of the UK water supply utilities. The result of this initiative was a set of 9 reports published by the UK Water Industry (WRc, 1994) on the subject of managing leakage. The intention of the reports was not to be prescriptive, but to provide a "tool kit" to the water industry to enable the water supply managers to evaluate leakage levels and to manage the system.*

*Leakage Economics was identified as one of the key issues with the result that one full report was dedicated to the subject. Several of the UK water companies have since developed commercial software to address this problem and ECONOLEAK represents a similar model developed specifically for use in South Africa.*

*The WRC initiated several studies between 1996 and 1999 to address certain of the issues concerning leakage management, including the development of a simple model to analyse minimum night flows, a water balance model and a model to assess the impacts of pressure management. In addition, another study was initiated to develop a simple economic model for leakage management. The new ECONOLEAK model will form one of a suite of self-contained programs which are all based on the BABE principles. The models are available free-of-charge through the WRC and will enable water suppliers to gain access to current international technology which would otherwise have been prohibitively expensive.*

***Data Requirements***

*To use the ECONOLEAK model the user must collect certain basic information for the water supply system in question. Much of the information used in ECONOLEAK is basically the same information used in a normal minimum nightflow analysis or pressure analysis. The following information is required:*

- *Basic System Data (length of mains, number of connections, pressure etc);*
- *Water Loss Data (real and apparent losses);*
- *Duration of reported bursts;*
- *Number and leakage rates for Reported and Unreported bursts;*
- *Marginal cost of water;*
- *Costs for leak detection and repair.*

***Analysis Procedure***

*The ECONOLEAK Model is designed to assess the leakage from a water distribution system based on the supplier undertaking Active Leakage Control every 2 years , every year and every six months. The water losses from the three options are then compared to the costs associated with each option and the most appropriate level of Active Leakage control is identified. The model has been designed in a very simple and straightforward manner to help water suppliers understand what is generally a very complex issue. By developing the model in the form of an EXCEL spreadsheet, it is possible to simplify the calculations and, in this manner, the calculation process can be understood easily.*

***Using ECONOLEAK***

*ECONOLEAK can be run on any modern personal computer which has access to the EXCEL program. There are no special requirements and the model is effectively a spreadsheet which has been protected to prevent users from overwriting certain cells/formulae. The model has been designed in such a manner that all cells requiring user input are colour coded in yellow with red text. Only the cells requiring user input have been unprotected and the user must simply overwrite the example data provided in the cells. All other cells are protected and a full set of example data is also provided to assist users to complete the spreadsheet properly.*

## *ACKNOWLEDGEMENTS*

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| ***Name*** | ***Organisation*** |
|---|---|
| *Mr JN Bhagwan* | *Water Research Commission* |
| *Dr GR Backeberg* | *Water Research Commission* |
| *Mr I Govender* | *Durban Metro Water* |
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| *Mr D Moor* | *SA Bureau of Standards* |
| *Mr A Muller* | *City Council of Pretoria* |
| *Mr E Johnson* | *Stewart Scott Inc.* |

# ECONOLEAK

## Economic Model for Leakage Management

### Table of Contents

# 1. INTRODUCTION

## 1.1. BACKGROUND

The ECONOLEAK Model is based on the standard BABE procedures which were developed initially in the UK for use in the UK Water Industry. The BABE techniques were developed to provide a standardised and methodical approach to the understanding and management of leakage from potable water distribution systems. This was one of the first and most comprehensive initiatives undertaken anywhere in the world to address the complex problem of leakage from water reticulation networks and involved input from the UK's top leakage management specialists who were working for various water companies.

Since the BABE procedures were developed in the mid 1990's, they have been improved, customised and used to great effect in many parts of the world including many third world areas. Full details of the BABE methodology can be found in the SANFLOW Model user Guide (WRC, 1999) while some of the key concepts are also summarised in **Section 2**.

In addition to the basic BABE methodology, the ECONOLEAK Model makes use of the basic principles of the Fixed Area and Variable Area Discharges (FAVAD) as developed by May (1994) in the mid 1990's. Details of the FAVAD principles are provided in **Appendix B** together with some details on the calculation of the Minimum Level of Leakage (MLL) as developed by Lambert et. al.(1999) as part of the recent International Water Association's initiatives on leakage benchmarking. Full details of the leakage benchmarking procedures are provided in the BENCHLEAK User Guide (WRC, 2001b) or the Australian BENCHLOSS Manual (WSAA, 2000)

## 1.2. PURPOSE OF THE ECONOLEAK MODEL

The ECONOLEAK Model is developed through the WRC to assist water suppliers throughout South Africa in understanding and managing their leakage. The software is supplied to water suppliers in South Africa free-of-charge as a service to the water industry and complements the three previous BABE models developed by the WRC (SANFLOW, PRESMAC and BENCHLEAK). The four packages together form a very useful suite of software which has been designed to be as simple and straightforward as possible. The four models are completely independent of each other although they are all based on the same principles and often involve much of the same input data. Further details of the models are provided in **Table 1.1.**

**Table 1.1: Details of the four 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 economic level of leakage and the most appropriate frequency for undertaking Active Leakage Control | 1 86845 | TT 169/02 | 2001 |

# 2. INTRODUCTION TO BABE PROCEDURES

## 2.1. GENERAL

The Burst and Background Estimate (BABE) concepts consist of effectively a very straightforward and pragmatic approach to the complex problem of quantifying and controlling leakage in water reticulation networks. While the key concepts are in themselves relatively simple, they can be combined in various ways to develop sophisticated and powerful tools that can greatly assist water utilities in understanding and managing their leakage.

## 2.2. COMPONENTS OF THE BABE METHODOLOGY

In order to appreciate and understand the importance of the ECONOLEAK Model, it is important to understand the main components (generally regarded as the “pillars”) of the BABE methodology. In the development of the BABE techniques, it was eventually agreed that four principle issues concerning leakage management should be addressed and models were developed for each as shown in **Fig. 2.1**.

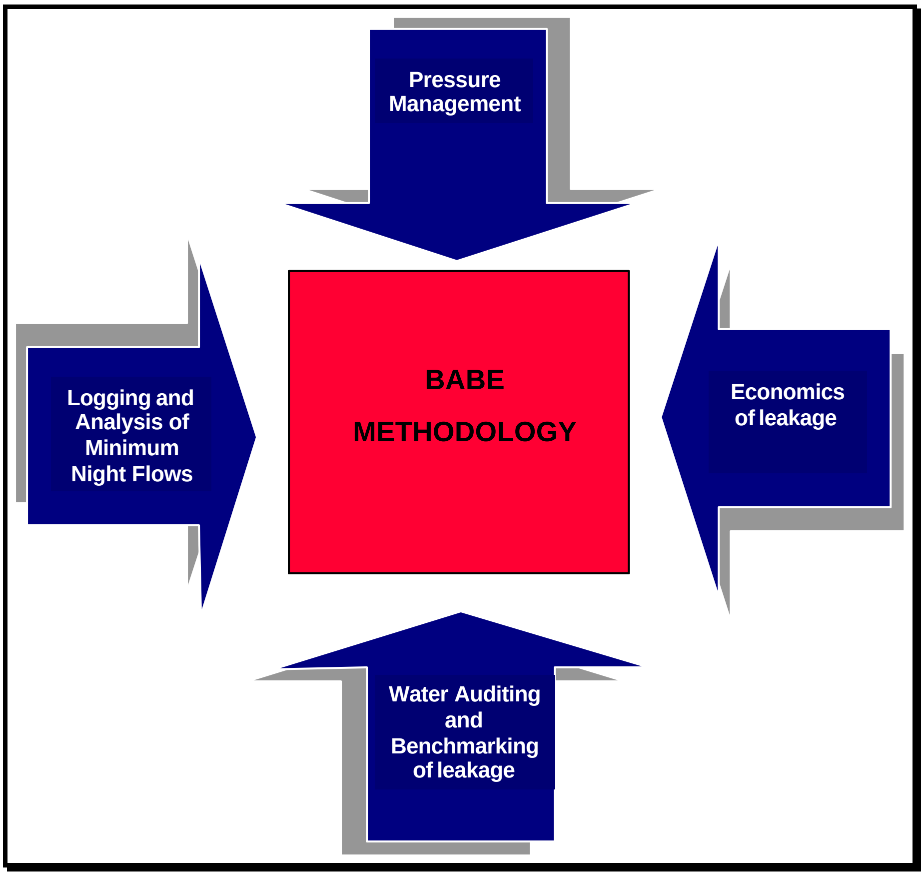


**Figure 2.1: Main Components of BABE Procedures.**

As can be seen in **Fig. 2.1** the four key elements of BABE are :

- Logging and analysis of minimum night flows;
- Water auditing and benchmarking of leakage;
- Economics of leakage;
- Pressure management.

Models were developed to address each issue and the four models developed through the WRC are shown in **Fig. 2.2**.

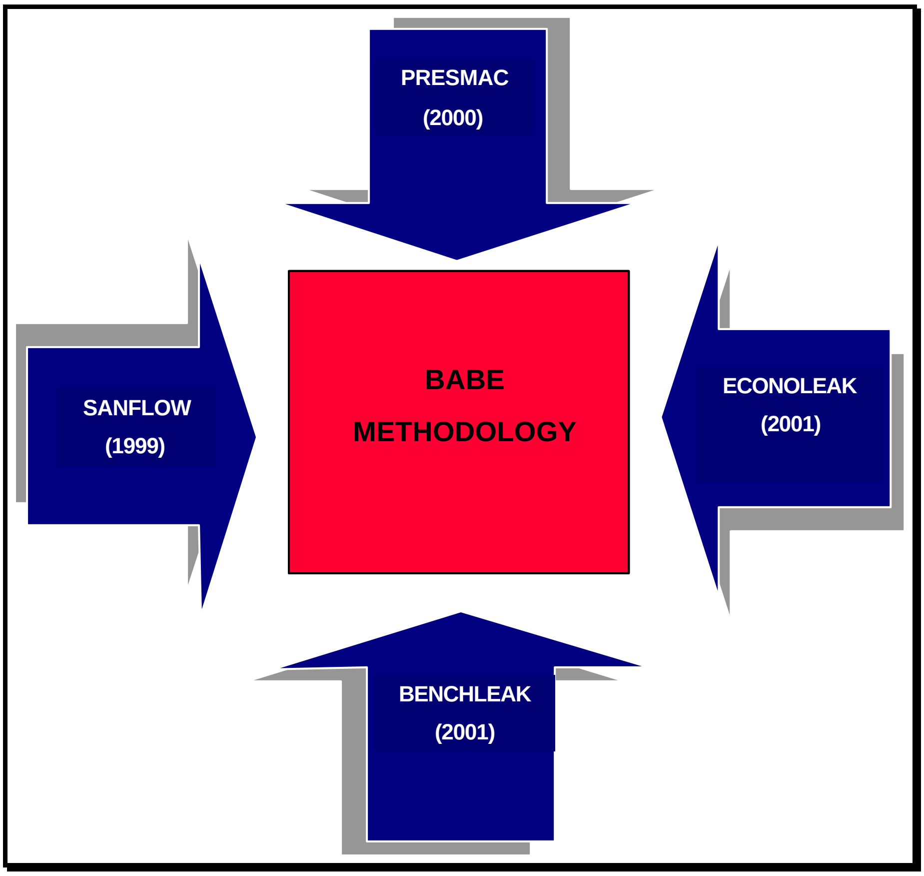


**Figure 2.2 : Models Developed through the WRC**

All four models are available through the WRC and this manual provides details of the ECONOLEAK model which is used to assess the Economic Level of Leakage in a particular system. The ECONOLEAK Model requires certain data that are often very difficult to obtain from water suppliers such as the statistics referring to mains and connection bursts and the associated repair times. Some water suppliers may therefore experience some problems using the model before implementing a proper management system. To assist the water suppliers overcome the possible data problems, a full set of sample data has been provided in the model which can be used by a water supplier until such time that more specific data become available for the system in question.

## 2.3. WHAT ARE BURST AND BACKGROUND LEAKS ?

In the course of the UK research into leakage management the leaks found in any water supply system were split into two types – those large enough to warrant serious attention with regard to location and repair and those that were too small to warrant such attention. The larger more serious leaks that warrant direct attention are referred to as bursts while those that are too small to deserve such attention are referred to as background leaks. The threshold between bursts and background leaks is not fixed and can vary from country to country. In the UK, a threshold limit of 0.5 $m^3/h$ is used while in South Africa a lower limit of 0.25 $m^3/h$ is considered to be more appropriate. In other words :

| | | | | |
|---|---|---|---|---|
| **Leaks** | **>** | **0.25 $m^3/h$** | **=** | **Bursts** |

and

| | | | | |
|---|---|---|---|---|
| **Leaks** | **<** | **0.25 $m^3/h$** | **=** | **Background Leaks** |

## 2.4. MAINS AND CONNECTION LEAKAGE

When using the ECONOLEAK Model the leakage in a system is broken down into several types of leakage, each of which has its own characteristics etc. The leakage is addressed under the following headings:

- Leakage from Transmission Mains
- Leakage from Reticulation Mains
- Leakage from Connections to property meter
- Service Pipe Leakage from property meter

### Transmission Mains Leakage

Transmission mains tend to be large diameter pipes operating at high pressures with relatively few off-takes. As a result, such pipes tend to experience few leaks and when a leak does occur it is so obvious and serious that it is repaired within a day if not within several hours. The frequency of leaks from transmission mains would be expected to be in the order of 0.030 per km mains per year with an average leakage rate of 30 $m^3/h$. It is unlikely that there will be any unreported bursts on Transmission Mains due to the high pressures and large diameter pipes involved. However, if such leaks were to occur, it is likely that the rate of leakage would be in the order of half that of the reported leaks.

### Reticulation Mains Leakage

Reticulation mains tend to be medium-sized pipes operating at high to medium pressures with regular branches and off-takes. Such pipes can experience regular leaks and when a leak does occur it is generally quite obvious and relatively serious, with the result that it is repaired within a day. The frequency of leaks from Reticulation Mains would be expected to be in the order of 0.150 per km mains per year with an average leakage rate of 12 $m^3/h$. While it is uncommon for reticulation mains leaks to remain undetected for any length of time, some unreported mains leaks will occur. The frequency of such unreported leaks would be expected to be in the order of 0.008 per km of mains per year with an average leakage rate of 6 $m^3/h$ – i.e. half the rate of the reported reticulation mains bursts.

### Connection Leakage

Leakage from connection pipes is normally the main source of leakage in any water distribution system and tends to exceed all other leakage combined. The frequency of leaks from connections would be expected to be in the order of 2.5 per 1 000 connections or 0.0025 per connection with an average leakage rate of 1.6 $m^3/h$. Connection leaks are often unreported and such leaks can represent a sizeable portion of leakage in any system. The frequency of such unreported connection bursts would be expected to be in the order of 0.825 per 1 000 connections per year with an average leakage rate of 1.6 $m^3/h$ – i.e. the same rate as for the reported connection bursts.

### Service Pipe Leakage

Service pipe leaks are relatively common and tend to run undetected for longer periods than other forms of leakage. In cases where service pipe leakage is considered to be important, the same figures can be used as suggested for the connection leakage. In cases where such leakage occurs after the customer meter and all water is being paid for by the consumer, the service pipe leakage can be disregarded from the calculation since it has been included as “consumption” in the water balance calculation. In most cases in South Africa, the service pipe leakage should be omitted from the overall financial calculation. The option of considering the service pipe leakage has, however, been incorporated into the ECONOLEAK Model for completeness.

### Summary

The leakage rates and frequencies for the different forms of leakage are summarised in **Table 2.2** for reference purposes. It should be noted that the figures provided are based on considerable international research. They should be used as first estimates which can be altered if more realistic figures can be obtained from the relevant water supplier.

Unfortunately in South Africa, it appears that few water suppliers record and analyse their burst pipes to the level of detail required to provide the figures given in the table.

**Table 2.2 : Basic Information on Reported and Unreported Bursts.**

| Details | Reported Bursts | | Unreported Bursts | |
|---|---|---|---|---|
| | Frequency | Leakage Rate ($m^3/h$) | Frequency | Leakage Rate ($m^3/h$) |
| **Transmission Mains** | 0.030 /km/yr | 30.0 | 0.00 /km/yr | 12.0 |
| **Distribution Mains** | 0.150 /km/yr | 12.0 | 0.008 /km/yr | 6.0 |
| **Connections** | 2.5 /1 000 conn/yr | 1.6 | 0.825 /1 000 conn/yr | 1.6 |
| **Service pipes** | 2.5 /1 000 conn/yr | 1.6 | 0.825 /1 000 conn/yr | 1.6 |

The other important aspect of reported and unreported leakage concerns the actual running time. In the case of unreported leaks the running time can be considered to be half of the interval between active leakage control interventions. For example, if an Active Leakage Control intervention is undertaken each year then the average running time for all unreported leaks is estimated to be 6 months. In the case of reported bursts, the running time will depend upon the level of efficiency in the awareness, location and repair process. The average running times of the different leaks are required for use in the ECONOLEAK Model and, in cases where reliable information is not available, the values recommended in **Table 2.3** can be used as a first estimate.

**Table 2.3 : Information on Duration of Reported Bursts.**

| Details | Duration of Reported Bursts (days) | | |
|---|---|---|---|
| | Awareness and Location | Repair | Total |
| **Transmission Mains** | 0.5 | 0.5 | 1.0 |
| **Distribution Mains** | 1.0 | 0.5 | 1.5 |
| **Connections** | 5.0 | 6.0 | 11.0 |
| **Service pipes** | 5.0 | 6.0 | 11.0 |

It should be noted that the figures given in Table 2.3 are average values for an average water utility. They should be replaced with more reliable estimates if such information is available. They can also be used in the model to test the sensitivity of the results to various possible scenarios where the water supplier wishes to improve some aspect of its service. For example, if the water supplier wishes to improve its repair time for reported connection pipe bursts on all connections from 6 days to 3 days. By altering the input data to the ECONOLEAK model, the user can determine if this would be worthwhile.

## 2.5. ACTIVE AND PASSIVE LEAKAGE CONTROL

Active and passive leakage control are the two terms used to describe proactive and reactive leakage control. Active Leakage Control is the proactive approach of sending leak detection and repair teams into areas to search for and repair **unreported bursts**. The procedure for active leakage control normally involves a series of steps which include, but is not limited to, the following:

- Administration and set up costs
- Manpower inspection costs
- Supervision costs
- Mains repair costs
- Connection repair costs
- Various other small costs

Passive leakage control, as the name implies, involves the passive approach of waiting for leaks to be reported after which the leak repair teams are dispatched to locate and repair **reported bursts**. This approach is considerably cheaper to operate and manage compared to the approach of Active Leakage Control. It can, however, also result in many unreported bursts running for many months, if not years, before they grow to such an extent that they are finally reported. Reports of relatively large leaks running undetected for many years are common in most water utilities.

While Passive Leakage Control is clearly not ideal from the viewpoint of reducing leakage, the key issue is to determine whether it is more cost effective to use teams of plumbers to detect and repair leaks or simply to react to customer complaints when the leaks become so large that they are reported. This is effectively the question answered by the ECONOLEAK Model which attempts to provide an indication of how often the leak detection and repair teams should visit a particular water supply system. In some instances, it is cost effective to investigate a system every 6 months, while in other instances it may not be cost effective to carry out such investigations more frequently than every two years. The ECONOLEAK Model only considers Active Leakage Control intervals at every 6, 12 and 24 months which should be sufficient for most systems in South Africa. If it is found that the model suggests implementing Active Leakage control at some interval outside the 6 to 24 month range, then there is likely to be some other factor dominating the calculation such as the cost of water which may be outside the normal range.

## 2.6. DURATION OF REPORTED AND UNREPORTED BURSTS

A key element in the ECONOLEAK Model concerns the assumptions regarding the length of time over which a leak will run. Obviously, reported bursts are identified and repaired much quicker than the unreported bursts, but in both instances there is a clearly defined period over which the leak will run. Unfortunately, few water service institutions in South Africa collect and process the data that are necessary to estimate the average running time of the various leaks. For this reason, the default values suggested in the UK have been used and should provide reasonable leakage estimates until more reliable South African information becomes available. In summary, the running time for any particular leak can be considered as the sum of three components namely:

- Awareness
- Location
- Repair

The awareness time for a leak will depend upon the size of the leak, its visibility to the public and its impact on water users in the system. A serious leak that is highly visible and causes low water pressures to certain consumers will be brought to the attention of the water supplier within hours. A smaller leak, however, that causes no real problems and perhaps runs directly into a stormwater drain may run undetected for several days, months or even years. If no form of Active Leakage Control is practised by the water supplier, such leaks can run indefinitely or until they become sufficiently large to draw some attention. The awareness time for a leak can vary considerably from system to system and will also depend upon how diligent the consumers are with regard to reporting leaks.

It is important to understand the issue of awareness, location and repair of leaks when using the ECONOLEAK Model. It is generally assumed that large leaks will result in greater wastage than small leaks and for this reason the repair of small leaks is often given a low priority. In many cases, however, this is not the case and the overall leakage from a small leak can exceed the water lost from a large leak. If one considers a typical mains leak which will normally run at approximately 3 $m^3/h$ or 72 $m^3$/day as shown in **Fig. 2.3**. This type of leak is normally highly visible and often causes low pressure problems to some consumers. As a result of the inconvenience caused, the leak is reported within a few hours and repaired as a priority in less than a day. This type of leak will typically run for approximately 1.1 days and result in leakage of 80 $m^3$.


**Figure 2.3 : Typical duration and losses from a mains burst**

If, however, a relatively small leak develops on a connection pipe, which is by far the most common type of leak in all water reticulation systems, it will run at approximately 25 $m^3$/day which is considerably less than the mains leak. In view of the fact that the leak may not cause such widespread disruption as the mains leak, it is not considered to be a high priority. It may also take a few days for the customer to notice the problem, after which it may take several more days before the water supplier has sent out a team to find the leak and assess the situation. Furthermore, it may then take a few more days to dig up the water pipe and repair the leak. In total, it takes an average of 16 days from the time a connection leak occurs until it is repaired. This type of leak will typically result in losses of 400 $m^3$ as shown in **Fig. 2.4**.

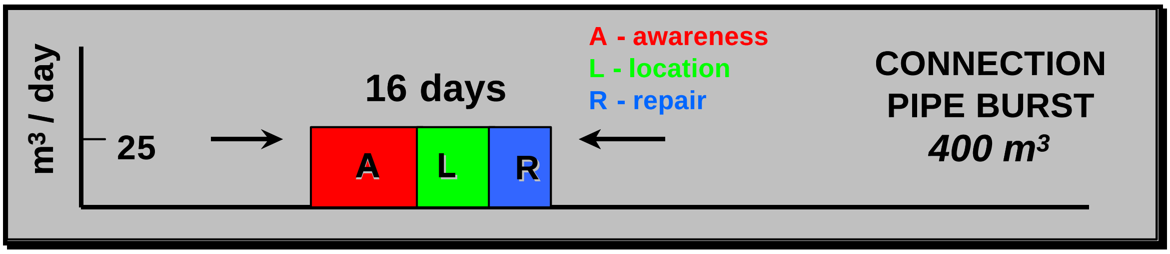


**Figure 2.4 : Typical duration and losses from a connection burst**

If the leak occurs on the consumer's property after the meter, the situation can be even worse from a leakage viewpoint. In such cases, the consumer may not pick up the leak for several weeks or even months. After identifying the leak, the location and repair may also take many days or weeks to complete, with the result that such leaks normally run for approximately 46 days. The water lost through such a leak will average out to approximately 1 050 $m^3$ as shown in **Fig. 2.5**.

It is important to realise that the water lost through burst leakage is dependent on the awareness, location and repair times for the water supplier and the performance of different water suppliers can vary significantly, depending upon where they place their priorities.

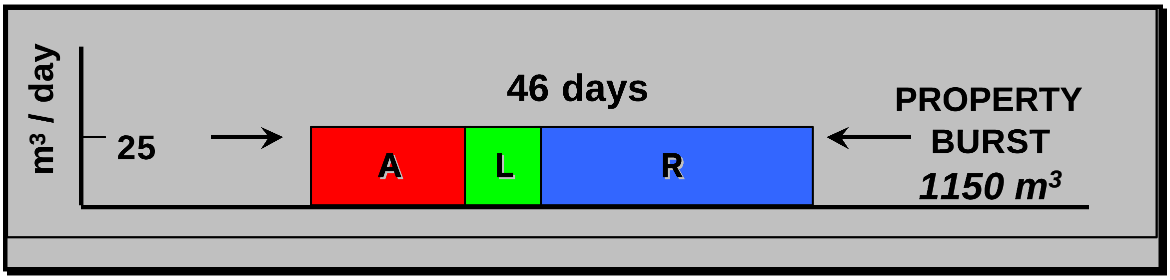


**Figure 2.5 : Typical duration and losses from a property burst**

In the UK, many water companies decided to repair leaks on customer's properties free-of-charge rather than leave such leakage to the customer. Part of this strategy was based on the fact that many customers are not metered individually and such leaks result in a loss to the water company. In cases where the customer is charged for the water, the water supplier may decide that such leakage is not a priority issue since the water is being paid for and the water company is not losing any revenue as a result of the leak. In South Africa the situation is probably somewhere between the two extremes in that many water suppliers supply water to customers who either have no meters or pay a fixed tariff each month. In such cases, the water supplier may decide that it is in its best interests to locate and repair all leaks on the customer's property. In other cases, the water supplier may decide that such repairs will be the customer's problem.

## 2.7. REAL AND APPARENT LOSSES

**Real Losses**

Real losses represent the physical water losses from the pressurised system, up to the point of measurement of customer use. Calculated as:

'System Input' – ('Authorised Consumption' + 'Apparent Losses')

The annual volume lost through all types of leaks, bursts and overflows depends on frequencies, flow rates, and average duration of individual leaks.

**Apparent Losses**

Apparent losses represent the unauthorised consumption (theft or illegal use) plus all technical and administrative inaccuracies associated with customer metering. It should be noted that the apparent losses should not be a major component of water balance in most parts of South Africa, except in areas where payment levels are low and/or flat rate tariffs are used. A systematic estimate should be made from local knowledge of the system and an analysis of technical and administrative aspects of the customer metering system.

In a normal well-managed system the apparent losses normally constitute between 10% and 20% of the total losses. In systems such as Johannesburg where there are large areas of fixed monthly tariffs as well as high levels of non-payment, the apparent losses tend to be in the same order of magnitude as the real losses. In some areas such as Khayelitsha where most of the water is lost through poor plumbing fixtures after the domestic meter, the apparent losses can be as high as 80%. In summary, the apparent losses can range in South Africa from less than 10% for a well-managed system to more than 80% for a system experiencing major problems with household leakage and high levels of non-payment for services.

## 2.8. UNAVOIDABLE ANNUAL REAL LOSSES (UARL)

One of the most important concepts used in the BABE procedures concerns the minimum or unavoidable level of leakage for any given system. Effectively, it is a simple concept based on the fact that no system can be entirely free from leakage and that every system will have some level of leakage which cannot be reduced any further. Even a new reticulation system with no use will have some level of leakage, although it may be relatively small. The minimum level of leakage for a system is termed the unavoidable annual real losses or UARL. This is the level of leakage that can be achieved if the system:

- Is in top physical condition and is well-maintained
- All reported leaks are repaired quickly and effectively
- Active leakage control is practised to reduce losses from unreported leaks

Considerable work was undertaken to assess the minimum level of leakage for any system (Lambert et. al., 1999) and after careful analysis a relatively simple and straightforward equation was developed. Full details of the equation are provided in **Appendix C**, and the form suitable for use in South Africa is as follows:

$$\boxed{\mathbf{UARL = (18 * Lm + 0.80 * Nc) * P}}$$

Where:

| | | |
|---|---|---|
| **UARL** | = | Unavoidable annual real losses (ℓ/d) |
| **Lm** | | Length of mains (km) |
| **Nc** | = | Number of service connections (main to meter) |
| **P** | = | Average operating pressure at average zone point (m) |

## 2.9. TARGET MINIMUM REAL LOSSES (TMRL)

The calculation of the unavoidable annual real losses has already been described and represents the lower bound of leakage for any given system. It should be noted, however, that this minimum level of leakage is generally well below the economic level of leakage which is the leakage level at which the savings achieved just balance the implementation costs. The minimum level of leakage or UARL is not an appropriate target for any water utility since it implies that a considerable portion of the budget is being spent on lowering leakage, without producing a positive pay-back. In order to identify a realistic and logical target level of leakage, it is now standard practice to simply scale up the UARL by some factor. The resulting leakage level can be considered to be the TMRL. The selection of the factor is perhaps a rather arbitrary operation and is normally based on experience gained from the analysis of many different areas with similar characteristics to the area being investigated. As a simple rule-of-thumb, a target loss of twice the unavoidable annual real losses can be used in areas which are very well managed, with sufficient funds to implement a wide range of WDM measures. A target factor of 2 is normally considered to be appropriate for affluent and well-managed areas such as Sandton or a small supply system which does not include any low-income and high-leakage areas. As soon as low-income areas are included in the calculation, the factor used to establish the TMRL can be as high as 10 times the theoretical minimum value. It is the responsibility of the leakage manager to select a target value that is appropriate for each area. The target value should be lower than the current annual real losses but should not be too restrictive as to set a target that cannot be achieved. A value of 2 would be appropriate in Sandton for example while a value of 8 or 10 may be more appropriate in Alexandra or Khayelitsha.

It should be noted that the factor is a relatively new concept and it has yet to be fully tested throughout South Africa. The intention is to provide some methodology for setting a realistic leakage target based on the actual ground conditions. Until further investigations using BENCHLEAK (WRC, 2001) have been completed, it is recommended that TLF of between 2 and 10 be selected. A factor of 2 will be used for an area with relatively low leakage and sound infrastructure, while a factor of 10 will be used for areas with extremely high leakage and poor infrastructure. Eventually, it is envisaged that even the areas with high levels of leakage will be managed properly to reduce leakage, in which case the Target Loss Factors can be reduced gradually. It is important to select a realistic Target loss Factor that is not too onerous since this may simply be demoralizing to the water supplier who knows that the target set is not achievable. By selecting a realistic Target Level of Leakage, the water supplier sets itself a target level of leakage that is achievable and can gain satisfaction by reaching or even surpassing the target.

## 2.10. NATURAL RATE OF RISE OF LEAKAGE

In any water distribution system, leakage of some form will certainly occur. In most systems there tends to be a natural rise of leakage which will continue to increase each year if left unattended. In certain circles, it is believed that the leakage will increase until it reaches a certain level at which it will stabilise. At this point the leakage is in balance with the system pressure and it will remain relatively constant, assuming that the system pressure and other factors influencing the system do not change. The other circle of thinking in this regard is that system leakage has a natural rate of rise which is relatively constant and that the leakage will simply continue to increase if left unchecked. This view is based on the assumption that the system pressure will be kept constant which, in turn, will involve supplying more water to the system. In reality, it is likely that the increase in leakage will gradually reduce as the system pressure is also reduced through the increasing losses. Effectively, it is a combination of the two different approaches.

In order to address leakage, it is important to understand the key elements which influence leakage. This is particularly important when considering the economics of leakage in order to identify the appropriate budget to allocate to leakage reduction.

If the leakage in a particular system is conceptualised, as shown in **Fig. 2.6,** it can be seen that there are three basic elements namely:

- The Unavoidable Annual Real Losses
- The Economic Level of Real Losses and,
- The Current Annual Real Losses.

Each of the items above has been described in detail earlier in this chapter. The next consideration is how to control the leakage and what factors have the most significant influence on the leakage. If the key influencing factors can be identified and quantified, it is then possible to make predictions regarding the likely influences of the different leakage reduction activities.

From work recently undertaken by the International Water Association (Lambert et.al. ,1999) it was concluded that the following four factors are the most important factors influencing system leakage:

- Speed and quality of repairs
- Pipeline and assets management, selection, installation, maintenance, renewal and replacement;
- Active leakage control and;
- Pressure management.

These four components can be considered as constraints which prevent the Annual Real Losses from increasing as shown in **Fig. 2.7**.

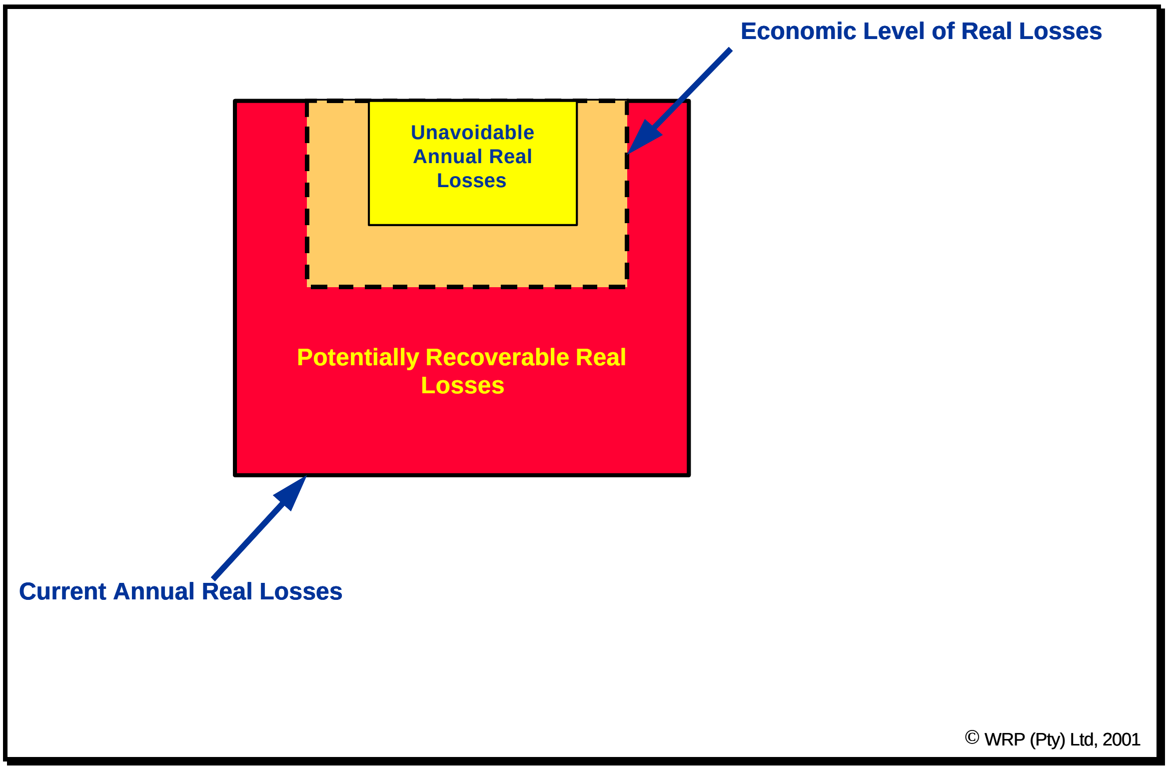


**Figure 2.6: Conceptual representation of system leakage**

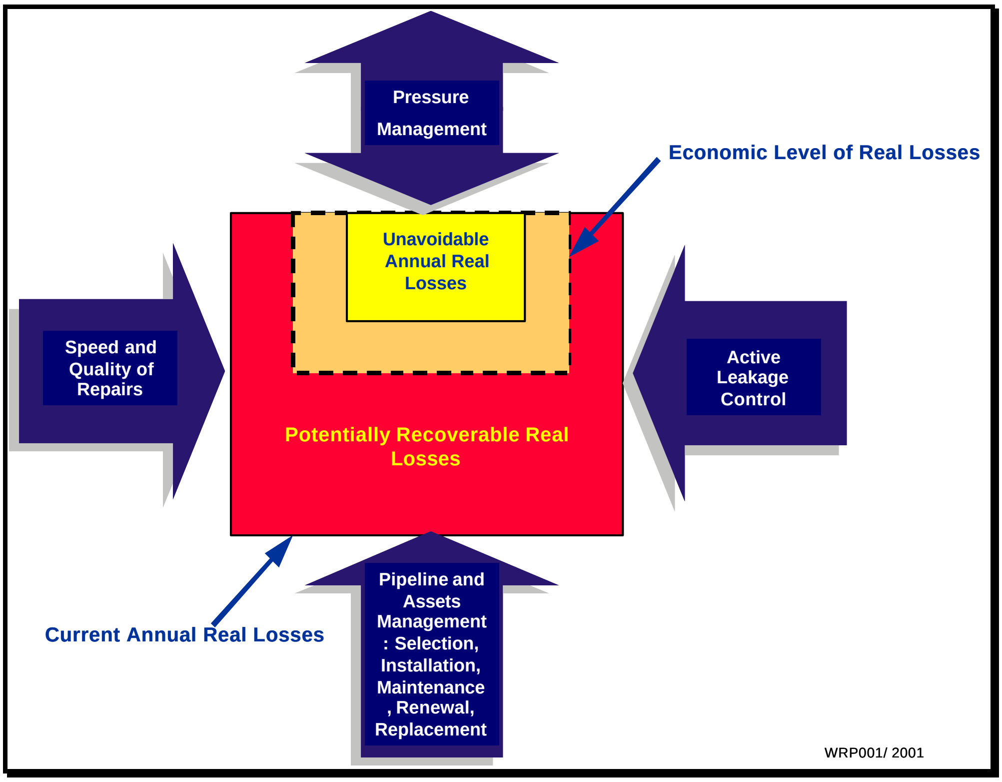


**Figure 2.7: Factors influencing levels of Real Losses**

The purpose of **Fig. 2.7** is to highlight the fact that system leakage is highly dependent on several key factors. If the water utility disregards or ignores one or other of these factors, the leakage will tend to increase. It is clearly necessary to address all four issues simultaneously if leakage is to be properly controlled and eventually reduced.

For example, if a water utility can improve the speed and quality of repairs through the use of better repair procedures and additional repair teams, then the leakage will improve to some degree as shown on **Fig. 2.8.**

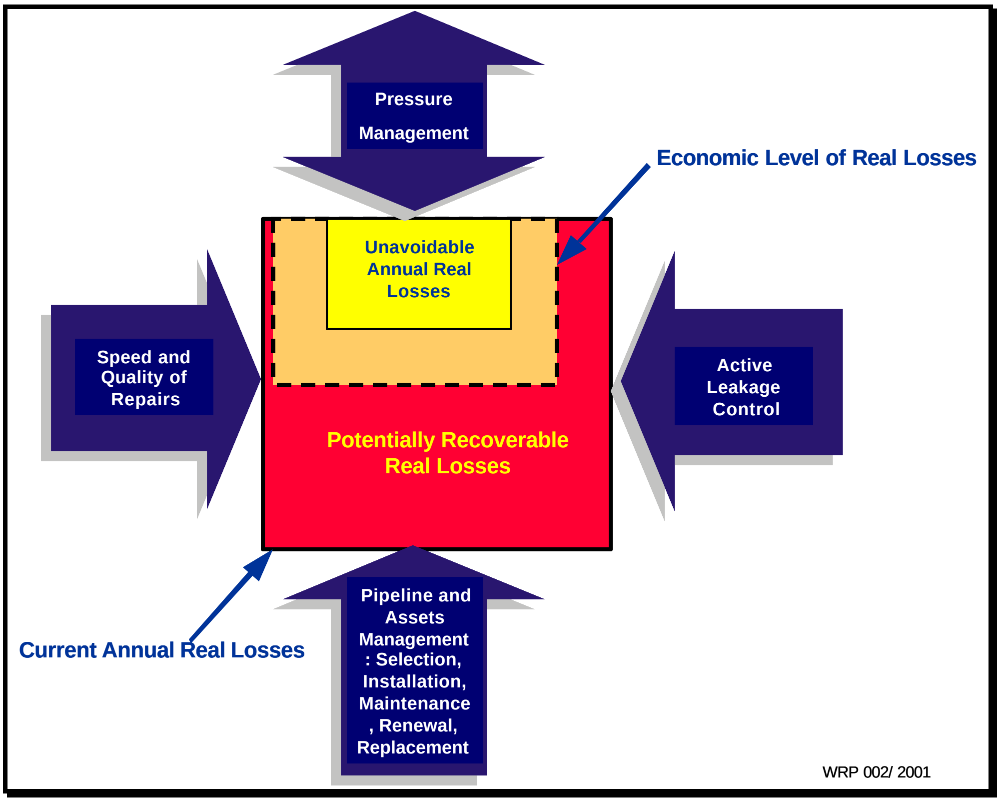


**Figure 2.8: Influence on leakage of improving Speed and Quality of Repairs**

Similarly, if the water utility can also improve the pipeline and assets management component of their operation as well as implement an effective maintenance and replacement programme, the system losses can be reduced further as shown in **Fig. 2.9.**

The same applies to active leakage control which can also be improved to reduce leakage as shown in **Fig 2.10** or if it is neglected the leakage will increase.

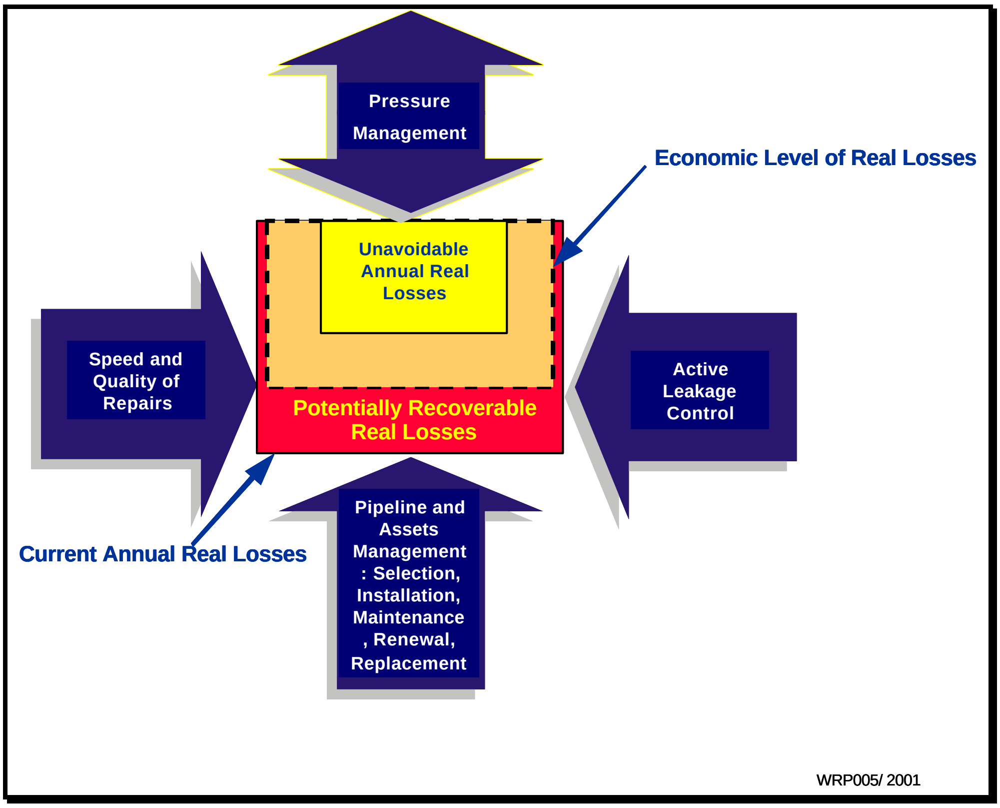


**Figure 2.9: Influence on leakage of improving Asset Management etc.**

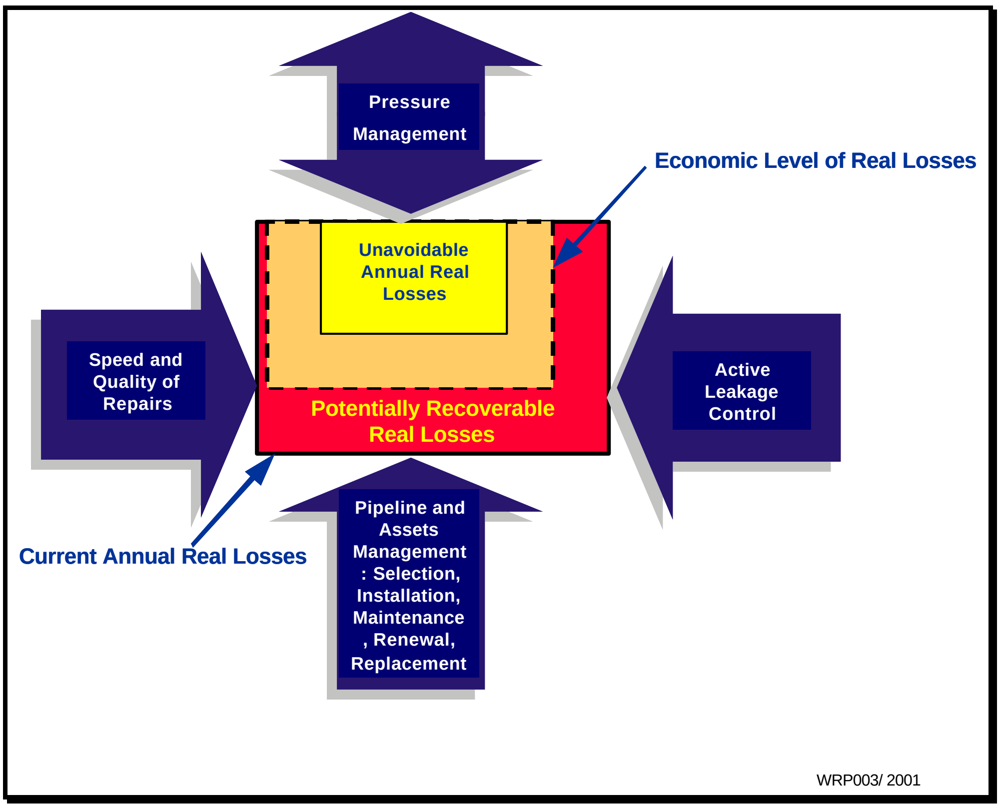


**Figure 2.10: Influence on leakage of improving Active Leakage Control.**

Finally, if Pressure Management is implemented to reduce leakage, the situation will be improved further. In this case, however, it should be noted that Pressure management not only reduces the real losses but also reduces the UARL which are dependent on pressure (see **Section 2.8**). This is shown schematically in **Fig. 2.11**.

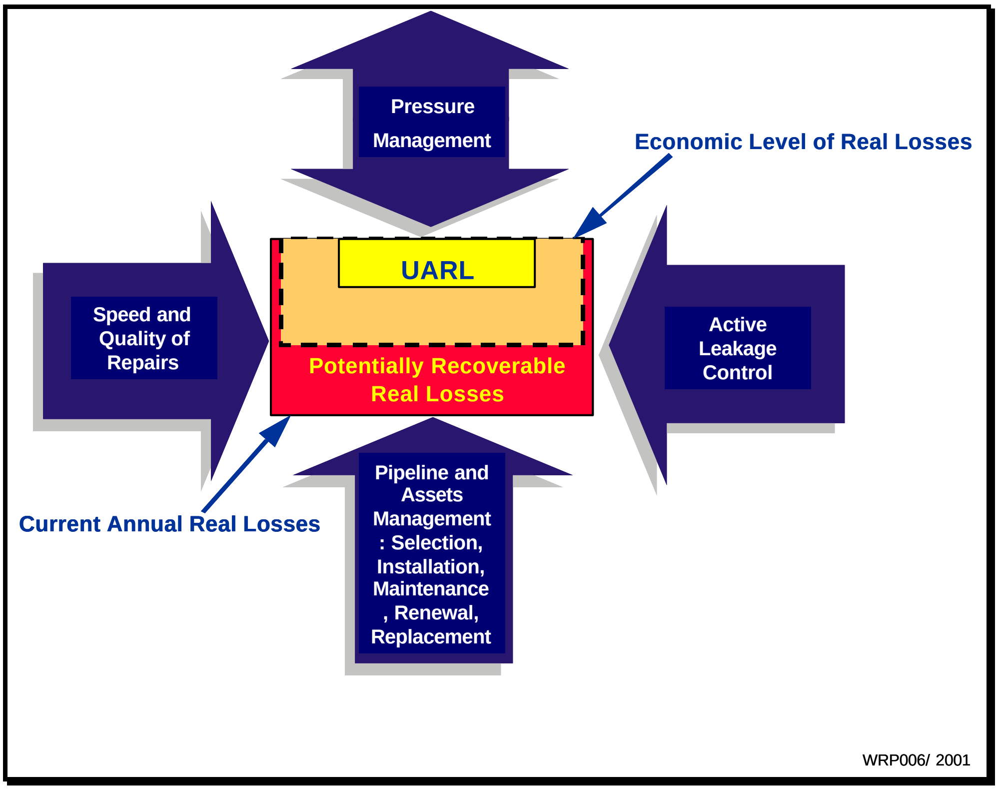


**Figure 2.11: Influence on leakage of implementing Pressure Management.**

## 2.11. PRESSURE CORRECTION

One of the most important factors influencing leakage is pressure. Considerable work has been undertaken over the past 10 years in many parts of the world to establish how leakage from a water distribution system reacts to pressure.

It is generally accepted that flow from a hole in a pipe will react to pressure in accordance with normal hydraulic theory that indicates a square root power relationship between flow and pressure (i.e. the power exponent = 0.5).

| | | | |
|---|---|---|---|
| $Flow_{P2}$ | = | $Flow_{P1}$ x PCF | where: |

P1 = Pressure 1 (m)

P2 = Pressure 2 (m)

$Flow_{P1}$ = Flow at pressure P1 ($m^3/h$)

| | | |
|---|---|---|
| $Flow_{P2}$ | = | Flow at pressure P1 ($m^3/h$) |
| PCF | = | Pressure correction factor = $(P1/P2)^{pow}$ |
| pow | = | power exponent. |

This implies that if pressure doubles, the flow will increase by a factor of 1.4 (i.e. PCF = $2^{0.5}$). This has been tested and found to be realistic, irrespective of whether the pipe is above ground or buried. The problem arises because in many systems the leakage has been found to react by a factor greater than 1.4. This has caused considerable debate and confusion, especially when trying to establish the likely savings through pressure reduction measures.

Although there are still various opinions concerning the explanation for the larger-than-expected influences of pressure on leakage in many systems, at least one plausible theory has been suggested. In 1994, John May in the UK (May, 1994) first suggested the possibility of fixed-area and variable-area discharges (FAVAD). He carried ourt considerable research on this topic and has found that systems will react differently to pressure, depending on the dominant leakage in the system being considered. If the leak is a corrosion hole, for example, the size of the opening will remain fixed as the pressure in the system changes on a daily cycle. In such cases, the water lost from the hole will follow the general square root principle as outlined above. This type of leak is referred to as a **fixed-area leak**.

If, however, the leak is due to a leaking joint, the size of the opening may, in fact, increase as the pressure increases due to the opening and closing of the joint with the changing pressure. Such leaks are referred to as **variable-area leaks**. In such cases the flow of water will increase by more than the fixed-area leak. Research suggests that a power exponent of 1.5 should be used for variable–area leaks while an exponent of 0.5 should be used for the fixed-area leaks. This suggests that if the pressure doubles, the leakage from a variable-area leak will increase by a factor of 2.83 (i.e. PCF = $2^{1.5}$).

In the case of longitudinal leaks, the area of leak may increase both in width as well as in length as is often the case with plastic pipes. In such cases, the power exponent can increase to 2.5. In other words, if the pressure doubles, the flow through the leak will increase by a factor of 5.6 (i.e. PCF = $2^{2.5}$).

The problem faced by the water distribution engineer is to decide what factor should be used when estimating the influence of pressure on leakage flow. In general, it is recommended that a power exponent of 0.5 should be used for all burst flows since a burst pipe is usually a fixed-area discharge. In the case of the background losses, however, the leaks are likely to be variable-area discharges, in which case, a larger power exponent should be used. A power exponent of 1.5 is usually used for the background losses, which is considered to represent a collection of leaks that have factors of between 0.5 and 2.5. If all of the pipe work is known to be plastic, a higher value may be appropriate and conversely, if the pipes are made from cast-iron, a lower value (e.g. 1.0) should be used.

The influence of the power exponent used in the analysis can be seen in **Table 2.4**, where the factors given relate to a basic pressure of 50 m. From the Table it can be seen that if the pressure is reduced from 50 m to 20 m, the leakage will decrease to 0.25 of the original value, i.e. a four-fold reduction in leakage.

From the figures in **Table 2.4** it can be seen that pressure can have a very significant influence on the flow through a leak and that the type of leak has an equally significant influence on the flow. In analyses, where the objective is to predict the savings from pressure-reduction measures, it is often advisable to adopt a conservative approach to ensure that the savings achieved are at least as great as those predicted. In such cases, power exponents of 0.5 for bursts and 1.0 for background leaks are suggested.

**Table 2.4: Pressure Correction Factors for Various Pressure Exponents**

| Average Zone Pressure (m) | Power Exponent = 0.5 (iron/steel) | Power Exponent = 1.0 (mixed pipes) | Power Exponent = 1.5 (mainly plastic) | Power Exponent = 2.5 (all Plastic) |
|---|---|---|---|---|
| 20 | 0.63 | 0.40 | 0.25 | 0.10 |
| 30 | 0.77 | 0.60 | 0.46 | 0.28 |
| 40 | 0.89 | 0.80 | 0.71 | 0.57 |
| 50 | 1.00 | 1.00 | 1.00 | 1.00 |
| 60 | 1.09 | 1.20 | 1.31 | 1.58 |
| 70 | 1.18 | 1.40 | 1.65 | 2.31 |
| 80 | 1.26 | 1.60 | 2.02 | 3.23 |
| 90 | 1.34 | 1.80 | 2.41 | 4.34 |
| 100 | 1.41 | 2.00 | 2.83 | 5.65 |
| 120 | 1.55 | 2.40 | 3.72 | 8.92 |
| 140 | 1.67 | 2.80 | 4.68 | 13.12 |
| 160 | 1.79 | 3.20 | 5.72 | 18.32 |
| 180 | 1.89 | 3.60 | 6.83 | 24.58 |
| 200 | 2.00 | 4.00 | 8.00 | 32.00 |

# 3. ECONOLEAK USER GUIDE

## 3.1. GENERAL THEORY

The methodology employed in the ECONOLEAK Model is straightforward and pragmatic. It effectively estimates the volume of water lost through leakage from a particular water reticulation system under three Active Leakage Control scenarios (i.e. every 6, 12 and 24 months). These three scenarios suggest that an active leakage control intervention will be undertaken at the suggested intervals. An intervention is effectively a full-scale leak detection and repair programme which generally involves basic sounding of the whole network followed by detailed leak location using acoustic leak noise correlators (or similar) to pin-point the physical leaks, after which they are repaired.

For each of the three scenarios, the value of the water lost is estimated using the general BABE methodology and the cost of implementing the Active Leakage Control is also estimated. For each scenario the net benefit (or cost) is then calculated as the difference between the value of the water saved and the cost of the Active Leakage Control intervention.

While the above approach is seemingly very clear and simple, the actual procedure and calculations can be complex and sometimes confusing. In order to assist water suppliers in understanding the key concepts and the basis for the calculations, the various components of the economic assessment have been split into several individual calculation sheets as shown in **Fig. 3.1**. Each main component of the economic analysis is provided on a separate sheet of the spreadsheet starting on **Sheet 2**. (**Sheet 1** is the Licence sheet and is self explanatory) and each will be discussed in detail in the remainder of **Chapter 3**.

It is important to realise that assessing the costs associated with Active Leakage Control is a relatively complicated and involved process. The calculations require reliable data on a number of key issues that many water suppliers in South Africa may not be able to derive. For example, it is important to gather information on the split between mains and connection bursts and assess the water losses and repair times associated with each. It is also important to gather some representative information on the likelihood of unreported bursts for the mains and connections. This information is fundamental to the economic analyses and is required to assess the influence of implementing the different levels of Active Leakage Control. Various default values are provided in the model to enable water suppliers to use the model in cases where they do not have access to all of the required data. It is anticipated that through the use of the model, the water suppliers will be encouraged to implement systems wherby the information can eventually be captured. In this manner the supplier will gain an understanding of the various issues that influence the level of Active Leakage Control appropriate to their system.

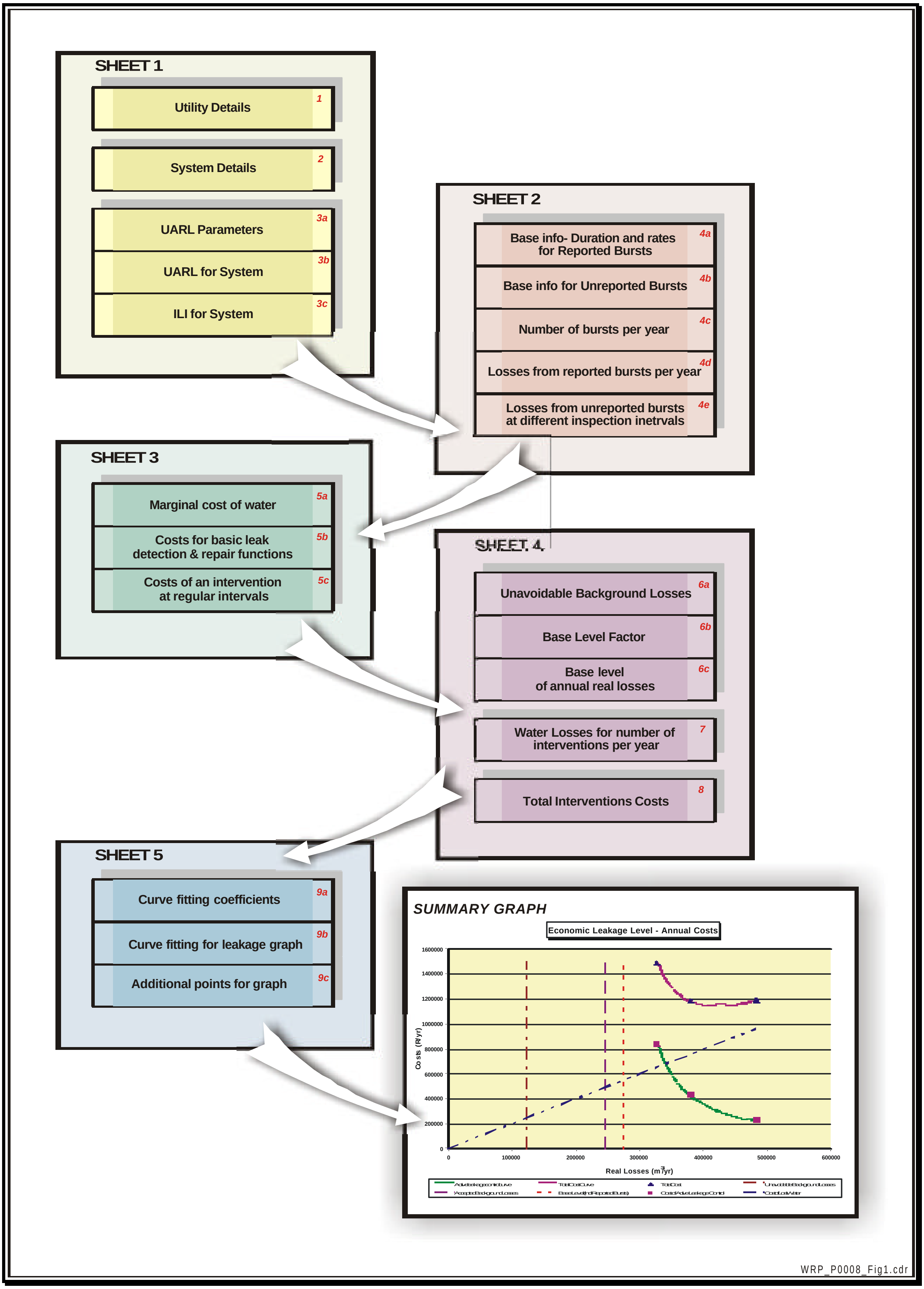
SHEET 1
Utility Details 1
System Details 2
UARL Parameters 3a
UARL for System 3b
ILI for System 3c
SHEET 2
Base info- Duration and rates for Reported Bursts 4a
Base info for Unreported Bursts 4b
Number of bursts per year 4c
Losses from reported bursts per year 4d
Losses from unreported bursts at different inspection inetrvals 4e
SHEET 3
Marginal cost of water 5a
Costs for basic leak detection & repair functions 5b
Costs of an intervention at regular intervals 5c
SHEET 4
Unavoidable Background Losses 6a
Base Level Factor 6b
Base level of annual real losses 6c
Water Losses for number of interventions per year 7
Total Interventions Costs 8
SHEET 5
Curve fitting coefficients 9a
Curve fitting for leakage graph 9b
Additional points for graph 9c
SUMMARY GRAPH
Economic Leakage Level - Annual Costs
Costs (R/yr)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
0
100000
200000
300000
400000
500000
600000
Real Losses (m³/yr)
WRP_P0008_Fig1.cdr

**Figure 3.1 : Basic Layout of the ECONOLEAK Model**

## 3.2. SHEET 2: GENERAL INFORMATION AND CALCULATION OF UARL AND ILI

The information captured on Sheet 2 provides the base data for all further calculations carried out in ECONOLEAK. Details of the water utility and the person completing the form are required as well as the key system data. Examples of the data required are shown in **Figs. 3.2** and **3.3**.

**1. General**

| | | |
|---|---|---|
| Name of Water Undertaking: | | |
| Name of Water Supply System: | | |
| Contact Details: | Name: | |
| | Address: | |
| | | |
| | | |
| | Tel: | |
| | Fax: | |
| | email: | |
| | Date: | |

**Figure 3.2: Example of General information on Water Undertaking**

| Input Description | Variable | Example Data | Actual Data | Units |
|---|---|---|---|---|
| Length of Transmission Mains | Lm_t | 20 | 20 | km |
| Length of Distribution Mains | Lm_d | 330 | 330 | km |
| Total Length of Mains | Lm | 350 | 350 | km |
| Number of Service Connections | Ns | 7500 | 7500 | Number |
| Density of Service Connections (per km of mains) | Ns/Lm | 40 | 21 | Per km |
| Length of underground pipe per connection (if greater than 10m) | Ls | 0 | 0 | m |
| Total volume of Storage Reservoirs in the System | Vol | 1.5 | 1.5 | Ml |
| Percentage of time system is pressurised during year | T | 100 | 100 | % |
| Average Operating Pressure of Transmission Mains | P_t | 45 | 45 | metres |
| Average operating pressure of reticulation system when system pressurised | P | 45 | 45 | metres |
| Population served by the supply system | Pop | 100000 | 250000 | Number |

**Figure 3.3: Example of General System Data**

Having established the basic characteristics for the water reticulation network, the model assesses the UARL and, finally, the Infrastructure Leakage Index (ILI) as shown in **Figs. 3.4 and 3.5** respectively.

**3b. Unavoidable Annual Real Losses (UARL) for System**

| | Example Data | | | | Actual Data | | | |
|---|---|---|---|---|---|---|---|---|
| Details | Litres/second | $m^3$/hr | $m^3$/day | $m^3$/yr | Litres/second | $m^3$/hr | $m^3$/day | $m^3$/yr |
| Transmission Mains | 0.19 | 0.7 | 16 | 5917 | 0.19 | 0.7 | 16 | 5917 |
| Distribution Mains | 3.09 | 11.1 | 267 | 97631 | 3.09 | 11.1 | 267 | 97631 |
| Connections | 3.13 | 11.3 | 270 | 98618 | 3.13 | 11.3 | 270 | 98618 |
| Service Pipes | 0.00 | 0.0 | 0 | 0 | 0.00 | 0.0 | 0 | 0 |
| Total Losses | 6.41 | 23.1 | 554 | 202166 | 6.41 | 23.1 | 554 | 202166 |

**Figure 3.4: Estimation of the Unavoidable Annual Real Losses**

**3c. Infrastructure Leakage Index (ILI)**

| Details | Example | Actual | Units |
|---|---|---|---|
| 1. Water Supplied to the System | 15000000 | 15000000 | $m^3/yr$ |
| 2. Authorised Consumption | 14000000 | 14000000 | $m^3/yr$ |
| 3. Current Total Annual Water Losses : 1 - 2 | 1000000 | 1000000 | $m^3/yr$ |
| 4. Apparent Losses as % of Total Losses | 25 | 25 | % |
| 5. Apparent Losses | 250000 | 250000 | $m^3/yr$ |
| 6. Current Annual Real Losses (CARL) | 750000 | 750000 | $m^3/yr$ |
| 7. Unavoidable Annual Real Losses (UARL) | 202166 | 202166 | $m^3/yr$ |
| 8. Infrastructure Leakage Index (ILI) : 6 / 7 | 3.7 | 3.7 | |

**Figure 3.5: Calculation of the Infrastructure Leakage Index (ILI)**

It can be seen in **Fig. 3.5** that the user is required to provide three items of information:

- The water supplied to the system
- The authorised consumption
- The apparent losses as a % of the total losses.

The first two items are straightforward and can usually be obtained from the water meter readings and billing records. The third item is more subjective and concerns the percentage of water thought to be lost through apparent losses and not through physical leakage. In a well-managed system, the apparent losses would normally be in the order of 10% to 20%, indicating that a reliable MIS system is in operation and that there is little or no theft of water or household wastage in cases where flat-rate tariffs are used. In South Africa, the level of apparent losses can vary from less than 10% in many areas to as high as 90% in extreme cases. In Johannesburg, for example, it is estimated that approximately 50% of the total losses are lost through the apparent losses, while in Khayelitsha the figure is thought to be as high as 80%. The actual percentage will depend upon the level of service, the level of payment for services and the level of illegal use (theft).

It should be noted that the ILI calculation is essentially the same as that used in the BENCHLEAK Model. Full details of the calculation can be found in the BENCHLEAK

User Guide (WRC, 2001) and the key issues are summarised in **Appendix B** for reference purposes.

## 3.3. SHEET 3: LOSSES FROM REPORTED AND UNREPORTED BURSTS

### 3.3.1. General

One of the key calculations in the ECONOLEAK Model concerns the losses from reported and unreported bursts. It is often very difficult to estimate such losses due to an absence of reliable information and it is necessary for the water supplier to set up and maintain a proper record of all bursts. For the purpose of the ECONOLEAK Model the information regarding the burst losses has been based on UK research and it may or may not be applicable in South Africa. It is anticipated that any user of the model will make use of the information provided and update any items where more appropriate information is available.

The calculation of the burst losses are based on the following steps:

- Define the rates and duration of reported bursts at standard pressure
- Define number and leakage rates for unreported bursts
- Define number of reported and unreported bursts per year
- Estimate losses from reported bursts at local pressure
- Estimate losses from unreported bursts for various levels of Active Leakage Control.

### 3.3.2. Define the rates and duration of reported bursts at standard pressure

The awareness, location and repair times associated with the reported bursts are key parameters in the ECONOLEAK Model. The speed at which leaks are repaired will influence the volume of water lost by each leak which, in turn, has financial implications. Details of the duration and rates for the reported bursts are provided in **Section 2.4** and the information is summarised in the model as shown in **Fig. 3.6**.

**4a. Duration and Rates for Reported Bursts**

| Details | Example Data | | | | Actual Data | | | |
|---|---|---|---|---|---|---|---|---|
| | Awareness and Location | Repair | Total Days | Losses $m^3$/hour | Awareness and Location | Repair | Total Days | Losses $m^3$/hr |
| Transmission Mains | 0.50 | 0.50 | 1.00 | 30 | 0.50 | 0.50 | 1.00 | 30 |
| Distribution Mains | 1.00 | 0.50 | 1.50 | 12 | 1.00 | 0.50 | 1.50 | 12 |
| Connections | 5.00 | 6.00 | 11.00 | 1.6 | 5.00 | 6.00 | 11.00 | 1.6 |
| Service Pipes | 5.00 | 6.00 | 11.00 | 1.6 | 5.00 | 6.00 | 11.00 | 1.6 |

**Figure 3.6 : Summary of Information used for the Reported Bursts**

### 3.3.3. Define number and leakage rates for unreported bursts

The only method of finding out how many unreported bursts are in a system is to carry out a full leak detection exercise. Such an exercise usually involves an initial sweep of the area using regular sounding after which some form of leak location device is used to pinpoint the leaks in areas where the sounding indicated that some leakage is present. There are a number of new devices on the market which claim to be able to identify and pin-point leaks and these can obviously be very cost effective in cases where they are shown to work effectively. For the purpose of the ECONOLEAK Model, the user must supply some information regarding the number of unreported leaks as a percentage of the reported leaks, as well as the typical flow rates for the various unreported leaks. The information is provided for the Transmission Mains, Distribution Mains , Connections and Service pipes. Typical values for the different model parameters are shown in **Fig. 3.7**.

**4b. Basic Information on Unreported Bursts**

| Details | Example Data | | | Actual Data | | |
|---|---|---|---|---|---|---|
| | Unreported as % of Reported | N1 Value for Bursts | Losses $m^3/hr$ | Unreported as % of Reported | N1 Value for Bursts | Losses $m^3/hr$ |
| Transmission Mains | 0 | 0.5 | 12.0 | 0 | 0.5 | 12.0 |
| Distribution Mains | 5 | 0.5 | 6.0 | 5 | 0.5 | 6.0 |
| Connections | 33 | 0.5 | 1.6 | 33 | 0.5 | 1.6 |
| Service Pipes | 33 | 0.5 | 1.6 | 33 | 0.5 | 1.6 |

**Figure 3.7: Basic Information used for Unreported Leaks**

### 3.3.4. Define number of reported and unreported bursts per year;

Based on unit burst rates supplied by the user, the number of reported and unreported bursts per year can be calculated. The number of bursts are calculated from the frequency of reported and unreported bursts as supplied by the user, multiplied by the appropriate length of pipe or number of connections. It is a very simple calculation and the results are provided in **Fig. 3.8**.

**4c. Number of Bursts per year**

| Details | Example Data | | | | Actual Data | | | |
|---|---|---|---|---|---|---|---|---|
| | Reported Bursts per Year | | Unreported Bursts per Year | | Reported Bursts per Year | | Unreported Bursts per Year | |
| | Frequency | Number of Bursts | Frequency | Number of Bursts | Frequency | Number of Bursts | Frequency | Number of Bursts |
| Transmission Mains | 0.030 (per km mains/yr) | 0.6 | 0.000 (per km mains/yr) | 0.00 | 0.030 (per km mains/yr) | 0.6 | 0.000 (per km mains/yr) | 0.0 |
| Distribution Mains | 0.150 (per km mains/yr) | 49.5 | 0.008 (per km mains/yr) | 2.48 | 0.150 (per km mains/yr) | 49.5 | 0.008 (per km mains/yr) | 2.5 |
| Connections | 2.500 (per 1000 conn/yr) | 18.8 | 0.825 (per 1000 conn/yr) | 6.19 | 2.500 (per 1000 conn/yr) | 18.8 | 0.825 (per 1000 conn/yr) | 6.2 |
| Service Pipes | 0.000 (per 1000 conn/yr) | 0.0 | 0.000 (per 1000 conn/yr) | 0.00 | 0.000 (per 1000 conn/yr) | 0.0 | 0.000 (per 1000 conn/yr) | 0.0 |

**Figure 3.8: Calculation of the number of bursts per year**

### 3.3.5. Estimate losses from reported bursts at local pressure;

Having established the number of reported bursts in the system (**Section 3.3.4**) as well as the typical leakage rates (see **Section 3.3.3**) it is possible to estimate the losses from the reported bursts. It should be noted that the losses have been corrected for local pressure since the base parameters supplied to the model are all based on standard pressure at 50 m. The pressure adjustments are made in accordance with the procedure discussed under **Section 2.11** and the resulting losses are shown in **Fig. 3.9**.

**4d. Losses from Reported Bursts (adjusted for local pressure)**

| Details | Example Data | | | | Actual Data | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of Bursts per yr | Duration Days | Rate(@50m) $m^3/hr$ | Ave. Losses $m^3/day$ | Number of Bursts per yr | Duration Days | Rate(@50m) $m^3/hr$ | Ave. Losses $m^3/day$ |
| Transmission Mains | 0.6 | 1.0 | 30.0 | 1.1 | 0.6 | 1.0 | 30.0 | 1.1 |
| Distribution Mains | 49.5 | 1.5 | 12.0 | 55.6 | 49.5 | 1.5 | 12.0 | 55.6 |
| Connections | 18.8 | 11.0 | 1.6 | 20.6 | 18.8 | 11.0 | 1.6 | 20.6 |
| Service Pipes | 0.0 | 11.0 | 1.6 | 0.0 | 0.0 | 11.0 | 1.6 | 0.0 |
| Totals | 69 | | | 77.3 | 69 | | | 77.3 |

**Figure 3.9: Estimating Losses from Reported Bursts**

### 3.3.6. Estimate losses from unreported bursts

The losses from the unreported bursts are calculated in the same manner as the losses from the reported bursts. The main difference is that the duration over which the leaks will run depends upon the frequency of active leakage control. For example, if a water supplier checks each area on an annual basis, the average duration of a leak will be 6 months. Using this simplistic but realistic approach, the leakage from unreported bursts is estimated for three scenarios :

- Active Leakage Control every 6 months
- Active Leakage Control every 12 months
- Active Leakage Control every 24 months.

The results from the analysis are shown in **Fig. 3.10**.

**4e. Losses from Unreported Bursts at Regular Inspection Intervals (adjusted for local pressure)**

| Details | Example Data | | | | | Actual Data | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Rate(@50m) $m^3/hr$ | Ave Losses $m^3/day$ | Losses ($m^3/day$) for interventions Every 2 yrs | Every year | Every 6 months | Rate(@50m) $m^3/hr$ | Ave Losses $m^3/day$ | Losses ($m^3/day$) for interventions Every 2 yrs | Every year | Every 6 months |
| Transmission Mains | 12.0 | 0.00 | 0.0 | 0.0 | 0.0 | 12.0 | 0.00 | 0.0 | 0.0 | 0.0 |
| Distribution Mains | 6.0 | 0.93 | 338.6 | 169.5 | 85.0 | 6.0 | 0.93 | 338.6 | 169.5 | 85.0 |
| Connections | 1.6 | 0.62 | 229.1 | 118.4 | 60.1 | 1.6 | 0.62 | 229.1 | 118.4 | 60.1 |
| Service Pipes | 1.6 | 0.00 | 0.0 | 0.0 | 0.0 | 1.6 | 0.00 | 0.0 | 0.0 | 0.0 |
| Totals | | 1.54 | 568 | 286 | 145 | | 1.54 | 568 | 286 | 145 |

**Figure 3.10: Estimating Losses from Unreported Bursts**

## 3.4. SHEET 4: COSTS OF WATER AND INTERVENTION COSTS

### 3.4.1. General

Having estimated the losses associated with the reported and unreported bursts, the next step in the analysis is to calculate the value of the lost water as well as the costs associated with implementing the active leakage control measures. The procedure used to calculate the costs are as follows:

- Define the marginal cost of water
- Determine the unit costs for leakage detection activities
- Calculate the costs associated with the Active Leakage Control.

### 3.4.2. Define the marginal cost of water

It should be noted that there are many publications which present and explain different techniques for estimating the marginal cost of water. Such techniques often consider long-term marginal costs and short-term marginal costs. For the purpose of the ECONOLEAK Model a very simplistic and basic approach is adopted to estimate the marginal cost of water to the water supplier. In many cases the cost will simply represent the purchase price of the water from a Water Board such as Rand Water or Umgeni Water. In other cases, however, it may involve various components in cases where the water supplier stores and treats its own raw water. The appropriate section from the ECONOLEAK Model is shown in **Fig. 3.11**.

**5a. Marginal Cost of Water**

| Details | Example Data | | | Actual Data | | |
|---|---|---|---|---|---|---|
| | Imported Water | Own Sources | Highest | Imported Water | Own Sources | Highest |
| Bulk Supply | 2.00 | 0.00 | | 2.00 | | |
| Power | 0.00 | 0.70 | | | 0.75 | |
| Chemicals | | 0.05 | | | 0.05 | |
| Other 1 | | | | | | |
| Other 2 | | | | | | |
| Other 3 | | | | | | |
| Total | 2.00 | 0.75 | 2.00 | 2.00 | 0.80 | 2.00 |

**Figure 3.11: Details of the Marginal Cost of Water**

### 3.4.3. Determine the unit costs for leakage detection activities

In order to estimate the cost of implementing Active Leakage Control, it is necessary to identify and assign rates to the various components involved with a typical Active Leakage Control initiative. The user of ECONOLEAK is requested to supply certain information while several rows have been left blank so that the user can define his/her own items and assign rates to them. Details of this section of the model are provided in **Fig. 3.12** and the table is self-explanatory.

**5b. Costs for Leak Detection**

| Details | Example | Actual | Units |
|---|---|---|---|
| Cost for regular sounding per km | 800 | 800 | R / km |
| % Coverage required for Correlation | 20 | 20 | % |
| Cost for Correlation per km | 1000 | 1000 | R / km |
| Supervision as % of Inspection Costs | 15 | 15 | % |
| Measuring Minimum Night Flows | 100000 | 100000 | Rand |
| Administrative Set Up Costs | 5000 | 5000 | Rand |
| Cost to repair Mains Leak | 5000 | 5000 | Rand |
| Cost to Repair Service/Connection Leak | 2000 | 2000 | Rand |
| | | | |
| | | | |
| 10. Other 3 | | | |

**Figure 3.12: Unit Costs for Leak Detection and Repair Activities**

### 3.4.4. Calculate the costs associated with the Active Leakage Control

Having established the unit costs associated with the Active Leakage Control activities, the next step is to calculate the costs associated with carrying out the Active Leakage Control every 6, 12 and 24 months. This calculation is based upon the unit rates mentioned in the previous section together with the basic system data (length of mains etc), as given in **Fig. 3.3**. The results from this exercise are shown in **Fig. 3.13**.

**5c. Costs for an Intervention at Regular Intervals**

| Details | Example Data | | | Actual Data | | |
|---|---|---|---|---|---|---|
| | Every 2 years | Every 1 year | Every 6 months | Every 2 years | Every 1 year | Every 6 months |
| Administration set up costs | 2500 | 5000 | 10000 | 2500 | 5000 | 10000 |
| Manpower Inspection Costs | 176000 | 350000 | 700000 | 176000 | 350000 | 700000 |
| Supervision Costs | 26250 | 52500 | 105000 | 26250 | 52500 | 105000 |
| Mains repair costs | 12375 | 12375 | 12375 | 12375 | 12375 | 12375 |
| Connection repair costs | 12375 | 12375 | 12375 | 12375 | 12375 | 12375 |
| Other Costs 1 | | | | | | |
| Other Costs 2 | | | | | | |
| Total Costs | 228500 | 432250 | 839750 | 228500 | 432250 | 839750 |

**Figure 3.13: Costs for an Intervention at regular Intervals**

## 3.5. SHEET 4: FINANCIAL ANALYSIS FOR ACTIVE LEAKAGE CONTROL

### 3.5.1. General

This sheet effectively takes all the basic information and costs developed in the previous sheets and calculates the total intervention costs for the three active leakage control scenarios. The analysis is undertaken in the following steps:

- Calculate the unavoidable background losses;
- Determine the base level of annual real losses
- Calculate the water losses occurring for the different active leakage control scenarios;
- Calculate the total intervention costs for the three active leakage control scenarios.

### 3.5.2. Calculate the unavoidable Background Losses

It should be noted that when assessing the impact of active leakage control at various intervals, it is important to separate the unavoidable background leakage from the avoidable burst leakage. The active leakage lontrol will only influence the burst leakage while the background leakage will remain unchanged. It is for this reason that the first step in the calculation is to determine the background leakage. This calculation is shown in **Fig. 3.14** and is in accordance with the details provided in **Appendix B**. It should be noted that the background leakage has been adjusted for local pressure conditions in accordance with the methodology discussed in **Section 2.11**.

| 6a. Unavoidable Background Losses (Adjusted for Local Pressure) | | | | | | |
|---|---|---|---|---|---|---|
| | Example Data | | | Actual Data | | |
| Details | Unavoidable Background Leakage | N1 Value | Unavoidable Background Leakage (m³/day) | Unavoidable Background Leakage | N1 Value | Unavoidable Background Leakage (m³/day) |
| 1. Service Reservoirs | 0.1 % of capacity/day | | 2 | 0.1 % of capacity/day | | 2 |
| 2. Transmission Mains | 20 l/km/hr @ 50m | 1.5 | 8 | 20 l/km/hr @ 50m | 1.5 | 8 |
| 3. Distribution Mains | 20 l/km/hr @ 50m | 1.5 | 135 | 20 l/km/hr @ 50m | 1.5 | 135 |
| 4. Connections | 1.25 l/conn/hr @ 50m | 1.5 | 192 | 1.25 l/conn/hr @ 50m | 1.5 | 192 |
| 5. Service pipes | 0 l/conn/hr @ 50m | 1.5 | 0 | 0.00 l/conn/hr @ 50m | 1.5 | 0 |
| Totals | | | 337 | | | 337 |

**Figure 3.14: Unavoidable Background Losses at Local Pressure**

It can be seen from **Fig. 3.14** that in the example the unavoidable background leakage is estimated to be 337 m³/day.

### 3.5.3. Determine the Base Level of Annual Real Losses

While the unavoidable background losses represent the theoretical minimum level of background losses that can be achieved, they are not normally achievable from a financial viewpoint. Such losses are generally too low to use as a target and normally some factor is applied to the unavoidable losses to derive a realistic and achievable level of background losses. In cases where the infrastructure is in relatively good condition, a factor of 2 may be appropriate. In other areas, however, where payment levels are low and infrastructure is in poor condition, it may be appropriate to use a factor of 5 or more. The resultant background losses can then be added to the estimated burst losses to give the base level of real losses. This calculation is shown in **Fig. 3.15**.

| 6b. Base Level for Annual Real Losses | | | |
|---|---|---|---|
| Details | Example Data | Actual Data | Units |
| Unavoidable Background Losses | 337 | 337 | m³/day |
| Factor for Base Level losses | 2.0 | 2.0 | m³/day |
| Total Base Background Losses | 674 | 674 | m³/day |
| Losses From Reported Bursts | 77 | 77 | m³/day |
| Base Level of Real Losses | 751 | 751 | m³/day |

**Figure 3.15: Base Level of Annual Real Losses**

In **Fig. 3.15** it can be seen that the unavoidable background losses of 337 $m^3$/day have been doubled using a factor of 2 to give total base background Losses of 674 $m^3$/day. The losses from the reported bursts of 77 $m^3$/day are then added to give a total base level of real losses of 751 $m^3$/day. This represents the base level of real losses which will be unaffected by the active leakage control. The burst losses in this case represent the losses from the reported burst expressed as an average daily value. The average burst losses of 77 $m^3$/day were estimated previously as shown in **Fig. 3.9** and as described in **Section 3.3.5**.

The base level of annual real losses is also provided in more detail in the ECONOLEAK Model as shown in **Fig. 3.16**.

**6c. Base Level of Annual Real Losses**

| Details | Example Data ($m^3$/day) Background Losses Basic | Base Level | Bursts | Total | Actual Data ($m^3$/day) Background Losses Basic | Base Level | Bursts | Total |
|---|---|---|---|---|---|---|---|---|
| Storage Reservoirs | 1.5 | 3.0 | | 3.0 | 1.5 | 3.0 | | 3.0 |
| Transmission Mains | 8.2 | 16.4 | 1.1 | 17.5 | 8.2 | 16.4 | 1.1 | 17.5 |
| Distribution Mains | 135.2 | 270.5 | 55.6 | 326.1 | 135.2 | 270.5 | 55.6 | 326.1 |
| Connections | 192.1 | 384.2 | 20.6 | 404.8 | 192.1 | 384.2 | 20.6 | 404.8 |
| Service Connections | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total ($m^3$/day) | 337.0 | 674.1 | 77.3 | 751.4 | 337.0 | 674.1 | 77.3 | 751.4 |
| Total ($m^3$/year) | 123023 | 246046 | 28210 | 274256 | 123023 | 246046 | 28210 | 274256 |
| Cost (Rand/yr) | 246046 | 492092 | 56420 | 548512 | 246046 | 492092 | 56420 | 548512 |

**Figure 3.16: Base Level of Real Losses in more Detail**

### 3.5.4. Water Losses occurring for the different Active Leakage Control scenarios

Having established the base level of losses as discussed in the previous section, it is then possible to calculate the total water losses each year for the three Active Leakage Control scenarios. The losses from the unreported bursts are calculated based on the number of such bursts as estimated previously and shown in **Fig. 3.10** and discussed in **Section 3.3.6**. The results of the analysis are shown in **Fig. 3.17**.

For example, if the case of an intervention every 6 months is considered, it was shown in **Fig. 3.16** that the base level of real losses was 751.4 $m^3$/day. If the estimated leakage from the unreported bursts of 145 $m^3$/day (see **Fig. 3.11**) is then added, the total water losses of 896.4 $m^3$/day are derived as shown in **Fig. 3.17**.

| 7. Water Losses for number of Interventions per year | | | | | | |
|---|---|---|---|---|---|---|
| Details | Example Data | | | Actual Data | | |
| | Every 2 years | Every year | every 0.5 years | Every 2 years | Every year | every 0.5 years |
| Storage Reservoirs | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Transmission Mains | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 |
| Distribution Mains | 664.6 | 495.6 | 411.1 | 664.6 | 495.6 | 411.1 |
| Connections | 633.9 | 521.2 | 464.9 | 633.9 | 521.2 | 464.9 |
| Service Connections | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total ($m^3$/day) | 1319.1 | 1037.3 | 896.4 | 1319.1 | 1037.3 | 896.4 |
| Total ($m^3$/year) | 481462 | 378620 | 327199 | 481462 | 378620 | 327199 |
| Cost (Rand/yr) | 962923 | 757239 | 654397 | 962923 | 757239 | 654397 |

**Figure 3.17: Water Losses for various Interventions per Year**

### 3.5.5. Calculate the total intervention costs for active leakage control

The final calculation on sheet 4 concerns the annual intervention costs for implementing active leakage control every 6, 12 and 24 months. This calculation uses the unit rates shown in **Fig. 3.13** and discussed in **Section 3.4.4,** together with the cost of the water losses which were discussed in **Section 3.5.4**. The resulting calculation is shown in **Fig. 3.18** and is the final leakage calculation undertaken in ECONOLEAK.

| 8. Total Intervention costs | | | | | | |
|---|---|---|---|---|---|---|
| Details | Example Data | | | Actual Data | | |
| | Intervention Cost | Cost of Losses | Total | Intervention Cost | Cost of Losses | Total |
| Every 2 years | 228500 | 962923 | 1191423 | 228500 | 962923 | 1191423 |
| Every year | 432250 | 757239 | 1189489 | 432250 | 757239 | 1189489 |
| Every 0.5 Years | 839750 | 654397 | 1494147 | 839750 | 654397 | 1494147 |

**Figure 3.18: Total Intervention Costs**

## 3.6. SHEETS 5 AND 6 :CURVE FITTING INFORMATION

The last two sheets of the ECONOLEAK model simply take the key information derived from the model and present it in a simple and straightforward graph. Sheet 5 contains the information and calculations used to create the curves shown on the graph while Sheet 6 presents the graph. For most purposes, the user of ECONOLEAK will not refer to Sheet 5 for any reason and Sheet 6 will generally be the most useful sheet from the model, since it effectively summarises all of the previous information. A typical example of the final graph is presented in **Fig. 3.19**.

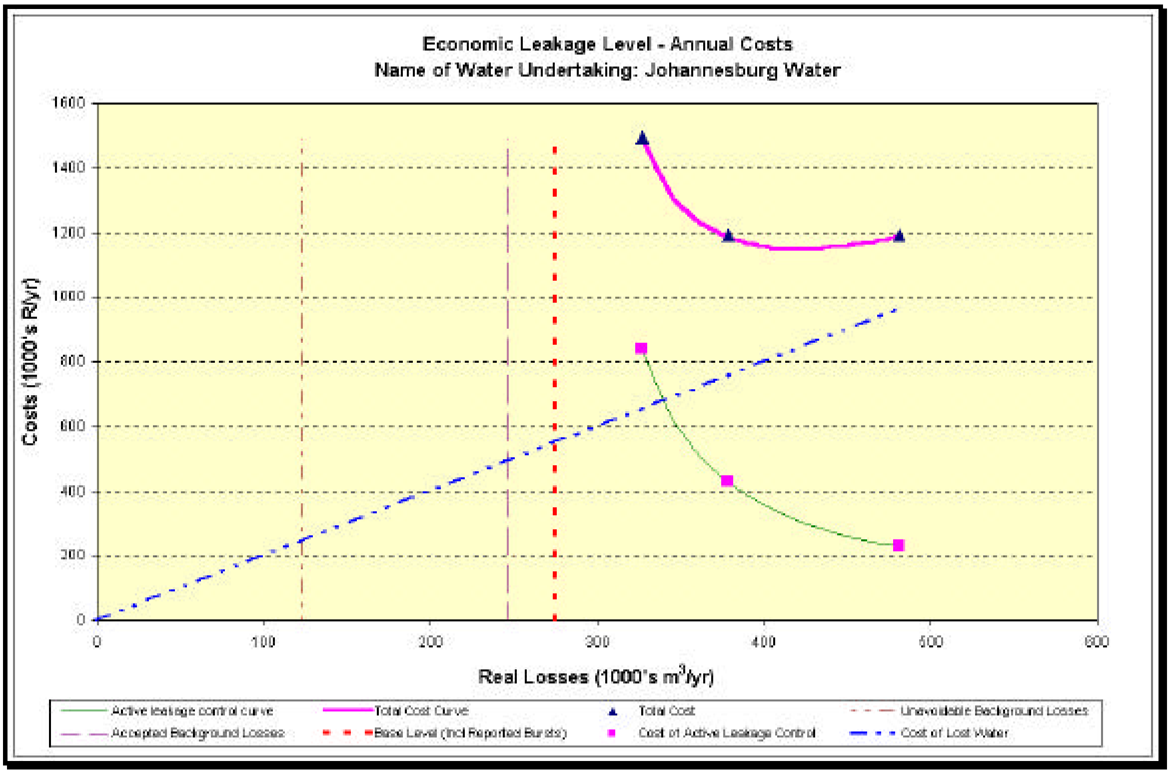


**Figure 3.19: Graph of results from the ECONOLEAK Model**

The final graph presents six items of information based on the results from the model. The following items are presented:

- The unavoidable background losses (see **Section 3.5.3**)
- The base level of background losses (see **Section 3.5.3**)
- The base level of real losses including reported bursts (see **Section 3.5.3**)
- The cost of lost water (see **Section 3.5.4**)
- The cost of active leakage control (see **Section 3.4.4**)
- The total intervention costs (see **Section 3.5.5**)

Ideally, the curve for the total intervention costs should indicate a minimum cost somewhere between the 6-month intervention and the 24-month intervention. In **Fig. 3.19**, it can be seen that the total cost appears to level out between the 12-month interval and the 24-month interval. This suggests that implementing active leakage control every year or two will be appropriate for the system used in the example. The graph also clearly shows that the costs increase dramatically as the period of active leakage control is reduced below 12 months and the curve will become asymptotic to some level of real losses. This highlights the fact that no matter how much money and effort is thrown at leakage, a certain level will be reached which cannot be reduced. This level is also clearly below the economic level of leakage which is represented by the point where the cost of water equals the cost of the active leakage control (i.e. where the cost curve crosses the straight line representing the cost of lost water).

# 4. USING ECONOLEAK

## 4.1. HARDWARE AND SOFTWARE REQUIREMENTS

The ECONOLEAK model has no special hardware requirements and will operate on any modern personal computer which has access to the Microsoft EXCEL spreadsheet package. The model is supplied as a standard EXCEL spreadsheet which should be loaded into any convenient directory. The spreadsheet should be copied for each new system and the appropriate figures overwritten according to the system configuration. It is recommended that the original spreadsheet be copied and protected for future use and that any changes are made to copies. The spreadsheet is protected in a very simple and standard manner to prevent users from overwriting equations and cell format

## 4.2. HOW THE ECONOLEAK MODEL WORKS

The ECONOLEAK Model is simply an Excel spreadsheet comprising five calculation sheets, an introduction/licence sheet as well as a summary graph sheet. Definitions of the various terms used in the ECONOLEAK Model are provided in **Appendix A**.

The model comprises the following data entry and calculation sheets/forms:

- **Sheet 1: Licence and Version Control**
  This sheet provides details of the licence conditions and also indicates the version number and date of creation of the software so that the user can quickly identify if the version being used has been superseded or updated.
- **Sheet 2: Utility details, System details and calculation of UARL and ILI**
  This sheet captures information on the water utility including the person responsible for the data capture and calculation. It also estimates the UARL and the ILI.
- **Sheet 3: Information on reported and unreported bursts**
  The information on the reported and unreported bursts is captured on this sheet. This is the base information used to estimate the number of bursts for each system as well as define the typical leakage rates associated with the different types of burst.
- **Sheet 4: Information on the costs of water and for leak detection and repair**
  This section captures the marginal cost of water as well as defines the unit costs associated with leak detection and repair. It processes this information to calculate the costs for leakage interventions at 6, 12 and 24 months respectively.

- **Sheet 5: Estimated leakage rates and associated intervention costs**
  This sheet utilises the previous base information to calculate the total net costs associated with interventions at 6, 12 and 24 month intervals. The results from this sheet form the basic output from the ECONOLEAK Model.
- **Sheet 6: Curve fitting information**
  This sheet contains all the calculations associated with the curve fitting routines for the final graph. The information in this sheet would not normally be used or examined by the user.
- **Sheet 7: Summary graph of intervention costs against savings**
  The summary graph basically presents the results from the model in an easily understood format from which it can be seen how often the utility should consider active leakage control.

The calculation procedure is summarised in **Fig. 3.1** and details of each element in the figure are provided in **Section 3** of this report.

Sheet 1 : Licence and Version Control
Sheet 2: Utility details, system details and calculation of UARL and ILI
Sheet 3: Information on reported and unreported bursts
Sheet 4: Information on reported and unreported bursts
Sheet 5: Estimated leakage rates and associated intervention costs
Sheet 6: Curve-fitting information
Sheet 7: Summary graph of intervention costs against savings

## 4.3. DATA REQUIREMENTS

The data requirements for the ECONOLEAK Model are relatively complex and in many cases it will be difficult to provide all information required. A form indicating the required data is provided in **Appendix D** and this can be used as a data request form in cases where someone is required to carry out an analysis on behalf of some water supplier. In such cases, the form can be sent to the water utility which can then provide all the required information. In cases where the information is not available, the values given in the example data set should be used until more accurate information becomes available.

## 4.4. GETTING STARTED

The ECONOLEAK Model is supplied on a disk as a standard EXCEL spreadsheet. To run the model simply copy the ECONOLEAK.XLS file into a suitable sub-directory and run the model as one would run any other spreadsheet. The spreadsheet is protected to prevent any formulae being inadvertently overwritten. Only the yellow coloured cells are unprotected to enable the user to input his/her own data.

# 5. SUMMARY AND CONCLUSIONS

The ECONOLEAK model completes the suite of BABE models developed through the Water Research Commission which includes SANFLOW, PRESMAC and BENCHLEAK. Together these four models provide water suppliers with the necessary tools to evaluate and manage the leakage from their water supply networks. The models are based on the latest IWA-recommended procedures and will facilitate a standard approach to water leakage for use throughout South Africa.

The ECONOLEAK model is designed to provide water suppliers with a tool to identify how often active leakage control measures should be implemented in a particular water supply system. In addition to this function, the model also provides a basic framework and explains the methodology for assessing the economic factors associated with leakage and leakage control. This aspect of the model may well prove to be more valuable and useful than the analysis of active leakage control interventions. Using the framework presented in this report, water suppliers can easily develop their own financial models to address specific issues using their own data and individual circumstances.

The ECONOLEAK model provides a systematic and pragmatic approach to the complex issue of assessing the economics of leakage control using the internationally accepted BABE methodology. Once a water supplier has set up the ECONOLEAK model for a specific water supply area, the model can easily be used to assess the financial implications of various possible water demand management strategies. For example, a water utility can determine the benefits from halving the repair times of reported bursts or increasing the number of leak detection teams etc. This type of analysis is often difficult to complete without a clear framework of the various costs involved as provided in the ECONOLEAK model.

From the work undertaken in South Africa as part of the ECONOLEAK project, it is clear that very few of the water suppliers record and collate accurate records of their burst pipes. While many suppliers claim to have such information available, in practice it was found that the information was either lacking in detail or could not be presented in a suitable format for use in the economic analysis. It is recommended that water suppliers attempt to collect and store the following key information:

- Number of mains busrts per year
- Number of connection pipe bursts per year
- Number of service pipe bursts per year
- Realistic estimates of the awareness/location times and repair times for each type of leak mentioned above

- The estimated repair costs for each type of leak including all associated overheads
- The costs associated with active leakage control measures as listed in this report.

If water suppliers can start to gather and process the above information, they will quickly realise the key issues which they should be addressing without necessarily having to use the ECONOLEAK Model.

# 6. REFERENCES


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# APPENDIX A

## GLOSSARY OF TERMS

# APPENDIX A : GLOSSARY OF TERMS

The basic standard terminology used to define the components in the water balance is depicted in **Fig. A.1**.

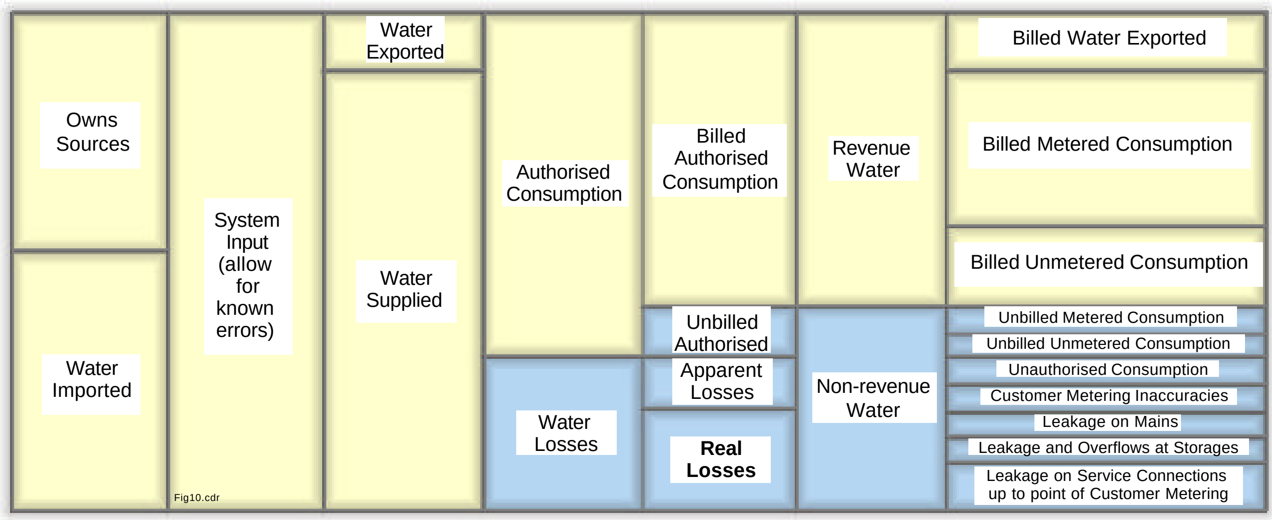



**Figure A.1: Main components of the water supply water balance**

Descriptions of the components shown in **Fig. A.1** as well as certain other terms used in the ECONOLEAK Model are provided below in alphabetical order.

## Apparent Losses

Unauthorised consumption (theft or illegal use) plus all technical and administrative inaccuracies associated with customer metering. It should be noted that the Apparent Losses should not be a major component of water balance in most parts of South Africa, except in areas where payment levels are low and/or flat rate tariffs are used. A systematic estimate should be made from local knowledge of the system and an analysis of technical and administrative aspects of the customer metering system.

## Authorised Consumption

The volume of metered and/or unmetered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorised to do so by the water supplier, for residential, commercial and industrial purposes.

It should be noted that authorised consumption also includes 'Water Exported' and, in some cases may include items such as fire-fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered or unmetered, according to local practice.

**Average Operating Pressure**

The average operating pressure for the whole system over the period in question. Details of the methodology used to calculate the average operating pressure are provided in **Appendix C**.

**Billed Authorised Consumption**

The volume of authorised consumption which is billed and paid for. This is effectively the Revenue Water which, in turn, comprises:

- Billed Water Exported;
- Billed Metered Consumption;
- Billed Unmetered Consumption.

**Current Annual Real Losses (CARL)**

The real losses for the period under consideration expressed in terms of $\ell$/conn/d or $m^3$/year etc. Same as Real Losses.

**Infrastructure Leakage Index (ILI)**

The infrastructure leakage index is a non-dimensional index which provides an indication of how serious the leakage occurring in a particular area is compared to the theoretical minimum level of leakage that can be achieved. The ILI is defined as:

**ILI = CARL / UARL**

**Length of Mains (Lm)**

The length of mains is the total length of bulk and distribution mains in a particular system. All pipes excluding the connection pipes are considered to be mains. The length of mains is normally given in km.

**Non-Revenue Water**

The non-revenue water is becoming the standard term replacing unaccounted-for water in many water balance calculations. It is a term that can be clearly defined, unlike the unaccounted-for water term which often represents different components to the various water suppliers. Non-Revenue Water incorporates the following items:

- Unbilled Authorised Consumption
- Apparent Losses and
- Real Losses

The above terms can be further sub-divided into the following :

- Unbilled Metered Consumption
- Unbilled Unmetered Consumption
- Unauthorised Consumption (theft)
- Customer meter inaccuracies
- Mains leakage
- Overflow leakage from storage facilities
- Connection leakage before customer meter

**Number of Service Connections (Ns)**

The number of connections to the mains. In cases where one saddle connection branches to two or more erf connections, the number of erfs (not properties) can be used.

**Real Losses**

Physical water losses from the pressurised system, up to the point of measurement of customer use. Calculated as:

'System Input' – ('Authorised Consumption' + 'Apparent Losses')

The annual volume lost through all types of leaks, bursts and overflows depends on frequencies, flow rates, and average duration of individual leaks.

**System Input**

The volume input to that part of the water supply system to which the water balance calculation relates, allowing for known errors. Equal to:

- 'Own Sources' + 'Water Imported'
- 'Water Exported' + 'Water Supplied'
- 'Authorised Consumption' + 'Water Losses'

**Total Consumption**

Total consumption is the sum of the following three components:

- Billed authorised consumption
- Unbilled authorised consumption
- Apparent losses

**Target Annual Real Loss (TARL)**

The target annual real loss is the level of real losses that a particular water supplier considers to be appropriate for their system. The TARL can be estimated from the UARL using a simple multiplier. For example, a water supplier in South Africa may judge that a realistic target level may be three times the theoretical minimum level, in which case the TARL would simply be set to three times the UARL.

**Total Losses**

Total losses are the sum of the real and apparent losses

**Unavoidable Annual Real Losses (UARL)**

The minimum level of real losses for a specific system that can be achieved under the most efficient operating conditions. It is an indication of the level of leakage that can theoretically be achieved if everything possible is done to minimise the leakage. It iis generally not an achievable target for most water suppliers since the UARL is normally well below the economic level of leakage.

**Unbilled Authorised Consumption**

The volume of authorised consumption that is not billed or paid for.

**Water Losses**

The sum of the real and apparent losses.

# APPENDIX B

## Introduction to BABE and FAVAD Concepts, and Calculation of Unavoidable Annual Real Losses

# APPENDIX B : INTRODUCTION TO BABE AND FAVAD CONCEPTS AND CALCULATION OF UNAVOIDABLE ANNUAL REAL LOSSES

## B1 : HISTORICAL BACKGROUND

As a result of the privatisation of the England & Wales Water Service Companies in 1989, it became necessary for all water suppliers to be able to demonstrate to their regulators that they fully understood their position on leakage. This did not imply that all water suppliers had to achieve the lowest possible leakage levels, but simply that correct and appropriate technical and economic principles were being applied to leakage management.

Accordingly, in 1990 a National Leakage Control Initiative (NLCI) was established in England & Wales by the Water Services Association and the Water Companies Association, to update and review the 'Report 26' guidelines (**NWCSTC, 1980**) for leakage control that had been in use in the UK since 1980. Considerable progress that had been made in equipment and metering technology over the previous ten-year period, but methods of data analysis had not kept pace with these technical improvements.

In order to co-ordinate the various research efforts described in the 'Managing Leakage' Reports (**UK Water Industry, 1994**), Mr Allan Lambert, then Technical Secretary of the NLCI, developed an overview concept of components of real losses, and the parameters which influence them. This concept, based on internationally-applicable principles, is known as the Burst and Background Estimates (BABE) methodology. The BABE concepts were first applied and calibrated in the UK, and three simple pieces of standard software using the BABE concepts were made available at the time of issue, in 1994, of the 'Managing Leakage' Reports.

Prior to 1994, a single relationship between minimum night flow and pressure was normally assumed in the UK, based on the 'Leakage Index' curve in Report 26. The 1994 'Managing Pressure' Report recognised that there was not a single relationship, but dd not offer an alternative method. However, a much improved understanding of the range of relationships between pressure and leakage rate was introduced separately from the 'Managing Leakage' Reports in 1994, when John May published the FAVAD (Fixed and Variable Areas Discharges) concept (**May, 1994**). Using FAVAD, it has been possible to reconcile apparently diverse relationships and data from laboratory tests and distribution sector tests in Japan, UK, Brazil, Saudi Arabia, and Malaysia,

Since 1994, the BABE and FAVAD concepts have been applied in many countries for the solution of a wide range of leakage management problems.

**Fig. B.1** shows the typical range of problems that can be tackled successfully with these concepts. The remainder of this Appendix explains the application of BABE and FAVAD concepts to the development of the International Performance Indicators for Real Losses.

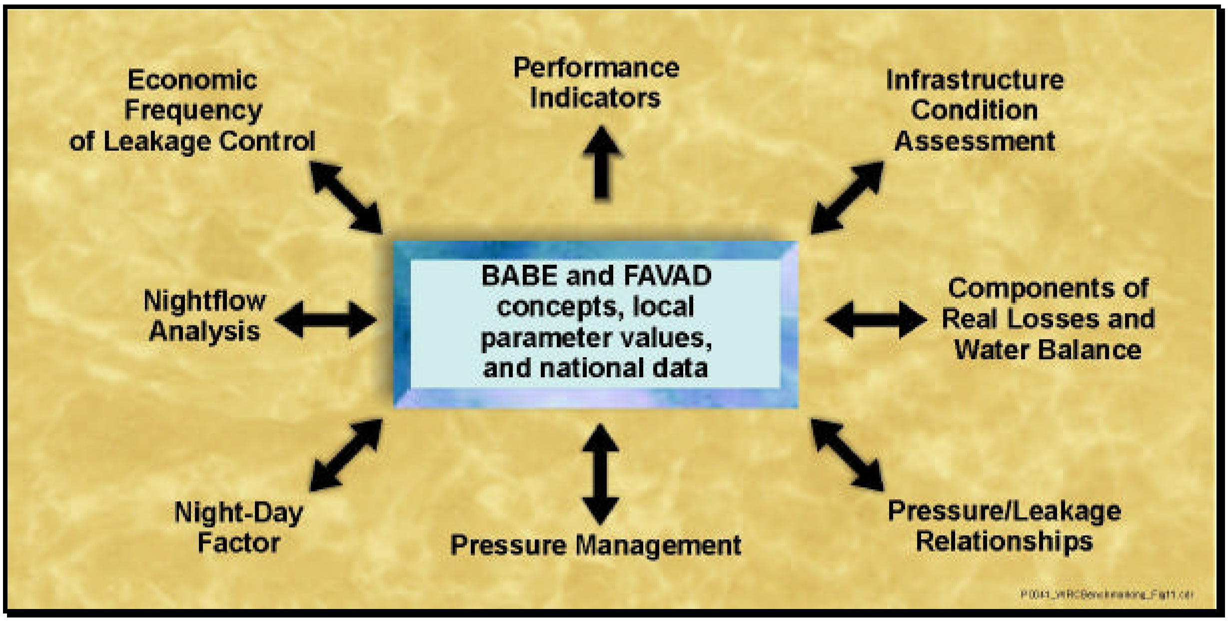



**Figure B.1: Problem-Solving using BABE and FAVAD concepts**

**B2 : BURST AND BACKGROUND ESTIMATE (BABE) procedures**

In order to address leakage, it was considered necessary to first understand the various components making up the water balance for a typical water supply network. The previous approach as shown in **Fig. B.2** was to consider three main components: Authorised Metered, Authorised Unmetered and the remainder which represents all unaccounted-for water, and is often referred to as the real and apparent losses. Further details on real and apparent losses are provided later in this section and are also shown in **Fig. B.4.**

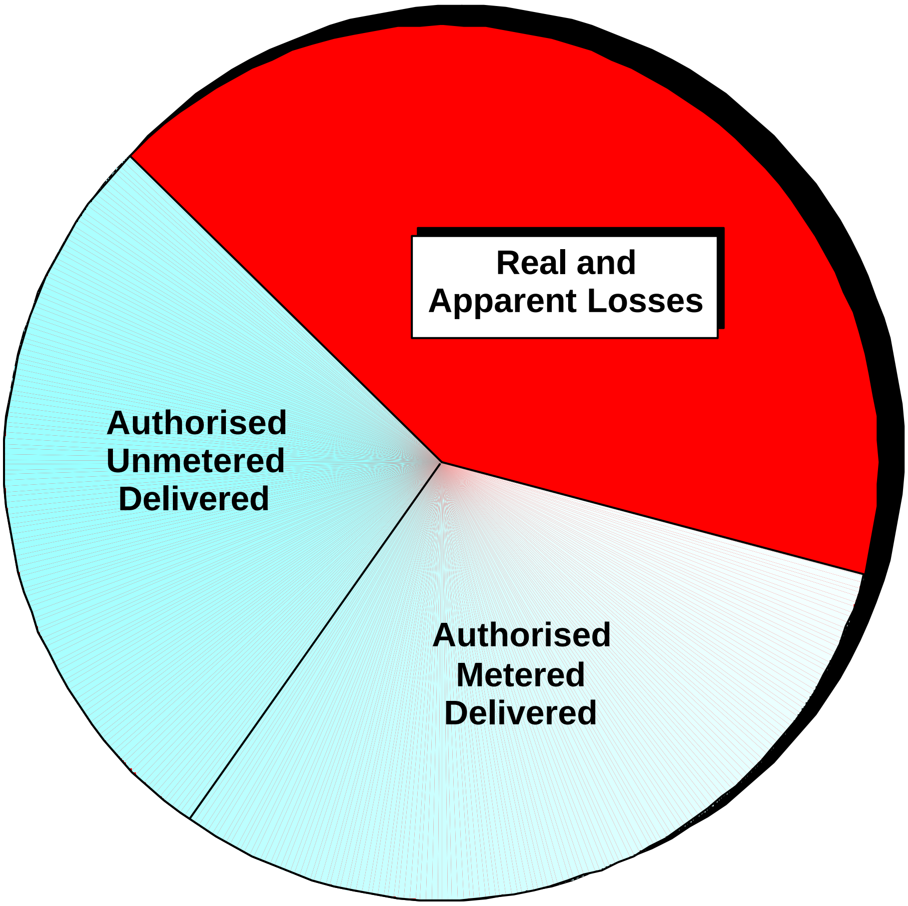



**Figure B.2: Traditional Water Balance.**

In view of the large portion of the traditional water-balance that was usually represented by the real and apparent losses, the whole water balance approach was revised by breaking the balance down into smaller components that could either be measured or estimated. In this manner, it was possible to gain a greater understanding of the different components and also of their significance to the overall water balance. A typical example of the BABE water balance is provided in **Fig. B.3**. It should be noted that the water balance need not be restricted to the components shown in this figure and, conversely, it can be split into a greater number of components or perhaps different components. Every system is different and it is the general approach that should be applied and not a specific and rigid framework.

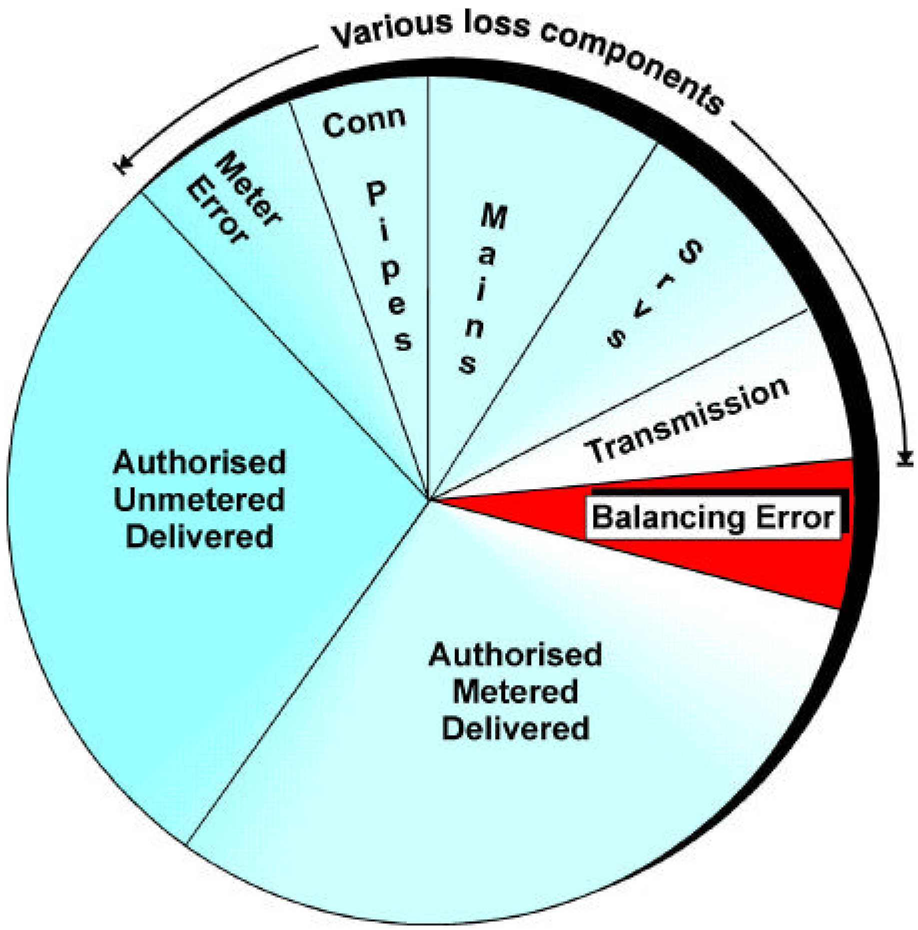
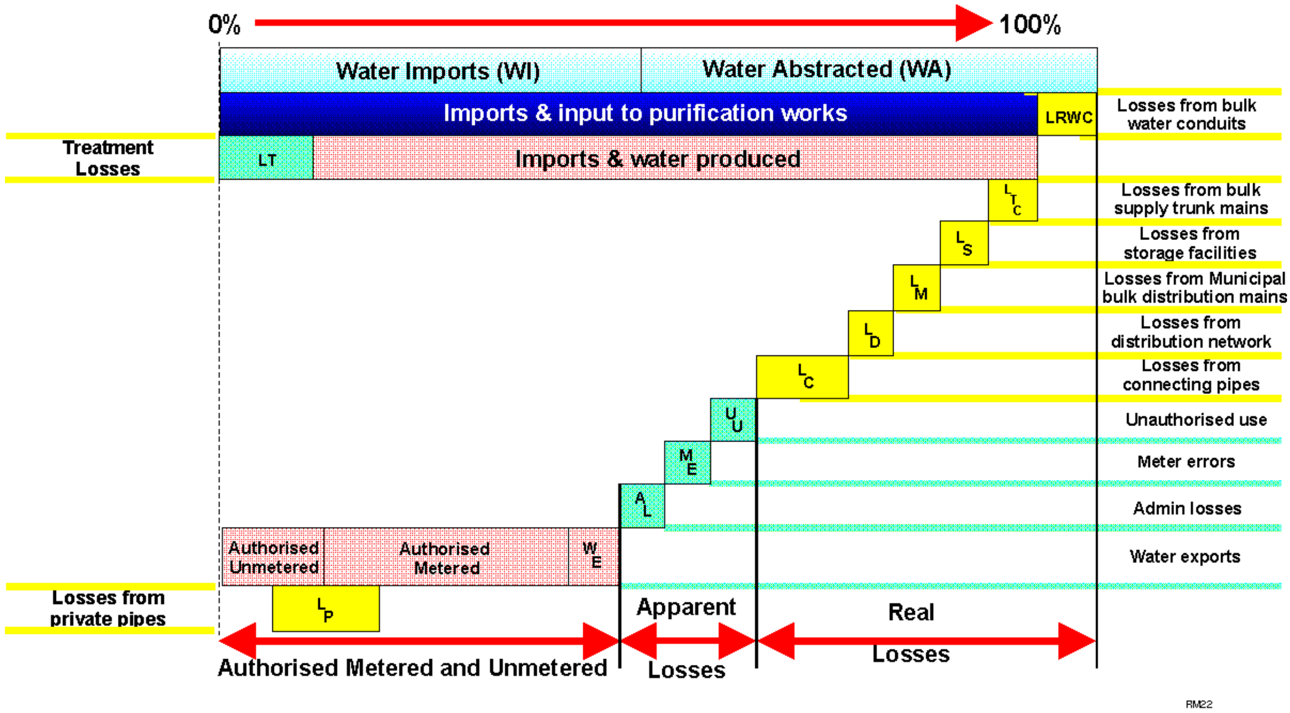



**Figure B.3: BABE Water Balance Approach.**

The BABE water balance approach has now been widely accepted worldwide and is also incorporated in much of the latest South African water legislation. It is not a highly technical or complicated approach; on the contrary, it is extremely simple and logical. The typical components that can be included in any particular water balance were established at the International Water Supply Association Workshop held in Lisbon in May 1997. The water-balance components identified at the workshop are shown in **Fig. B.4**. It should be noted that the components shown in this figure also include the losses associated with the bulk water system as well as the purification system. For municipalities supplying only the water on the distribution side of the bulk supply system, many of the items shown in **Fig. B.4** can be omitted. Similarly, in many of the municipalities in South Africa, the internal plumbing losses dominate the whole water balance, although such losses are represented by only a small block in the figure. In such cases, it may not be necessary to undertake a full and detailed water balance until the plumbing losses are under control.




*(Based on IWSA recommendations: Lisbon Workshop, May '97)*

**Figure B.4: Recommended BABE Water Balance Components.**

**Fig. B.4** provides a breakdown of the most important components that can be included in a water balance for a specific water supplier. It is important to note that the losses have been broken down into real and apparent losses. Real losses are those where the water has left the system and has not been utilised in any way. If such losses can be reduced, the total water required by the supplier will also be reduced. Apparent losses, on the other hand, are simply "paper" losses that do not represent a loss from the system. They are usually due to illegal connections, and meter and billing errors. If such losses are eliminated, the total water required by the supplier may not change. However, the "unaccounted-for" component in the water balance will be reduced. In such, cases certain other components such as "Authorised Metered" or even "Authorised Unmetered" will increase as the apparent losses are reduced.

## B3 : WHAT ARE BURST AND BACKGROUND LEAKS ?

The larger detectable events are referred to as bursts, while those too small to be located (if not visible) are referred to as background leaks. The threshold between bursts and background leaks can vary from country to country, depending on factors such as minimum depth of pipes, type of ground and surface, etc. In the UK a threshold limit of 500 ℓ/h was used in the 1994 Managing Leakage Reports, but advances in technology and other factors suggest that a figure of around 250 ℓ/h would be more appropriate in South Africa. In other words:

| | | | | |
|---|---|---|---|---|
| **Events** | **>** | **250 ℓ/h** | **=** | **Bursts** |

| | | | | |
|---|---|---|---|---|
| **Events** | **<** | **250 ℓ/h** | **=** | **Background Leaks** |

In all water supply systems there are likely to be both bursts and background leaks since it is not possible to develop a system completely free of leakage. However, using the BABE concepts, it is possible to calculate the UARL on a system-specific basis.

## B4 : USE OF FAVAD AND BABE CONCEPTS IN THE DEVELOPMENT OF PERFORMANCE INDICATORS

As discussed in **Section 3.7**, the best of the traditional; basic (IWA Level 1) performance indicator for operational management of real losses is the following:

| |
|---|
| **ℓ/conn/d (when the system is pressurised)** |

This basic operational performance indicator, however, does not take account of three system-specific key factors which can have a strong influence on lowest volume of real losses which can be achieved in any particular system. These are:

- Average operating pressure;
- Location of customer meters on service connections (relative to the street/property boundary);
- Density of service connections (per km of mains).

**The WSAA 'Intermediate' Operational Performance Indicator for Real Losses**, deals with the first of these key factors by assuming a linear relationship between average leakage rate and pressure, i.e. the intermediate performance indicator becomes:

| |
|---|
| **ℓ/conn/d/m of pressure (when the system is pressurised)** |

The justification for this assumption can be explained using the FAVAD concept. In its' simplest form, this assumes that leakage rate (L) varies with Pressure (P) to the power N1, i.e.

**L varies with $P^{N1}$**

International research has shown that different types of leakage paths have different values of N1, which can range from 0.5 to 2.5. Values of N1 derived from tests on small sectors of distribution systems are usually in the range 0.5 to 1.5. When a weighted average of these N1 values is calculated, for application to larger distribution systems, the average N1 value is usually quite close to 1.0 (**see Ogura, 1981 and Lambert, 1997**), i.e a linear relationship can be assumed.

The 'Intermediate' Operational Performance Indicator does not, however, deal with the second and third of the system-specific key factors which can influence the lowest volume of real losses which can be achieved in any particular system, i.e.

- Location of customer meters on service connections (relative to street/property boundary);
- Density of service connections (per km of mains).

**The 'Detailed' operational performance indicators for real losses**, deals with both these factors, and average operating pressure, by calculating a system-specific value for UARL. The ratio of the current annual real losses (CARL, calculated from the standard water-balance) to the UARL, is the ILI, i.e.

**Infrastructure Leakage Index ILI = CARL/UARL**

The equation for UARL is based on BABE concepts, using auditable assumptions. With BABE concepts, it is possible to calculate, from first principles, the components which make up the annual volume of real losses. This is because the leaks occurring in any water supply system can be considered conceptually in three categories:

- Background leakage – small undetectable leaks at joints and fittings
- Reported bursts – events with larger flows which cause problems and are reported to the water supplier

- Unreported bursts – significant events that do not cause problems and can only be found by active leakage control.

## B5 : CALCULATION OF UNAVOIDABLE ANNUAL REAL LOSSES (UARL)

The procedure to estimate the UARL was developed by Lambert during the period of the International Water Association's Task Force on Water Losses. The methodology is described in a paper in AQUA (Lambert et.al., 1999) and involves estimating the unavoidable losses for three components of infrastructure, namely:

- Transmission and distribution mains (excluding service connections)
- Service connections, mains to street/property boundary
- Private underground pipe between street/property boundary and customer meter.

In South Africa, the third of these components can normally be ignored since customer meters are located close to the edge of the street.

The parameters used in the calculation of the losses are indicated in **Table B1**. From this table it can be seen that the one variable which is common to all elements is pressure. This is also the one variable that is normally excluded from most commonly used leakage performance indicators such as percentage, leakage per connection per year and leakage per km of mains per year.

**Table B1: Parameters required for the calculation of UARL**

| Component of infrastructure | Background losses | Reported bursts | Unreported bursts |
|---|---|---|---|
| Mains | • Length<br>• Pressure<br>• Minimum loss rate/km* | • Number/year<br>• Pressure<br>• Average flow rate*<br>• Average duration | • Number/year<br>• Pressure<br>• Average flow rate<br>• Average duration |
| Service connections to street/property line | • Number<br>• Pressure<br>• Minimum loss rate/conn* | • Number/year<br>• Pressure<br>• Average flow rate*<br>• Average duration | • Number/year<br>• Pressure<br>• Average flow rate<br>• Average duration |
| Service connections after street/property line | • Length<br>• Pressure<br>• Minimum loss rate/km* | • Number/year<br>• Pressure<br>• Average flow rate*<br>• Average duration | • Number/year<br>• Pressure<br>• Average flow rate<br>• Average duration |

**** these flow rates are initially specified at 50m pressure***

Each of the elements in **Table B1** can be allocated a value which is appropriate to infrastructure in good condition, operated in accordance with best practice, based on the analysis of data from numerous systems throughout the world. The results are provided in **Table B2**. It should be noted that the general guideline for infrastructure replacement is in the order of 2% per annum. In the South African context, this figure is too high and a more realistic value of between 0.25% and 0.5% is applicable due to the severe financial constraints placed on most of the country's water suppliers.

**Table B2: Parameter values used to calculate UARL**

| Component of Infrastructure | Background losses | Reported bursts | Unreported bursts |
|---|---|---|---|
| Mains | 20*<br>ℓ/km/h | • 0.124 bursts /km/year at<br>• 12 $m^3$/h per burst*<br>• average duration of 3 d | • 0.006 bursts /km/year at<br>• 6 $m^3$/h per burst*<br>• average duration of 50 d |
| Service connections to street/property line | 1.25*<br>ℓ/conn/h | • 2.25/1 000 connections/year at<br>• 1.6 $m^3$/h per burst*<br>• average duration of 8 d | • 0.75/1 000 conn/yr at<br>• 1.6 $m^3$/h per burst*<br>• average duration of 100 d |
| Unmetered Service connections after street/property line | 0.50*<br>ℓ/conn/h<br>per 15m length | • 1.5/1 000 connections/year at<br>• 1.6 $m^3$/h per burst*<br>• average duration of 9 d | • 0.50/1 000 conn/yr at<br>• 1.6 $m^3$/h per burst*<br>• average duration of 101 d |

**** these flow rates are initially specified at 50m pressure***

The parameter values indicated in **Table B2** include data for minimum background loss rates and typical burst frequencies for infrastructure in good condition, and for typical average flow rates of bursts and background leakage at 50 m pressure. The average duration assumed for reported bursts is based on best practice world-wide. The average duration for unreported bursts is based on intensive active leakage control, approximating to night-flow measurements once per month on highly sectorised water distribution systems.

Methods for calculating the average pressure in the system under consideration are explained in **Appendix C**.

Assuming a simplified linear relationship between leakage rate and pressure, the components of UARL can be expressed in modular form for ease of calculation as shown in **Table B3**. Sensitivity testing shows that differences in assumptions for parameters used in the 'Bursts' components have relatively little influence on the 'Total UARL' values in the 5th column of **Table B3**.

**Table B3: Calculated Components of Unavoidable Annual Real Losses (UARL)**

| Component of Infrastructure | Background Losses | Reported Bursts | Unreported Bursts | Total UARL | Units |
|---|---|---|---|---|---|
| Mains | 9.6 | 5.8 | 0.16 | 18 | ℓ/km mains/d per m of pressure |
| Service connections to street/property line | 0.60 | .04 | 0.16 | 0.8 | ℓ/conn/d/ m of pressure |
| Unmetered Service connections after street/property line | 16.0 | 1.9 | 7.1 | 25 | ℓ/km underground. pipe/d/m of pressure |

*NOTE: the UARL from Unmetered Service Connections after the street/property line can be ignored in the South African context, as all customers are metered and these meters are located close to the street/property line. The losses from the service connections (main to meter) tend to dominate the calculation of UARL in most parts of South Africa, except at low density of connections (less than 20 per km of mains).*

Based on the figures provided in **Table B3,** the calculation of the UARL can be expressed as follows:

**UARL = (18 * Lm + 0.80 * Nc + 25 * Lp) * P**

Where:

**UARL** = Unavoidable annual real losses (ℓ/d)
**Lm** Length of mains (km)
**Nc** = Number of service connections (main to meter)
**Lp** = Length of unmetered underground pipe from street edge to customer meters (km)
**P** = Average operating pressure at average zone point (m)

**Example**: A system has 114 km of mains, 3 920 service connections all located at the street property boundary edge and an average operating pressure of 50 m.

**UARL** = (18 * 114 + 0.80 * 3920 + 25 * 0) * 50 ℓ/d
= 102 600 + 156 800 ℓ/d
= 259 400 ℓ/d
= 259.4 $m^3$/d
= 94 681 $m^3$/year
= 66 ℓ/conn/d

# APPENDIX C

## Methods Of Calculating Average Pressure In Distribution Systems

# APPENDIX C: METHODS OF CALCULATING AVERAGE PRESSURE IN DISTRIBUTION SYSTEMS

## C1 : A SYSTEMATIC APPROACH TO CALCULATING AVERAGE PRESSURE

As pressure is a key parameter in modelling and understanding leakage, it is worthwhile to adopt a systematic approach to its calculation. The procedure is as follows:

- For each individual zone or sector, calculate the weighted average ground level;
- Near the centre of the zone, identify a convenient pressure measurement point which has the same weighted average ground level – this is known as the **Average Zone Point (AZP)**;
- Measure the pressure at the AZP, and use this as the surrogate average pressure for the Zone.

AZP pressures should be calculated as average 24-hour values; night pressures at the AZP point are known as AZNP's (Average Zone Night Pressures).

For relatively small sectors with well-sized mains in good condition, with reliable information on average zone inlet pressure at a single inlet point, preliminary estimates of average pressure can be made as follows:

- Measure or estimate the average pressure at the inlet point to the zone or sector, and estimate the average zone pressure, taking into account the difference in datum levels between the inlet point and the AZP point, assuming no frictional loss.

The average pressure for aggregations of zones should be calculated using the weighted average value of pressure based on the number of service connections in each zone.

If network analysis models are not available, the approach used in **Section B2** of this appendix should be followed. If network analysis models are available, the approach suggested in **Section C3** should be followed.

## C2. AVERAGE ZONE PRESSURES WHERE NO NETWORK MODELS EXIST

### C2.1 Calculate Weighted Average Ground Level for Each Sector

The distribution system should be split (conceptually) into sectors defined by pressure management zones or district metered areas. The system should be split into the smallest areas for which average pressures may be required.

For each sector a plan of the distribution system should be superimposed over a contour map, preferably with 2-metre intervals. One of the following infrastructure parameters should be allocated to each contour band. (parameters are in order of preference):

- Number of service connections;
- Number of hydrants;
- Length of mains.

The weighted average ground level can then be calculated based on whichever infrastructure parameter is selected as shown in **Table C1** below**.**

**Table C1: Example calculation of weighted ground level**

| **Contour Band (m)** | | | **Number of service connections** | **Contour Band Mid point * number of connections** |
|---|---|---|---|---|
| Lower Limit | Upper Limit | Mid-Band | | |
| 2.0 | 4.0 | 3.0 | 18 | 54 |
| 4.0 | 6.0 | 5.0 | 43 | 215 |
| 6.0 | 8.0 | 7.0 | 40 | 280 |
| 8.0 | 10.0 | 9.0 | 41 | 369 |
| 10.0 | 12.0 | 11.0 | 63 | 693 |
| 12.0 | 14.0 | 13.0 | 70 | 910 |
| 14.0 | 16.0 | 15.0 | 41 | 615 |
| 16.0 | 18.0 | 17.0 | 18 | 306 |
| 18.0 | 20.0 | 19.0 | 12 | 228 |
| 20.0 | 22.0 | 21.0 | 8 | 168 |
| 22.0 | 24.0 | 23.0 | 3 | 69 |
| 24.0 | 26.0 | 25.0 | 0 | 0 |
| **Totals** | | | **357** | **3 907** |

**Weighted Average Ground Level = 3907 / 357 = 10.9 m**

### C2.2 Measure or Calculate Average Zone Pressure

The average pressure at the AZP can then be derived in the following manner:

- Measurements over a period of one year
- Preliminary estimate based on average Inlet pressure adjusted for difference in ground levels between Inlet Point and AZP.

**Example:** In the sector data in **Table C1**, the average inlet pressure at a service reservoir is 1.5 m below the overflow level (which is 65.0 m above sea level).

- The average inlet pressure is (65.0 – 1.5) = 63.5 m above sea level;
- The ground level at the AZP point is 10.9 m above sea level;
- The AZP pressure is estimated as (63.5 – 10.9) = 43.6 m.

### C2.3 Calculate Weighted Average Pressure for Aggregation of Zones

The weighted average pressure for sectors of a distribution system, consisting of aggregations of individual zones with different average pressures, is obtained by calculating a weighted average for all the zones. If possible, the number of service connections should be used as the weighting parameter (if not available, use length of mains or number of hydrants). An example calculation is shown in **Table C2**.

**Table C2: Example calculation of weighted ground level**

| Area Reference | Number of service connections | Average zone pressure | Number of service connections * AZP |
|---|---|---|---|
| A | 420 | 55.5 | 23 310 |
| B | 527 | 59.1 | 31 146 |
| C | 443 | 69.1 | 30 611 |
| D | 1352 | 73.3 | 99 102 |
| E | 225 | 64.1 | 14 423 |
| F | 837 | 42.0 | 35 154 |
| G | 1109 | 63.7 | 70 643 |
| H | 499 | 56.3 | 28 094 |
| I | 1520 | 57.0 | 86 640 |
| | **6 932** | | **419 122** |

**Weighted average pressure for the whole area = 419 122/6 932 = 60.5 m**

## C3. AVERAGE ZONE PRESSURES USING NETWORK MODELS

### C3.1 Calculate Weighted Average Ground Level for Each Sector

Because each node of a Network Analysis Model will normally have a number of properties, a datum ground level, and an average pressure value, it is relatively easy to calculate the weighted average pressure for all the nodes in the model (or any defined part of it). It is worthwhile, however, to ensure that a weighted average ground level, and an AZP point are defined for each zone/sector, as these will occasionally be required for test measurement.

# APPENDIX D

- **Example of completed ECONOLEAK Form**
- **Listing of Data Request Form**