BENCHMARKING OF LEAKAGE FOR WATER SUPPLIERS IN SOUTH AFRICA

User Guide

For the

BENCHLEAK Model

developed through

SOUTH AFRICAN WATER RESEARCH COMMISSION

by

RS McKenzie, AO Lambert, JE Kock and W Mtshweni

Report TT 159/01

January 2002

Obtainable from:

Water Research Commission

PO Box 824

Pretoria

0001

or

www.wrc.org.za **(manual and software)**

The publication of this report emanates from a project entitled: *Benchmarking of Leakage for Water Suppliers in South Africa (WRC Project No. 1145)*

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Every effort has been taken to ensure that the model and manual are accurate and reliable. Neither the Water Research Commission nor the model developers (R Mckenzie, A Lambert), shall, however, assume any liability of any kind resulting from the use of the program. Any person making use of the BENCHLEAK Model, does so entirely at his/her own risk.

ISBN 1 86845 773 7

Printed in the Republic of South Africa

IMPORTANT

PREFACE

This document is the User Manual for the Water Losses Benchmarking Software (BENCHLEAK), which has been developed for the South African Water Research Commission. The objectives of the Software and the Manual are:

- to introduce a standard terminology for components of the annual water balance calculation
- to encourage South African water suppliers to calculate components of Non-Revenue Water, Apparent Losses and Real Losses using the standard annual water balance
- to promote performance indicators suitable for national and international benchmarking of performance in managing water losses from public water supply transmission and distribution systems

The methodologies used in BENCHLEAK draw strongly on recent 'best practice' recommendations of Task Forces of the International Water Association (IWA)

The BENCHLEAK software is available directly from the Water Research Commission and further details can be obtained from the web site at: ***http://www.wrc.org.za.***

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TECHNICAL SUPPORT

The WRC does not provide technical support on the BENCHLEAK 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.***

ACKNOWLEDGEMENTS

The authors of this report would like to acknowledge the South African Water Research Commission for its support in funding the project and also to the members of the Steering Committee who provided invaluable support and direction during the project. The members of the steering committee are listed below:

Name	***Organisation***	***Email***
Mr JN Bhagwan	*Water Research Commission*	jbhagwan@wrc.org.za
Ms L Boyd	*Department of Water Affairs & Forestry*	tbg@dwaf.pwv.gov.za
Mr C Chapman	*City of Cape Town*	cchapman@cmc.gov.za
Mr P Coetzee	*City of Johannesburg*	pcoetzee@mj.org.za
Mr H Cronjé	*Emalahleni Local Municipal Council*	
Mr I Govender	*Durban Metro Water and Waste*	
Mr D James	*Buffalo City*	desel@iafrica.com
Mr EH Johnson	*Stewart Scott (Pty) Ltd*	edgarj@ssi.co.za
Dr SA Mitchell	*Water Research Commission*	steve@wrc.co.za
Mr JA Müller	*Tshwane Metropolitan Municipality*	muller.andre@pretoria.gov.za
Mr L Naudé	*IMESA*	leonn@erwat.co.za

BENCHLEAK: User Guide

Executive Summary

The BENCHLEAK software and this User Manual are part of the ongoing process of refining and improving the methodologies for calculating and presenting performance data associated with management of public water supply systems in South Africa. Recent recommendations of International Water Association Task Force, which have been developing 'best practice' approaches to this topic, have demonstrated that it is now appropriate to improve on the terminology, calculation process and performance indicators traditionally used for calculating Water Losses in South African public water supply systems.

The Water Research Commission already supports many initiatives that are currently being undertaken in South Africa to improve the levels of leakage in potable water distribution systems. The whole question of how to evaluate such leakage, however, has not been addressed in sufficient detail to allow meaningful comparison of leakage between different systems. The BENCHLEAK model has been developed to facilitate the evaluation of leakage levels and, in particular, non-revenue water, in potable water distribution systems.

A transition from traditional familiar terminology and methods is never easy to accomplish, and a commitment is needed from all water suppliers in South Africa to effect some important changes. For example, the terms 'Non-Revenue Water' and 'Water Losses' should replace the familiar (but often vague) term 'Unaccounted-for-Water' – since, with modern techniques, it is now possible to account for virtually all water entering a water distribution system. The use of percentages to express real losses is now also recognised internationally as being potentially misleading when used as a measure of the efficiency of managing real losses (leakage and overflows) from distribution systems with different levels of consumption.

The process of change can be eased through the use of the BENCHLEAK software since it includes definitions for all the components of the standard Water Balance, and greatly facilitates the annual water balance calculation. It also calculates the 'Unavoidable' real losses for any system, taking into account just 3 key parameters: Length of Mains, Number of Service Connections and Average Operating Pressure, assuming that customer meters are located close to the street/property boundary. The Unavoidable Annual Real Losses are used in the calculation of a new and versatile Performance Indicator – the Infrastructure Leakage Index (ILI) as described by Lambert (1999).

Various Performance Indicators for Non-Revenue Water and Real Losses are calculated automatically by BENCHLEAK. This User Manual explains the background to the development of the International Water Association (IWA) recommended methodologies, and takes the reader through the BENCHLEAK calculations on a step-by-step basis. BENCHLEAK also includes an example calculation alongside the actual calculation to assist users and to clarify the calculations.

It is anticipated that all main Water Supply organisations in South Africa, and their consultants and regulators will eventually use the BENCHLEAK software for calculating and comparing their performance in managing Water Losses in a standard format. All Water Supply organisations should at least undertake an annual calculation on a 'whole system' basis. In this manner, the information supplied to the Water Research Commission by the water suppliers on an annual basis will be captured using the standard IWA terminology and would be directly comparable both within South Africa and also with many other organisations worldwide.

This manual contains full details of the leakage benchmarking procedures as well as a simple User-Guide to the BENCHLEAK Model. It also contains a summary of the results obtained from more than 20 completed benchmarking forms. Although the information requested in the BENCHLEAK Model is relatively simple, it was found that many of the water suppliers in South Africa are currently unable to supply all of the information requested. For this reason, the document containing the results from the various completed forms only provides information on approximately half of the water suppliers who were willing to supply the requested information. It is anticipated that this situation will improve with time especially after the official release of the BENCHLEAK Model and the presentation of various courses throughout the country to assist water suppliers with the completion of the various forms.

BENCHLEAK: USER GUIDE

South African Leakage Benchmarking Model

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1. LAYOUT OF THIS USER MANUAL

The user manual contains 4 sections and 6 appendices, as described below.

Section 2: Introduction

Problems associated with the traditional use of percentages for comparing water losses are explained in **Section 2**. The objectives of the leakage benchmarking project, and design considerations for the software, are described.

Section 3: Outline of the BENCHLEAK Software

This section is essentially the "User Guide", in which each component of the BENCHLEAK software is explained and examples are provided to assist the new user to understand the benchmarking process.

Section 4: Using the BENCHLOSS Software

The Hardware and Software requirements of BENCHLEAK are provided together with details of how the software should be installed and executed.

Section 5: References

This section provides a few useful references for users wishing to gain more in-depth knowledge of the subject of leakage benchmarking. Sufficient information is already provided in the report for most users and the references will only be needed by those who wish to gain a more comprehensive understanding of the subject or the BABE procedures.

Appendix A: Glossary of Terms

Appendix A provides a small glossary of terms to assist new users with the standardised terminology used throughout the user-guide.

Appendix B: Introduction to Leakage Modelling Concepts (BABE and FAVAD)

Appendix B outlines the basic BABE (Bursts and Background Estimates) concepts of components of real losses, and the FAVAD (Fixed and Variable Area Discharges) concept of pressure:leakage relationships. It is then explained how these concepts were used in the development of the equation for calculating Unavoidable Annual Real Losses.

Appendix C: Methods of Calculating Average Pressure

Methods of calculating average pressure for a distribution system, for entering in the calculation for Unavoidable Annual Real Losses, are described.

Appendix D: Printout of the BENCHLEAK Worksheets

The five sheets making up the BENCHLEAK model are listed together with a listing of the data capture sheet which can be used by water suppliers who are unable to run the model but would like their system to be analysed.

Appendix E: Results and Analysis of Local Authorities Data Using BENCHLEAK

As part of the Benchmarking of Leakage project undertaken for the Water Research Commission (WRC), it was decided to carry out a number of case studies to assess the ease-of-use of the BENCHLEAK Model and also to gain a perspective on the level of leakage in South African water reticulation networks. **Appendix E** provides details and the results obtained from more than 20 completed benchmarking forms from various water suppliers across all categories and throughout South Africa.

Appendix F: Results in Graphical Format

Appendix F contains the results from the case studies in graphical format.

2. INTRODUCTION

2.1. THE PROBLEM OF USING PERCENTAGES TO DEFINE LEAKAGE

As awareness grows that South African water resources are finite and require careful management, the water lost from potable water distribution systems is becoming an important issue. Figures for the 'Unaccounted-for Water' are often quoted in the media or in public presentations, usually expressed as a simple percentage of system input volume. Such figures tend to be accepted blindly by both the media and public, who find them easy to grasp and assume they are a meaningful indicator of performance.

Over the last decade, however, it has been recognised that percentages are often unsuitable and can be very misleading when used to assess the operational efficiency of management of real losses (leakage and overflows) in distribution systems (**see SABS, 1999**). This is due to the fact that percentage figures are strongly influenced by the consumption of water in each individual system.

A simple example can be used to highlight this problem. In this example a distribution system with 100 000 service connections experiences real losses of 15 000 m^3/day (150 litres/service connection/day). The % Real Losses can easily be calculated for a range of different unit consumption as shown in **Table 2.1**.

Table 2.1: Problems with using % Real Losses as a Performance Indicator

Consumption per service connection (λ/conn/d)	Real losses (λ/conn/d)	System Input (λ/conn/d)	Real losses as % of system input
250 (e.g. Malta)	150	400	38
500 (e.g. UK)	150	650	23
1000 (e.g. Australia)	150	1150	13
2000 (e.g. Japan)	150	2150	7
3000 (e.g. California)	150	3150	5
8000 (e.g. Singapore)	150	8150	2

From **Table 2.1** it can be seen that although the real losses in litres/connection/day are identical in all cases, the percentage losses vary between 2% and 38%. It is clearly not meaningful to compare the percentage losses of a water distribution system in South Africa with the percentage losses for systems in other countries with different levels of average consumption. This is not only true for comparisons between one country and another but it is also true for comparisons between different systems in the same country. In addition, if demand management activities or seasonal factors influence consumption, the percentage Real Losses will increase or decrease despite the fact that the volume of Real Losses remains unchanged. In many parts of South Africa, these considerations are particularly relevant and it is for this reason that the final worksheet (Detail_2) provides details of the various water balance components expressed in terms of both percentage and litres/connection/day. The spreadsheet automatically undertakes a calculation similar to the one presented in **Table 2.1** for each particular system (after the water balance calculations have been completed) and depicts the information in graphical form to demonstrate these effects.

2.2. MOVING FORWARD

The problem to be overcome is how to express real losses in such terms that the leakage in one system can be meaningfully compared to the leakage in other systems. Following various presentations and international developments during 1999, the South African Water Research Commission commissioned a study to develop a leakage benchmarking system to enable the leakage rates in the many water supply systems throughout South Africa to be defined, calculated and compared in a standard and more meaningful manner. The objectives of the project were therefore:

- to promote the systematic identification and accounting of all components of the Water Balance;
- to promote a standard terminology and methodology for calculating components of Non-Revenue Water in South Africa;
- to identify appropriate Performance Indicators, for comparison and Benchmarking purposes, with the emphasis on Real Losses and Non-Revenue Water;
- to draw on similar initiatives being undertaken elsewhere in the world to ensure that an internationally recognised methodology is adopted;
- to promote the use of the approach through close liaison with the various water suppliers;
- to produce nationally applicable user-friendly software with a high quality User Manual.

The success or failure of the proposed methodology will depend on how diligently water suppliers complete the various forms and obtain the required information. If the information requested is too onerous, the water supplier may refuse to complete the form on the grounds that it is too time-consuming and there are insufficient resources to devote valuable time and effort to form filling. On the other hand, users of the methodology require sufficient detail to be able to gain familiarity with the process and confidence in the calculations. A key objective of the BENCHLEAK software is to ensure that the information requested is relatively simple to provide. At the same time, the results and details provided from the software should be of interest and use to the water suppliers by detailing their water balances in a simple and pragmatic manner.

The potential problems of 'too much detail', or 'not enough detail' have been tackled by developing a colour-coded piece of software – BENCHLEAK: Version 1a – which, with this User Manual, provides all the optional details that are likely to be required. Most of the items in the software are calculated fields with the result that the user need only provide some very basic information that should be readily available from its information system, or can be determined with minimal effort (e.g. average pressure, see **Appendix C**).

The BENCHLEAK software has been designed in such a manner that it can easily be condensed into a single worksheet for all data entry once the water suppliers are accustomed to the data requirements and use of the software.

In order to add value to the South African leakage benchmarking initiatives, it was necessary to ensure that the proposed methodology is fully compatible with the latest current international best practice. For this reason Mr Allan Lambert of International Water Data Comparisons Ltd (IWDC) assisted the project in a key advisory capacity. Mr Lambert is widely recognised as an international expert in leakage management and recently chaired the Water Losses Task Force of the International Water Association (IWA). He was instrumental in the development of the Burst and Background Estimate (BABE) methodology and more recently established a procedure to estimate the minimum level of leakage that can be achieved in any given water supply system. The BENCHLEAK software is based on the most recent work undertaken by Mr Lambert and represents the current "best practice" with regard to the benchmarking of leakage.

It should be noted that while percentage values are not recommended for comparing leakage rates from one system to another, they are still useful for comparing the leakage rates for the same system from one year to another. They can be used for "internal benchmarking", but should not be used for "external benchmarking".

3. DETAILS OF THE BENCHLEAK MODEL

3.1. HOW THE BENCHLEAK MODEL WORKS

The BENCHLEAK Model is simply an Excel spreadsheet comprising three forms that utilise certain basic information supplied by the water supplier. Definitions of the various terms used in the BENCHLEAK Model are provided in **Appendix A**.

The information provided by the Water Supplier is processed in such a way that the leakage can be evaluated and compared between supply systems in a meaningful and realistic manner.

The model contains three parts namely:

- The **Summary** form (1 sheet when printed)
- The **Detail-1** form (3 sheets when printed)
- The **Detail-2** form. (1 sheet when printed)

The Summary Sheet:

The Summary form simply provides a one-page summary of certain key performance indicators and requires no input from the user with the exception of the reference number for the water supply system (optional). It should be noted that most of the cells on the Summary sheet are protected to prevent the user from over-writing any of the cell formulae. In addition, all cells are colour coded to indicate which cells require user input (yellow cells) and which cells are either examples (blue) or calculated fields (green).

The Detail-1 Sheet:

The Detail-1 sheet is the sheet where most of the information required in the model is supplied by the user or water supplier. Only the yellow cells need to be considered since all other cells are calculated by the model or are simply examples supplied to help new users to understand the calculations. It should be noted that the Detail-1 sheet has been split into three sheets for printing purposes.

The Detail-2 Sheet:

Most of the information used in the Detail-2 sheet is taken from the previous sheet and very little additional information is required. The only information required from the user is the Target Loss Factor as explained in **Section 3.10**.

The model carries out several basic functions that can be summarised as follows:

- Estimate the **current annual real leakage (CARL)** occurring from the system based on the water purchases, water sales and the suppliers estimate of apparent losses (see definitions in **Section 3.1**.

- Estimate the **unavoidable annual real losses (UARL)** that will occur from the system based on the methodology developed by A Lambert (**1999**) together with the required system data (i.e., length of mains, number of connections etc).

- Estimate an appropriate **target annual real leakage (TARL)** for the system based on the theoretical minimum level factored up by a suitable multiplier. For example, it may be considered to be appropriate to set the acceptable leakage at three times the theoretical minimum level of leakage in a particular region, in which case a multiplier of three would be used.

- Estimate the **potential for savings in leakage (PSL)** based on the difference between the actual real leakage and the acceptable leakage. This provides a realistic estimate of the potential savings in leakage that can be achieved in a particular system based on a simple yet pragmatic approach.

The analysis procedure is depicted in **Fig. 3.1**.

3.2. ESTIMATION OF UNAVOIDABLE ANNUAL REAL LOSSES (UARL)

The procedure to estimate the unavoidable annual real losses (UARL) was developed by Lambert as part of the International Water Association's Task Force on Water losses. The methodology is fully described in the paper by Lambert (1999) and basically involves estimating the unavoidable leakage for three components; namely, mains, connections at street edge and service connections after street edge. In South Africa the third term of service connections after street edge can normally be ignored since the losses associated with this component are usually insignificant.

Full details of the procedure developed by Lambert are provided in **Appendix B** in **Section B5**.

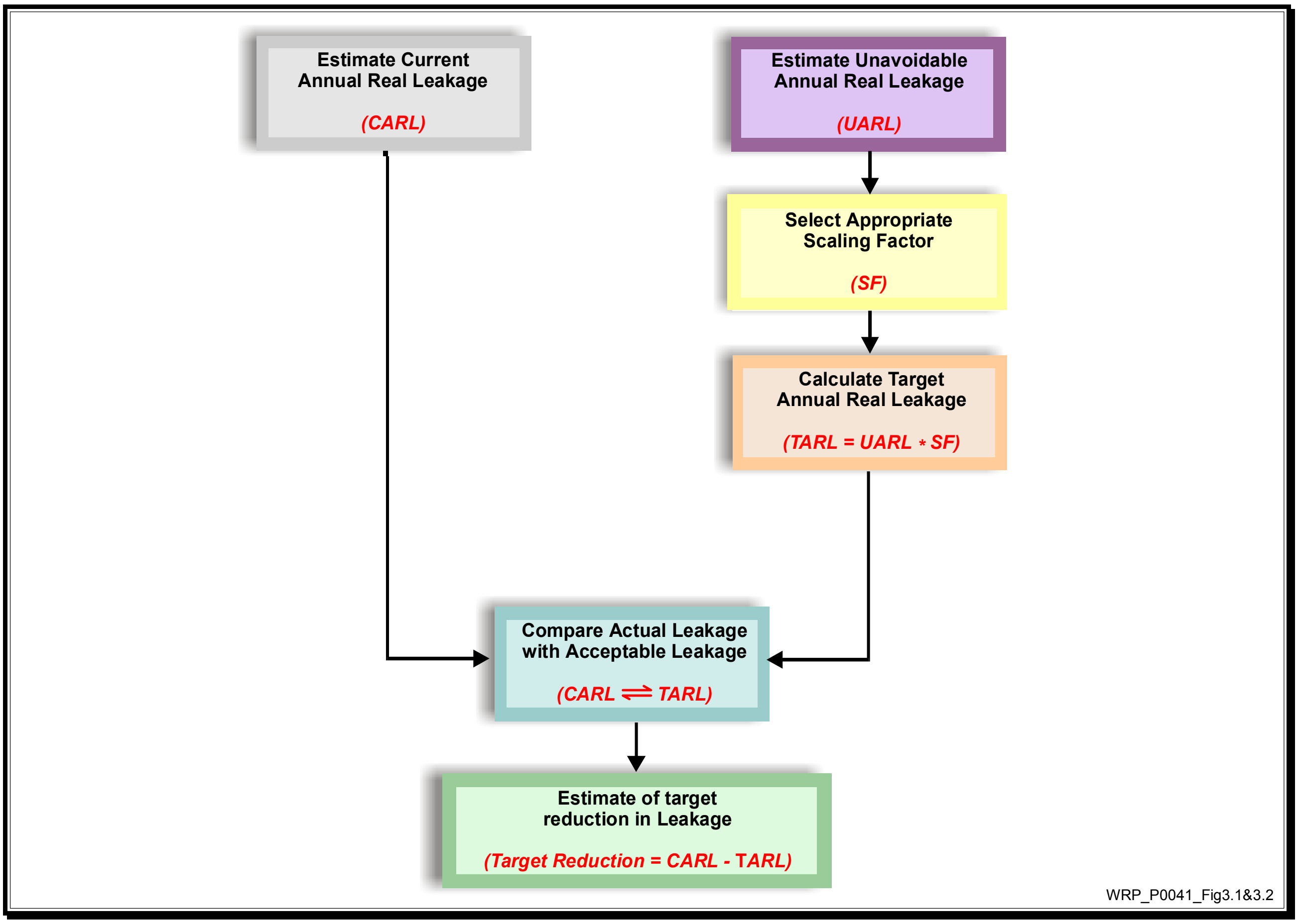

Figure 3.1: Procedure for using BENCHLOSS

The UARL calculation is undertaken in **Section D3** of the BENCHLEAK Model and no user input is required. Details of the calculation are shown in **Figure 3.2**.

D3. UNAVOIDABLE ANNUAL REAL LOSSES (UARL)

Details	Calculation	Example Result	Actual Data	Units
On mains	18 x Lm x P x 365 x T/10^8	443	84	10^3 m^3/yr
On Service Connections	0.8 x Ns x P x 365 x T/10^8	788	415	10^3 m^3/yr
Total Volume of UARL		**1232**	**499**	10^3 m^3/yr
UARL in litres/service conn./day when the system is pressurised	Annual Volume of UARL x 10^6 / (Ns x 365 x T/100)	**56**	**38**	Litres/ conn./day

Figure 3.2: Details of the UARL calculation in the BENCHLEAK Model

3.3. SYSTEM INPUT VOLUME

The System Input comprises the water supplied from the supplier's own sources as well as water purchased from other sources. A correction is allowed for the source bulk meters as well as any input from unmetered sources which would usually be relatively small. The details are entered into **Section D4b** of the BENCHLEAK Model as shown in **Fig. 3.3.**

D4b. System Input Volume

Water Supplied	Example Data					Actual Data				
	Metered 10^3 m^3/yr	Correction to Source Meter data		Unmetered 10^3 m^3/yr	Total 10^3 m^3/yr	Metered 10^3 m^3/yr	Correction to Source Meter data		Unmetered 10^3 m^3/yr	Total 10^3 m^3/yr
		+/- %	10^3 m^3/yr				+/- %	10^3 m^3/yr		
From Own Sources:	36000	2.00%	720		36720	26426				26426
From Other Suppliers:	1000			280	1280					
Total:	37000		720	280	38000	26426				26426

Figure 3.3: Components of System Input Volume in BENCHLEAK

3.4. AUTHORISED CONSUMPTION

Details of the components of Authorised Consumption included in the BENCHLEAK Model are shown in **Fig. 3.4.**

D4c. Components of Authorised Consumption

Components of Authorised Consumption	Example Data					Actual Data				
	Billed Metered 10^3 m^3/yr	Billed Unmetered 10^3 m^3/yr	Unbilled Metered 10^3 m^3/yr	Unbilled Unmetered 10^3 m^3/yr	Total 10^3 m^3/yr	Billed Metered 10^3 m^3/yr	Billed Unmetered 10^3 m^3/yr	Unbilled Metered 10^3 m^3/yr	Unbilled Unmetered 10^3 m^3/yr	Total 10^3 m^3/yr
Water Exported:	1500				1500	1951				1951
Households:	24500	500			25000	10151	574			10725
Non-households:	6900	100			7000	6180				6180
Standpipes:		500	10		510					
Firefighting:				100	100					
Mains Flushing:				100	100					
Building water:	1040				1040					
Other (specify): Departmental						184				184
Other (specify):										
TOTALS:	33940	1100	10	200	35250	18466	574			19040

Figure 3.4: Components of Authorised Consumption included in BENCHLEAK

From **Fig. 3.4** it can be seen that the total authorised consumption has been split into several components including exports, households, non-households, standpipes, fire-fighting, mains flushing, building water and the option for adding another two user-defined categories. In most instances the categories included will be sufficient to allow the supplier to provide a reasonable breakdown of the water use in the area of supply and some of the items listed may be excluded or estimated since they may not be recorded directly. The various headings (billed metered, billed unmetered etc) are self-explanatory and no further details are necessary.

3.5. ESTIMATION OF WATER LOSSES

There are basically three elements of water losses considered in the BENCHLEAK Model namely:

- Total Losses;
- Apparent Losses; and
- Real Losses.

The **Total Losses** are estimated as the difference in the System Input and the Authorised Consumption as discussed in the previous sections.

Apparent losses are generally considered to be losses associated with:

- Meter error;
- Unauthorised use;
- Administration errors.

The BENCHLEAK Model allows the water supplier to provide an estimate of losses associated with bulk meter error as mentioned in **Section 3.4,** but this does not include the losses associated with the consumer accounts which are based on the consumer meters. The individual components of the Apparent Losses are not listed separately in the model since few, if any, of the water suppliers will be in a position to supply reliable information in this regard. Instead, the Apparent Losses are simply considered to be a percentage of the Total Losses mentioned above. A value to the order of 20% is normally considered appropriate, although it can vary from system to system. The Apparent Losses represent the water that escapes the revenue system and any reduction in Apparent Losses will result in a greater income to the water supplier at the effective selling price of the water. In some South African situations the Apparent Losses can be very high and can even exceed the physical losses, especially in cases where levels of payment are low and the payment is based on a flat tariff rather than measured consumption.

The **Real Losses** are then calculated directly as the difference between the Total Losses and the estimated Apparent Losses. The Real Losses represent the physical water lost from the system and any reduction in Real Losses will result in lower purchases of water by the water supplier. The reductions must be applied to the purchase price (or production cost) of the water and not the selling price.

Details of the loss calculations are provided in **Section D4d** of the BENCHLEAK Model and are also shown in **Fig. 3.5**.

D4d. Components of Water Losses

Details	Example Result	Actual Result	Units
Water Losses = System Input – Authorised Consumption	2750	7386	10^3 m^3/yr
Percentage of Total Losses estimated to represent the Apparent Losses	20	20	%
Apparent Losses	550	1477	10^3 m^3/yr
Annual Real Losses (ARL) = Water Losses – Apparent Losses	**2200**	**5909**	10^3 m^3/yr

Figure 3.5: Components of water losses included in BENCHLEAK

3.6. OPERATIONAL PERFORMANCE INDICATORS

Various performance indicators can be used to measure the operational performance of a particular system. For the purpose of the BENCHLEAK Model it was decided that the main performance indicator would be the Real Losses expressed in terms of λ/conn/d which can then be compared to the total consumption in the same units. This calculation is undertaken in **Section D5a** of the model and is shown in **Fig. 3.6**. No user input is required for the calculation.

D5a. Current Annual Real Losses per Connection (CARL) at Current Pressures

Details	Calculation	Example Result	Actual Result	Units
CARL is expressed in Litres/service connection/day, when system is pressurised	ARL x 10^6 / (Ns x T/100 x 365)	**100**	**456**	Litres /conn./day
Consumption in litres/conn/day		**1610**	**1468**	Litres /conn./day

Figure 3.6: Operational performance indicators included in BENCHLEAK

3.7. ESTIMATION OF THE INFRASTRUCTURE LEAKAGE INDEX (ILI)

As mentioned previously, 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. Details of the ILI calculation are given in **Section D5b** of the BENCHLEAK Model as shown in **Fig. 3.6**. No user input is required for the calculation.

D5b. Infrastructure Leakage Index (ILI)			
Details	**Calculation**	**Example Result**	**Actual Result**
ILI is the ratio of Current Annual Real Losses (CARL) to Unavoidable Annual Real Losses	CARL / UARL	1.79	11.84

Figure 3.6: Calculation of the ILI value in BENCHLEAK

The non-revenue water is then expressed in terms of the percentage of the system input. The non-revenue water includes the Total Losses (ie Real and Apparent) plus the unbilled consumption which also represents a loss of revenue to the supplier. It has been stated that percentages are not favoured for expressing leakage from a system since they can be misleading and cannot be used to compare leakage from different systems. Despite these shortcomings with the use of percentages, it is often useful to revert to percentages for comparing certain losses in a system with the same losses in the same system in subsequent years. In this manner the percentages can still be used as a performance indicator. Details of the performance indicators for the non-revenue water are provided in **Section D5c** of the BENCHLEAK Model as shown in **Fig. 3.7**. No user input is required for the calculation.

D5c. Non-Revenue Water as a % by Volume of System Input						
Description of Unbilled Items	**Example Result**			**Actual Result**		
	Volume 10^3 m^3/yr	**System Input** 10^3 m^3/yr	**% of System Input**	**Volume** 10^3 m^3/yr	**System Input** 10^3 m^3/yr	**% of System Input**
Unbilled Consumption	210	38000	0.55		26426	
Apparent Losses:	550	38000	1.45	1477	26426	5.59
Real Losses:	2200	38000	5.79	5909	26426	22.36
Total Unbilled:	**2960**	**38000**	**7.79**	**7386**	**26426**	**27.95**

Figure 3.7: Non-revenue water performance indicators in BENCHLEAK

3.8. FINANCIAL PERFORMANCE INDICATORS

It is often useful to express the leakage from a system in some form of monetary values or to express the losses as a percentage of the operating costs of the system. Various financial performance indicators are calculated in **Section D6** of the BENCHLEAK Model.

The various losses are expressed in financial terms and it is first necessary to provide information on the unit cost of water (purchases and sales) as well as the annual cost of running the system. These details are entered into **Section D6** of the BENCHLEAK Model as shown in **Fig. 3.8**.

It should be noted that the purchase and selling price of the water is given in R/m^3 while the annual running cost for the system is given in thousands of Rand. It should also be noted that the selling price is the average selling price and does not permit details of block-tariffs to be included in the analysis since most water suppliers have difficulty in providing the breakdown of the water sales into the different tariff blocks.

D6. SELECTED FINANCIAL PERFORMANCE INDICATORS

D6a. Local Valuation of Real and Apparent Losses

Details	Example Result	Actual Result	Units
Unit Value of Real Losses (eg bulk purchase price)	0.15	1.05	R/m^3
Unit Value of Apparent Losses (eg selling price)	2.70	1.47	R/m^3

D6b. Annual Cost of Running System

Details	Example Cost	Actual Cost	Units
Annual Cost of running system in 1000's of Rand per year	45000	28099	10^3 R/year

Figure 3.8: Details of water costs and system running costs in ECONOLEAK

Having supplied the buying and selling costs of the water, it is possible to calculate a few simple financial performance indicators. The financial performance indicators are provided in **Section D6c** of the ECONOLEAK Model and are shown in **Fig. 3.9**.

From the sample values shown in **Figs. 3.9 and 3.7,** it can be seen that the performance indicators are significantly different when expressed in terms of percentage of system input and percentage of system running costs. Both measures are useful under certain circumstances.

D6c. Non-Revenue Water as % by Value of Cost of Running System								
Description of Unbilled Items	Example Result				Actual Result			
	Volume	Unit Value	Value	% of Annual Running Costs	Volume	Unit Value	Value	% of Annual Running Costs
	10^3 m^3/yr	R /m^3	10^3 R/year	Costs	10^3 m^3/yr	(R /m^3)	10^3 R/year	Costs
Unbilled Consumption	210	2.70	567	1.26		1.47		
Apparent Losses:	550	2.70	1485	3.30	1477	1.47	2171	7.73
Real Losses:	2200	0.15	330	0.73	5909	1.05	6204	22.08
Total Unbilled:	2960		**2382.00**	**5.29**	7386		8376	**29.81**

Figure 3.9: Details of the financial performance indicators given in ECONOLEAK

3.9. POTENTIAL FOR SAVINGS IN REAL LOSSES

So far, the emphasis of the BENCHLEAK Model has been to express the leakage from a system in some manner that it can be compared directly to other systems. This led to the ILI as discussed in **Section 3.3**. Knowing the ILI will help a supplier gauge whether or not the leakage from the system is good, bad or average. What it does not provide, however, is an estimate of the potential savings that can be achieved in the system. Estimating the potential savings is a very difficult and often subjective exercise. It is not possible to gauge the potential savings in the Apparent Losses since such losses depend upon so many external factors that are not captured in the relatively simple BENCHLEAK Model. How much of the Apparent Losses can be converted into income-generating sales will vary from supplier to supplier and will depend to a large degree upon the available budget for such measures. The question of Real Losses, however, can be considered using the information available in the BENCHLEAK Model and in this regard a relatively simple approach has been suggested. The approach involves the following steps:

- Calculate the CARL as a percentage of the system input
- Calculate the UARL in the manner discussed in **Section 3.4**.
- Develop the TARL by selecting an appropriate multiplier or Target Loss Factor (TLF) which is used to scale up the UARL.
- The potential savings are then calculated as the difference between the Real Losses and the Target Losses.

The above approach is a very simple and easy to use procedure for estimating the potential for reduction in the Real Losses from a system. It is obviously subjective to some extent since an “appropriate” factor must be supplied. It is envisaged that in future, a water regulator will select appropriate factors for the different supply areas based on the financial position of the supplier and the type of customer being supplied. In a very poor area, for example where the supplier experiences high levels of non-payment, a factor of

4 or 5 may be selected until such time as the non-payment is under control. In other areas where the water supplier has a reliable income base, a lower factor of 2 or 3 may be appropriate. This approach has yet to be ratified and is simply one possible way of deriving the potential reduction in Real Losses from an area. The calculation is provided in **Section D7c** of the BENCHLEAK Model and the only input required from the user is to set the Target Loss Factor. Details of the calculation are shown in **Fig. 3.10**.

D7d. Potential Real Losses as % of System Input Volume			
Details	**Calculation**	**Actual Result**	**Units**
Unavoidable Annual Real Losses (UARL)	from D3	38	Litres/conn/day
Target Loss Factor (TLF)	User defined for each system	2	Dimensionless
Target Annual Real Losses (TARL)	TLF x UARL	77	Litres/conn/day
Current Annual Real Losses (CARL)	CARL from D5a	456	Litres/conn/day
Potential savings	CARL - TARL	379	Litres/conn/day
Potential ARL as % of System Input	TARL / (System input volume-Potential savings) x 100	5	%

Figure 3.10: Estimation of potential savings in Real Leakage in BENCHLEAK

From **Fig. 3.10**, it can also be seen that the potential level of Real Losses is provided as a percentage of the system input. Again, this is not considered good practice. However, it can be used to compare results from the same system in subsequent years in which case it is permitted to use percentages.

It should be noted that the factor used in **Section D7d** of the BENCHLEAK Model is a 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. For example, it is not appropriate to set the same Target Loss Factor for an affluent area with low leakage as would be selected for an informal area with high leakage. Until further investigations using BENCHLEAK have been completed, it is recommended that TLF of between 2 and 5 be selected. A factor of 2 will be used for an area with relatively low leakage and sound infrastructure while a factor of 5 will be used for areas with 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 will gradually be reduced.

3.10. PRESENTATION OF RESULTS

Although the spreadsheet is self-explanatory and requires little added information, it was decided to add some figures as part of the BENCHLEAK Model to assist suppliers in understanding the different loss components and the potential for saving. In this regard, two additional figures are provided in **Sections 7b and 7e** of the BENCHLEAK Model.

The first figure simply presents details of the different components of the water balance (see **Section 3.1**) in terms of litres/service connection per day. These units are often used when checking on the validity of the data and the values obtained can often highlight problem areas. A typical example is shown in **Fig. 3.11** and it should be noted that the size of the compartment for each element in the water balance is not to scale.

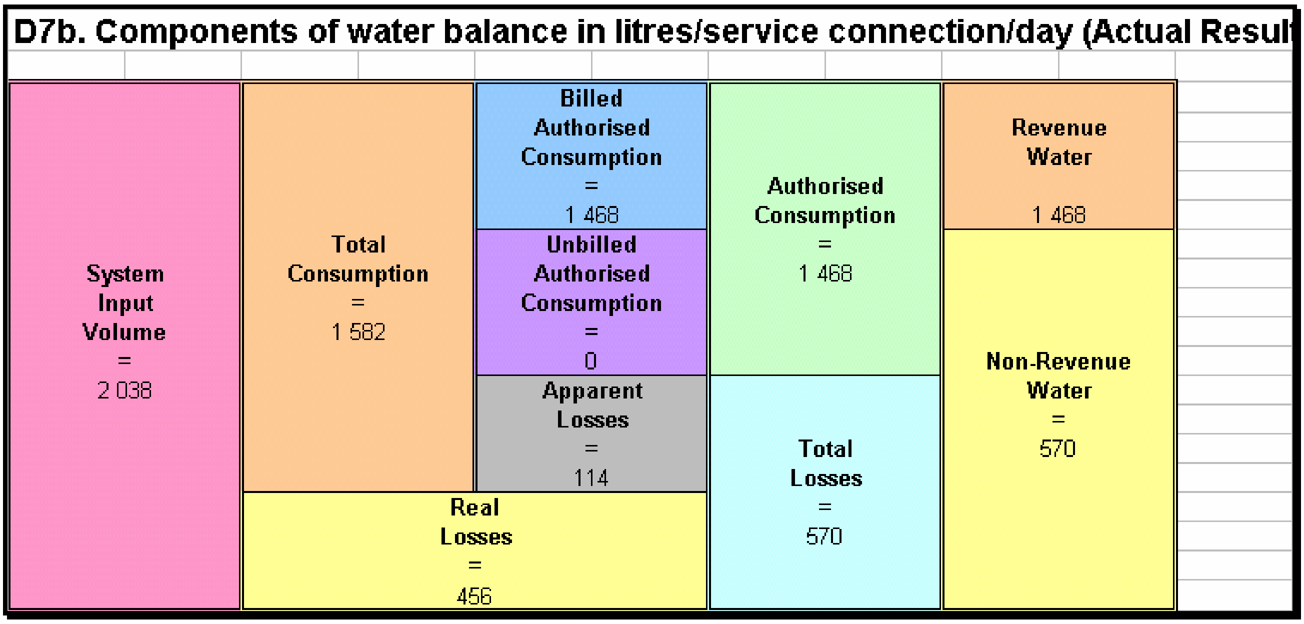

Figure 3.11: Figure showing the overall water balance in BENCHLEAK

The second figure provided in the BENCHLEAK Model is more complicated and helps to portray a very important concept that is often overlooked. As mentioned in **Section 3.1**, the percentage leakage from a system is heavily influenced by the consumption. In many countries, the leakage is expressed in terms of λ/conn/d and so too is the consumption. Based on this, a set of curves can be prepared which indicate the percentage leakage for different consumption and real leakage, the latter two of which are expressed in Litres/service connection per day. This is best explained using the figure provided in the BENCHLEAK Model. A typical example is shown in **Fig. 3.12**.

If a system has an average Total Consumption of 4 000 λ/conn/d and the Real Leakage is 1 000 λ/conn/d, it can be seen from **Fig. 3.12** that the Real Losses are 20%. If, however, the Total Consumption is only 1 000 λ/conn/d, then the percentage losses rise to 50% despite the fact that the real losses have not changed.

This figure can be used to explain why many water services providers will struggle to bring their leakage levels below 20% or even 30% when their Total Consumption is in the order of 500 λ/conn/d (as is the case in the UK). In countries such as Singapore, however, where the Total consumption is more than 8 000 λ/conn/d due to the high number of apartment blocks with a single connection, the percentage losses can easily drop to 5% or below.

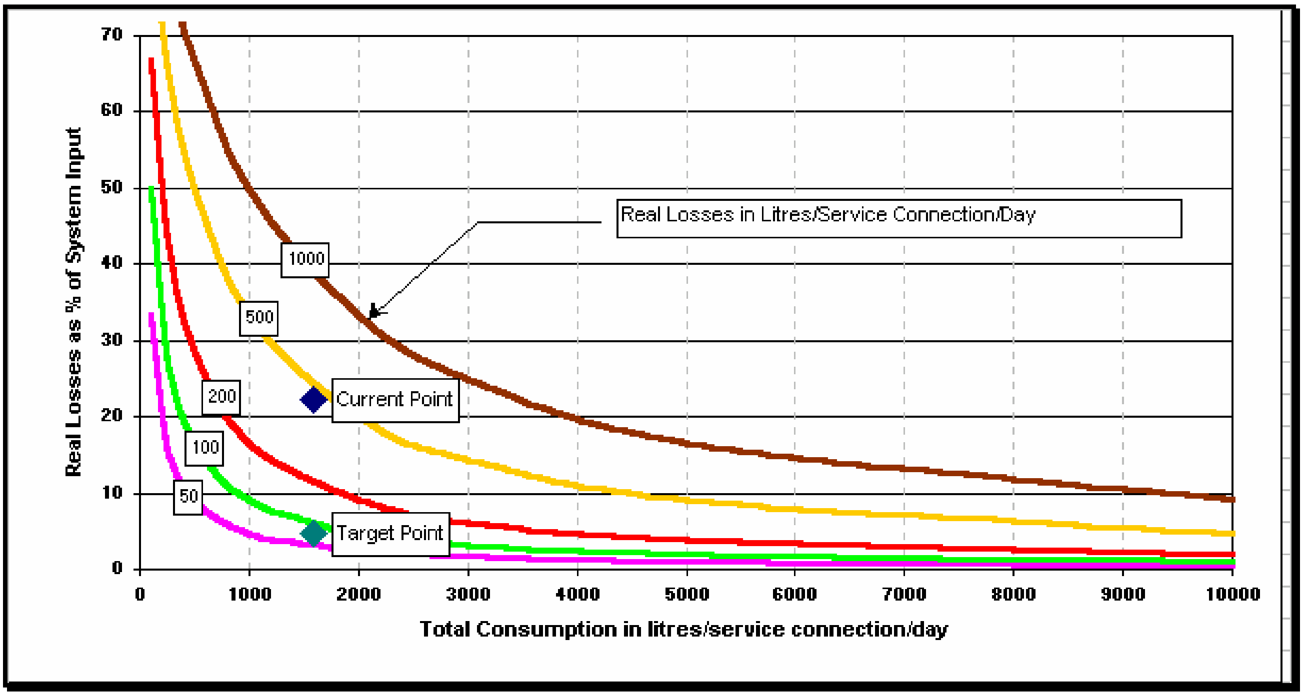

Figure 3.12: Curves demonstrating the importance of consumption on % real losses

Suppliers in South Africa tend to operate between Total Consumption of 1 000 to 2 000 λ/conn/d. If an acceptable level of leakage is considered to be 200 λ/conn/d, the percentage leakage will lie somewhere between 10% and 20%.

On **Fig. 3.12** it can also be seen that the actual Real Losses and the Target Real Losses are depicted on the chart. The Total Consumption in this example was found to be 1 582 λ/conn/d with the result that the two points are fixed on the horizontal at 1 582. In the example it can be seen that the Real Losses are 23% of the System Input while the target setting is below 10%. In this example, the potential reduction in leakage is estimated to be 379 λ/conn/d (i.e. more than 18% of system input). The target leakage level is estimated to be 5% compared to the current leakage level of 23% as can be seen from **Figs. 3.10 and 3.11**.

4. USING BENCHLEAK

4.1. HARDWARE AND SOFTWARE REQUIREMENTS

In order to run the BENCHLEAK Model the user requires a basic PC with the Windows operating system and the EXCEL spreadsheet program. If the EXCEL program is not available, the user can still complete a hard copy of the spreadsheet forms, although the numerous calculated fields will have to be completed manually when they are normally calculated automatically by the Excel program. Some users have successfully copied the spreadsheet onto QUATRO without experiencing any major problems.

4.2. INSTALLING BENCHLEAK

The BENCHLEAK Model can be downloaded directly from the WRC web site. It is a relatively small file at approximately 130K and can be run from anywhere on the user's PC as long as the Excel program can be accessed. There is no sophisticated installation shield and it is simply the case of copying the **BENCHLEAK.XLS** file into a suitable directory and using the model in the same manner as a normal Excel spreadsheet.

4.3. DATA REQUIREMENTS

The BENCHLEAK Model is colour-coded in such a manner that:

- Yellow blocks must be completed by the user
- Blue blocks simply provide an example data set;
- Green blocks are calculated fields and require no user input.

The user must complete only the yellow blocks which involves the following information:

- System name and contact details (**Section D1**)
- System data: length of mains, number of connections, percentage of time system is pressurised and the average operating pressure of the system;
- Period over which the information refers i.e. calendar year, financial year
- Details of water input to the system (i.e. water purchased from bulk supplier and water produced from own sources etc);
- Details of water supplied to customers including estimates of all unmetered and unbilled water;
- Estimate of Apparent Losses as a percentage of the total losses.

To facilitate the capture of data from water suppliers, a data request form has been created that includes only the basic information required. This form is included at the end of **Appendix D**.

5. REFERENCES

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- UK WATER INDUSTRY, 1994**.** The ‘Managing Leakage’ Series of Reports

  Report A: **Summary Report**. ISBN: 1 898920 06 0

  Report B: **Reporting Comparative Leakage Performance**. ISBN: 1 898920 07 9

  Report C: **Setting Economic Leakage Targets**. ISBN: 1 898920 08 7

  Report D: **Estimating Unmeasured Water Delivered**. ISBN: 1 898920 09 5

  Report E: **Interpreting Measured Night Flows**. ISBN: 1 898920 10 9

  Report F: **Using Night Flow Data**. ISBN: 1 898920 11 7

  Report G: **Managing Water Pressure**. ISBN: 1 898920 12 5

  Report H: **Dealing with Customers’ Leakage**. ISBN: 1 898920 13 3

  Report J: **Leakage Management Techniques, Technology & Training**.
  ISBN: 1 898920 14 1

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**.

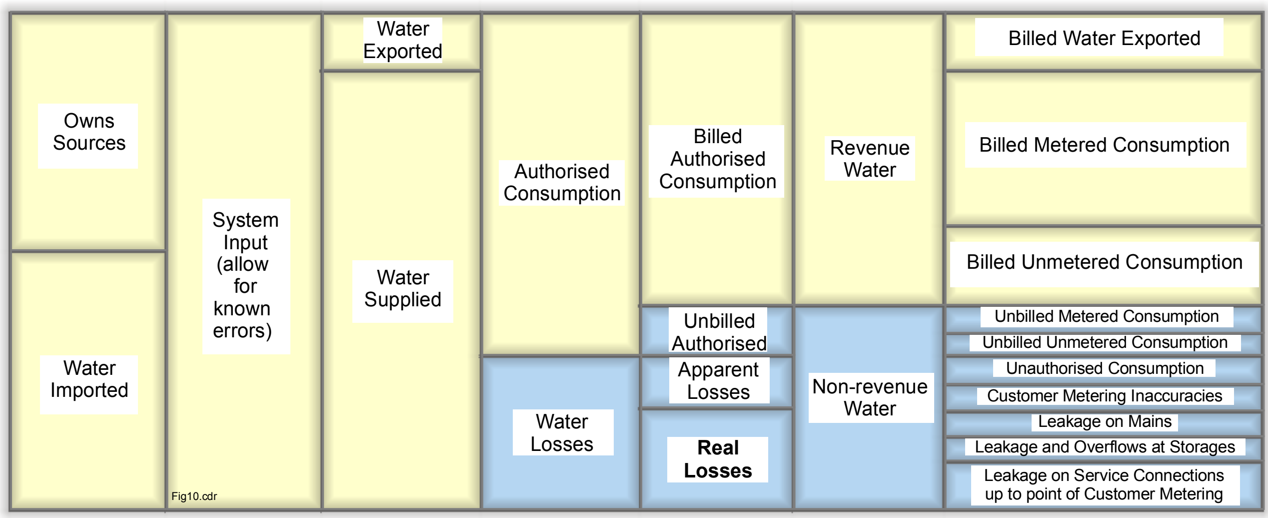


Figure A.1: Main components of the water supply water balance

Descriptions of the components shown in **Fig. A.1** as well as for various other terms used in the BENCHLEAK 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 λ/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 and is 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 did 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 his 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 successfully tackled 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.

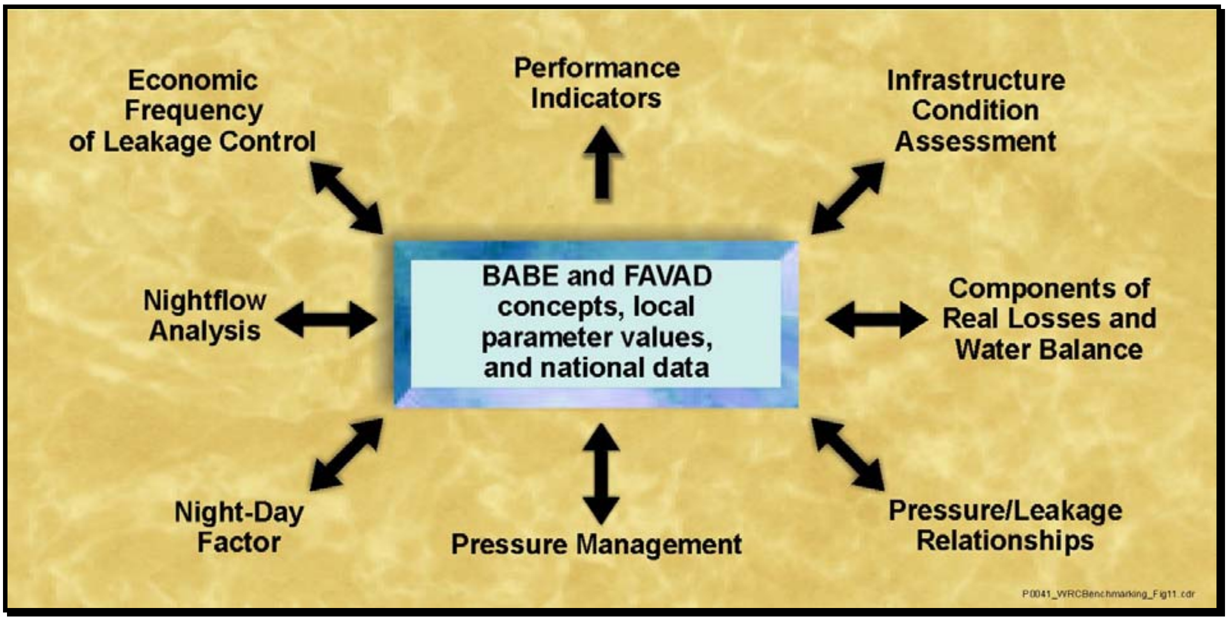


Figure B.1: Problem-Solving using BABE and FAVAD concepts

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.**

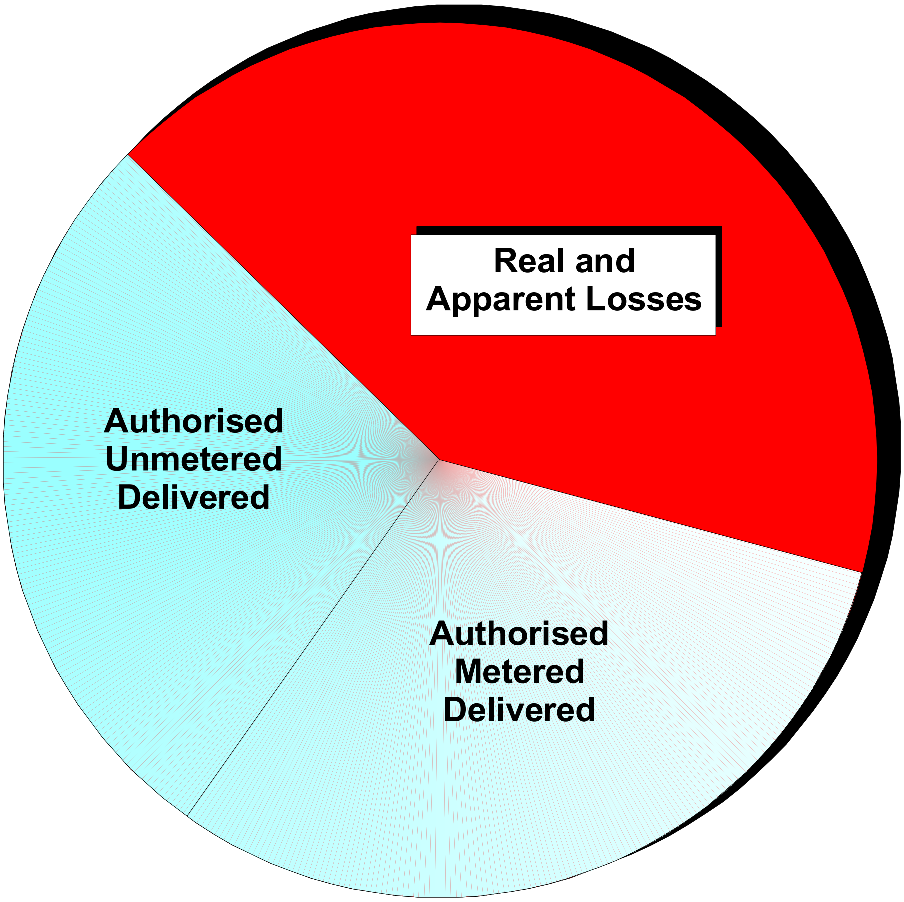


Figure B.2: Traditional Water Balance.

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.

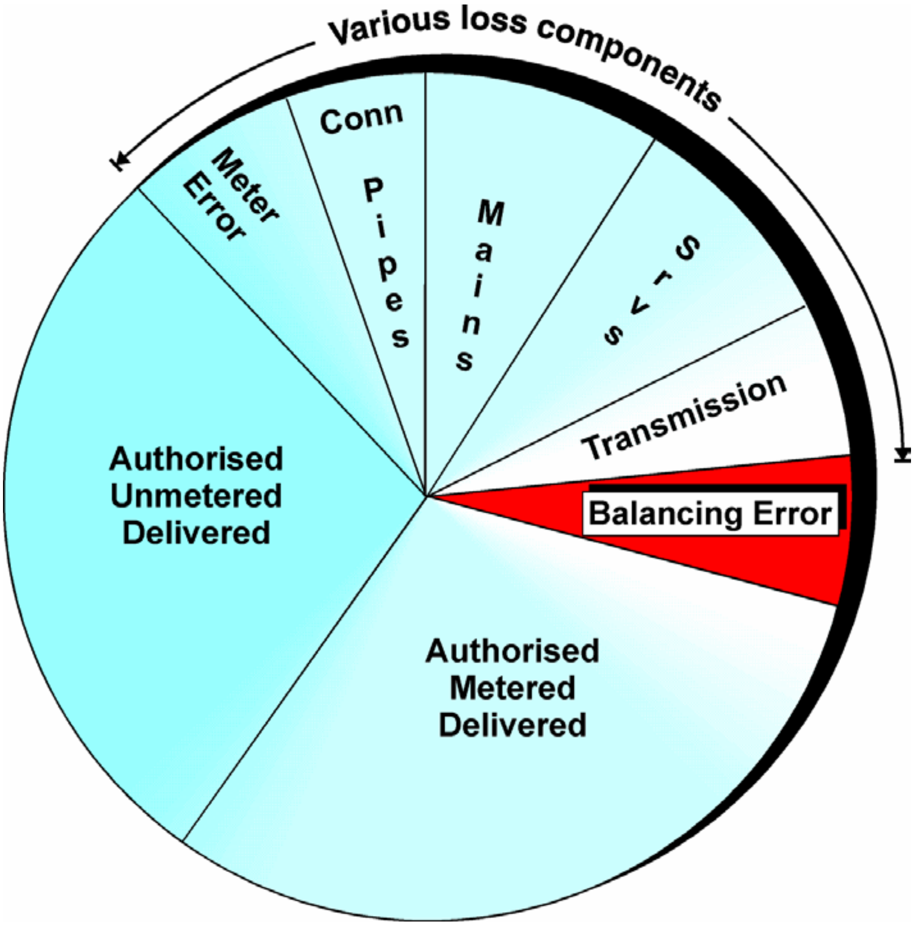


Figure B.3: BABE Water Balance Approach.

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.

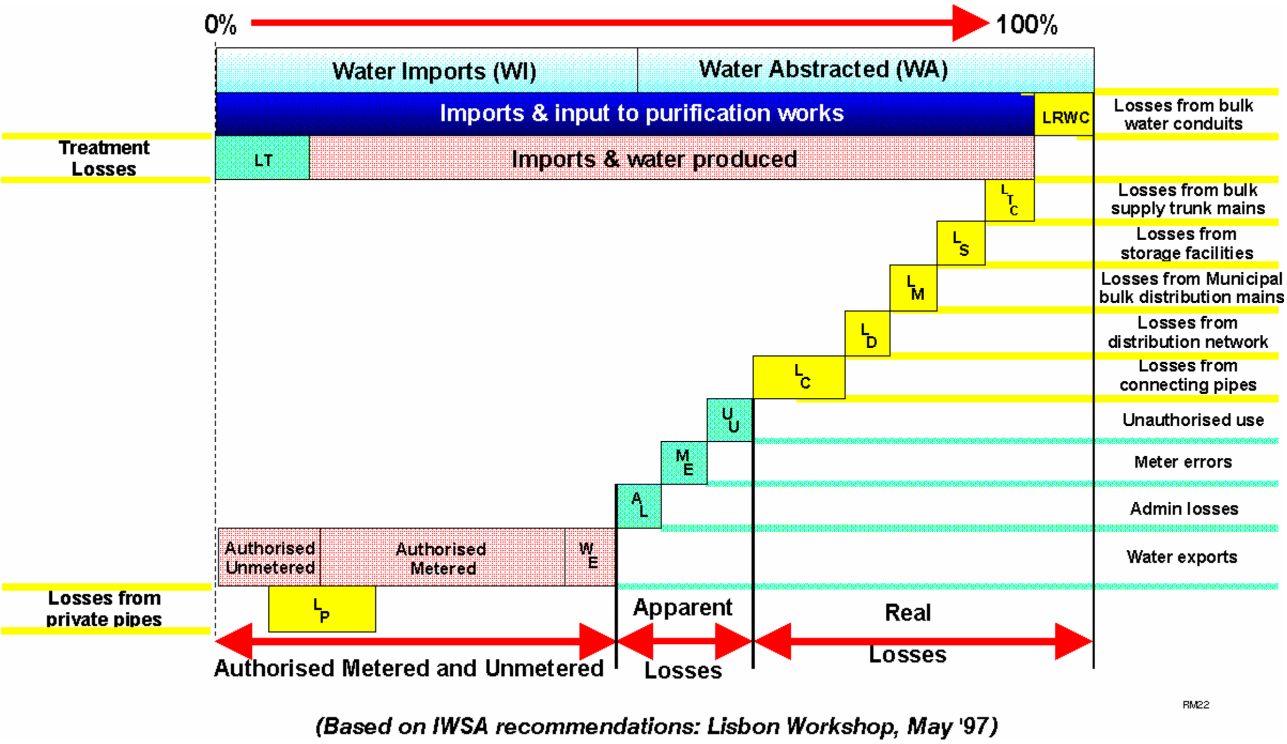


Figure B.4: Recommended BABE Water Balance Components.

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 λ/h was used in the 1994 Managing Leakage Reports, but advances in technology and other factors suggest that a figure of around 250 λ/h would be more appropriate in South Africa. In other words:

Events >	**250 λ/h**	**=**	**Bursts**

Events Leaks	**< 250 λ/h**	**=**	**Background**

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 Unavoidable Annual Real Losses 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:

λ/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:

λ/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 'Unavoidable Annual Real Losses' (UARL). The ratio of the Current Annual Real Losses (CARL, calculated from the standard Water Balance) to the UARL, is the Infrastructure Leakage Index (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 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 • Pressure • Minimum loss rate/km*	• Number/year • Pressure • Average flow rate* • Average duration	• Number/year • Pressure • Average flow rate • Average duration
Service connections to street/property line	• Number • Pressure • Minimum loss rate/conn*	• Number/year • Pressure • Average flow rate* • Average duration	• Number/year • Pressure • Average flow rate • Average duration
Service connections after street/property line	• Length • Pressure • Minimum loss rate/km*	• Number/year • Pressure • Average flow rate* • Average duration	• Number/year • Pressure • Average flow rate • Average duration

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

Each of the elements in **Table B1** can be allocated a value 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* λ/km/h	• 0.124 bursts /km/year at • 12 m^3/h per burst* • average duration of 3 d	• 0.006 bursts /km/year at • 6 m^3/h per burst* • average duration of 50 d
Service connections to street/property line	1.25* λ/conn/h	• 2.25/1000 connections/year at • 1.6 m^3/h per burst* • average duration of 8 d	• 0.75/1000 conn/yr at • 1.6 m^3/h per burst* • average duration of 100 d
Unmetered Service connections after street/property line	0.50* λ/conn/h per 15 m length	• 1.5/1000 connections/year at • 1.6 m^3/h per burst* • average duration of 9 d	• 0.50/1000 conn/yr at • 1.6 m^3/h per burst* • 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 50m 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	2.6	18	λ/km mains/d per m of pressure
Service connections to street/property line	0.60	.04	0.16	0.8	λ/conn/d/ m of pressure
Unmetered Service connections after street/property line	16.0	1.9	7.1	25	λ/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. This component of UARL has not, therefore, been included in the BENCHLEAK software. 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 (λ/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, 3920 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 λ/d
= 102 600 + 156 800 λ/d
= 259 400 λ/d
= 259.4 m^3/d
= 94 681 m^3/yr
= 66 λ/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**;
- Measure the pressure at the Average Zone Point, 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.

To obtain Average Pressure for aggregations of Zones, calculate the weighted average value of pressure using (preferably) number of service connections in each zone.

If Network Analysis models are not available, the approach used in part B2 of this Appendix should be followed. If Network Analysis models are available, follow the approach in **Section C3**.

C2. AVERAGE ZONE PRESSURES WHERE NO NETWORK MODELS EXIST

C2.1 Calculate Weighted Average Ground Level for Each Sector

Split the distribution system conceptually into sectors defined by pressure management zones or district metered areas; break the system down into the smallest areas for which average pressures may be required.

Next, for each sector, superimpose a plan of the distribution system over a contour map, preferably with 2-metre intervals. Allocate to each contour band one of the following infrastructure parameters (parameters are in order of preference):

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

Whichever infrastructure parameter is selected, the weighted average ground level can then be calculated 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**	**3907**

Weighted Average Ground Level = 3907 / 357 = 10.9 m

C2.2 Measure or Calculate Average Zone Pressure

Obtain the average pressure at the Average Zone Point 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 average zone pressure is therefore 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
	6932		**419 122**

Weighted average pressure for the whole area = 419,122/6932 = 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 BENCHLEAK Form**
- **Listing of Data Request Form**

APPENDIX E

BENCHMARKING REAL WATER LEAKAGE IN SOUTH AFRICA: RESULTS AND ANALYSIS OF LOCAL AUTHORITIES DATA USING BENCHLEAK

BENCHMARKING REAL WATER LEAKAGE IN SOUTH AFRICA: RESULTS AND ANALYSIS OF LOCAL AUTHORITIES DATA USING BENCHLEAK

Executive Summary

Until recently (mid 1990's) no standard methodology or terminology for the calculation of water losses existed. Misunderstandings and problems arose often because of differences in the definitions and methods used by different people in different parts of the world to calculate and describe water losses. National and international comparisons of the performance of a system cannot be made in the absence of standard terminology and methodology to calculate and describe losses. The main issue to be addressed is how leakage and losses should be calculated to provide meaningful results and what performance indicators should be used to allow meaningful comparison of leakage between different systems.

The South African Water Supply Industry has undergone some dramatic changes in recent years. Not only did the industry see numerous changes in the institutional arrangements, but the emphasis of demand and supply has also changed. Local authorities are becoming more autonomous, with the result that more of the responsibilities from the national government bodies are being transferred to the local authorities.

As part of the Benchmarking of Leakage project undertaken for the Water Research Commission (WRC), it was decided to carry out a number of case studies to assess the ease-of-use of the BENCHLEAK Model and also to gain a perspective on the level of leakage in South African water reticulation networks. Water suppliers across all categories and throughout South Africa were contacted and invited to participate in this study. To facilitate the capture of data from water suppliers, a data request form was created that includes the basic information required. The data request form was sent to water suppliers and the BENCHLEAK model was sent to those with access to the MS Excel program. Most water suppliers could not complete the form within the required four-week period due to the required information not being readily available and also due to a lack of resources.

It is important to note that the study was carried out before the new 2001 municipal demarcation and the water suppliers therefore relate to the former municipal areas. The total number of forms sent out represented approximately 10% of the total number of water suppliers in South Africa. They included Transitional Local Councils (TLCs), Transitional Rural Councils (TRCs), Regional

Councils (RCs), District Councils (DCs) and Metropolitan Local Councils (MLCs). Of the total number of forms sent out, approximately 60% were returned from which only 85% were finally selected after detailed screening. The other 15% were rejected due to anomalous data. The final selected entities represented about 4% of the total number of water suppliers in South Africa. It is interesting to note that all the MLC's contacted responded positively to the request for data and most were very interested in receiving feedback from the project team.

In order to validate the results, the data were thoroughly checked for any obvious anomalies. Numerous mistakes and incorrect data were identified during this screening process. In cases where dubious date were identified the water supplier was contacted again to verify the data. While most of the large errors were identified, there are still likely to be other less obvious errors which can only be identified through thorough and regular completion of the BENCHLEAK form. Typical errors and mistakes identified included:

- Mistakes related to the units of the input data.
- Errors in the input data, e.g. Authorised Consumption equal or more than the Input Volume.
- Where parts of the supply area are excluded from certain data, but included in other data, e.g. a certain area would be metered by one bulk meter only and would be included in the System Input Volume but not in the Authorised Consumption since individual consumers are not metered.
- Inaccurate or incorrect data leading to unrealistic results, e.g. where the inputs to Length of Mains and Number of Service Connections results in a Density of Service Connections of 200 conn/ km of mains. This would suggest a property every 10 m on both sides of the road which is unrealistic in South Africa.

One of the key concepts on which the BENCHLEAK Model is based concerns the development of a method to estimate the minimum level of leakage for any given water distribution system. This theoretical lowest possible achievable annual volume of Real Losses is termed the Unavoidable Annual Real Losses (UARL). While the calculation of the minimum level of leakage for a system initially appears very simple and almost empirical, it is in fact based on considerable research and factual information taken from many of the best-managed water supply systems throughout the world.

Another key concept is the introduction of a new performance indicator which can be used to gauge the level of leakage in any given system. This is termed the Infrastructure Leakage Index (ILI), which is a non-dimensional index that compares the current real leakage to the theoretical minimum level of leakage that can be achieved. The ILI therefore provides an indicator of the current level of leakage management in the particular system in relation to the (absolute) minimum level of leakage. A high ILI value indicates poor performance with large potential for improvement, while a small ILI value indicates a well-managed system with little scope for improvement. The index would normally be expected to range form 1.0 (excellent) to in excess of 10.0 (poor). In South Africa it is unusual to achieve an ILI value of below 2.0 and values in the order of 5.0 are common which represent systems in a reasonable condition with some scope for improvement. The key performance indicators for the case study are provided in **Table 1**.

Table 1: Key Performance Indicators

Utility Ref No.	Unavoidable Annual Real Losses		Infrastructure Leakage Index
	(Ml/yr)	(l/conn/d)	
Group 1 – Large (No of service connections > 50 000)			
1	6 086	53	6.2
2	4 510	44	5.2
3	2 722	46	4.2
4	3 322	57	3.0
5	3 202	83	5.2
6	1 576	41	2.6
7	3 526	121	9.1
8	1 237	48	5.4
9	1 452	58	2.9
10	1 752	70	4.3
11	1 682	77	10.2
12	1 083	51	3.4
Group Ave	**2 679**	**62**	**5.1**
Group 2 – Medium (10 000 < No of service connections < 50 000)			
13	860	50	2.2
14	604	39	4.6
15	499	38	11.8
16	722	58	3.7
17	776	66	4.3
18	829	73	4.4
19	349	53	9.4
20	305	51	1.9
21	190	49	17.5
22	275	73	19.8
Group Ave	**541**	**55**	**8.0**
Group 3 – Small (No of service connections < 10 000)			
23	203	58	2.9
24	165	49	6.4
25	119	37	2.0
26	120	56	3.7
27	113	73	10.0
28	124	85	2.7
29	39	40	6.5
30	33	50	9.4
31	28	58	4.4
32	21	40	11.3
33	26	73	1.0
34	7	74	17.0
Group Ave	**83**	**58**	**6.4**
Sample Ave	**1 134**	**59**	**6.4**

From examination of the completed case study forms, the following conclusions can be drawn:

- The South African water supply industry is generally lagging best international practices with respect to leakage management in potable water distribution systems. It was only during 1996 that the Water Research Commission (WRC) identified the need to control the level of unaccounted-for water in South Africa with the result that the development of a standard methodology or terminology for the calculation of water losses was only initiated in the late 1990's.
- The information required to calculate the various performance indicators used in this case study is often not available from the water suppliers despite the fact that the information is very basic. For example, many water suppliers have difficulties in providing information such as the total length of mains and number of service connections in their system.
- While the benchmarking procedure was initially developed for complete water distribution systems, the same approach can easily be used for individual management zones within a single supply system. In this manner this approach can be used to identify problem management zones within a system as well as to compare one system with another.
- Water supply systems in South Africa are poorly metered with regard to both bulk and consumer metering.
- Of the total sample group consisting of 34 local councils, 35% have more than 50 000 service connections (Group 1), 30% have less than 50 000 but more than 10 000 connections (Group 2) and 35% have less than 10 000 service connections (Group 3). The sample group is considered to be representative of local councils in South Africa. Since the sample group contains all of the Metropolitan Local Councils, making up the majority but not 100% of Group 1, it is evident that most supply systems in the country would typically have less than 50 000 connections.
- In the respective groupings, 100% of cases in Group 1 has mains in excess of 1 000 km, 90% of cases in Group 2 has mains less than 1 000 km but more than 300 km, while in Group 3 80% of cases has mains less than 300 km. It is evident that most supply systems in the country would typically have less than 1 000 km of mains, while very few would have a total length of mains less than 10 km.
- No conclusive remarks can be made with regard to the density of connections in relation to the size of the distribution system until more data are collected and analysed for supply systems in South Africa. The average density of connections for Group 1, Group 2 and Group 3 are 57, 52 and 38 respectively. Based on this case study, 50 connections per km of mains is considered to be an average value for supply systems. Few systems have a density of less than 20 connections/ km or more than 100 connections/ km of mains.
- For Group 1 System Input Volume is typically more than 25 000 Mλ/yr, while for Group 2 it is typically more than 10 000 Mλ/yr. Water systems in Group 3 typically reported System

Input Volume of more than 1 000 Mλ/yr, but less than 10 000 Mλ/yr. The distribution within the respective groups is erratic and displays a larger variance. This is simply because System Input Volume is not directly proportional to system size. The average System Input Volume for the total sample group is about 36 000 Mλ/yr (or 36 x 10^6 m^3/ yr). Assuming that there are approximately 300 municipalities in the country (under the new demarcation system), it means that the total System Input Volume in the country is approximately 11 000 x 10^6 m^3/ yr, almost as much as the mean annual runoff (MAR) of the Orange-Vaal River system (approximately 12 000 x 10^6 m^3/ yr).

- In terms of Authorised Consumption, Groups 1, 2 and 3 typically reported values of more than 20 000 Mλ/yr, between 20 000 Mλ/yr and 6 000 Mλ/yr, and between 6 000 Mλ/yr and 200 Mλ/yr, respectively. The average for the total sample group is approximately 29 000 Mλ/yr (or 29 x 10^6 m^3/ yr). If this figure is assumed to be representative of the 300 municipalities in the country, it suggests that the total water used could be as high as 40 times the Authorised Consumption for Durban Metro or more than 25 times the water supplied by Rand Water.
- Group 1 displays the largest Total Losses (more than 5 000 Mλ/yr) followed by Group 2 (more than 1 500 Mλ/yr) and Group 3 (less than 1500 Mλ/yr). The average Total Losses for Groups 1, 2, 3 and the total sample group is 18 000, 4 000, 500 and 8 000 Mλ/yr respectively. The losses in the Group 1 systems are of particular concern since they represent the average System Input Volume of 19 000 Mλ/yr for Group 2. Similarly, the Group 2 Total Losses are almost equal to the average System Input Volume for Group 3 of 4 000 Mλ/yr.
- Apparent Losses for Group 1 ranges from about 860 Mλ/yr to about 9 380 Mλ/yr with an average of about 3 570 Mλ/yr. For Group 2 it ranges from a minimum of approximately 150 Mλ/yr to a maximum of 1 480 Mλ/yr with an average of 830 Mλ/yr. Group 3 reports Apparent Losses of minimum, maximum and average of approximately 6 Mλ/yr, 280 Mλ/yr and 100 Mλ/yr respectively.
- The Real Losses (also termed Current Annual Real Losses or CARL) for Group 1 range from approximately 3 700 Mλ/yr to approximately 37 500 Mλ/yr with an average of almost 14 500 Mλ/yr. For Group 2 the Real Losses range from less than 600 Mλ/yr to a maximum of 6 000 Mλ/yr with an average of 3 300 Mλ/yr. Group 3 reports Real Losses of between 25 Mλ/yr and 1 100 Mλ/yr with an average value of 400 Mλ/yr. The median (or 50^{th} percentile) value of Real Losses for Groups 1, 2 and 3 are approximately 10 700 Mλ/yr, 3 300 Mλ/yr and 300 Mλ/yr respectively. The average Real Losses for the total sample group is approximately 6 000 Mλ/yr (or 6 x 10^6 m^3/ yr). If it is assumed that this average value can be used for the 300 systems for the whole of South Africa this equates to

approximately 1.8 x 10^9 m^3/ yr. If the average selling price of water is accepted to be R2.00/kλ, it suggests that the value of Real Losses throughout South Africa is almost R3 600 million/ yr. Furthermore, if it is assumed that the average urban water demand in South Africa is approximately 250 λ/c/d, then the Real Losses could supply the daily water demand of almost 20 million people.

- The average Real Losses per service connection per day for Groups 1, 2 and 3 are 353, 447 and 375λ/conn/d respectively. Based on these figures, it is reasonable to assume that an average of 400 λ is lost per connection per day in South African water supply systems. Almost twice the average urban water demand of 250 λ/c/d or almost 4 full domestic baths every day for every connection!
- Expressing Real Losses per connection shows no definite trends with regard to grouping, which indicates that it is not biased in terms of system size, system input, unit consumption, etc. As in the case of CARL per connection/day, expressing Real Losses per kilometre of mains or per connection per metre of pressure also show no definite trends or distribution patterns.
- The total Non-Revenue water as percentage of System Input Volume ranges from approximately 6% to 52%. No definite trends can be identified between the different groupings and the distribution seems to be almost random. The average percentage for the groups is almost uniform with 26%, 23% and 21% for Groups 1, 2 and 3 respectively. It is therefore reasonable to assume that approximately one fifth of water supplied will not contribute to revenue collection.
- Water Suppliers found it difficult to provide details of the various components of Non-Revenue water. It is even more difficult for Water Suppliers to provide a break-up of the components of the Unbilled Authorised portion of Non-Revenue water. 9% of Water Suppliers could not provide an estimate of the average annual operating cost of the system. This is a major part of the problem of successful cost recovery for water services.
- No definite trends are evident with regard to the distribution of the Unavoidable Annual Real Losses (UARL) or the Infrastructure Leakage Index (ILI) for the three groups, proving the effectiveness of this methodology as an unbiased tool that successfully removes various influential factors when benchmarking the performance of one system against that of another.
- The average UARL value for Groups 1, 2 and 3 are 62, 55 and 58 λ/conn/d respectively. Based on this case study, it is considered reasonable to assume that the UARL for South African systems is in the order of 60 λ/conn/d. More data need to be collected and analysed to add greater confidence to these figures. Accepting that the Real Losses are in the order of 400 λ/conn/d, it implies that only 15% of Real Losses per connection are unavoidable and that the remaining 85% could be recovered.

- The ILI values for the sample group range from 1.0 to approximately 28.0 with an average value in the order of 7.0. The average values are 5.1, 8.0 and 6.4 for Groups 1, 2 and 3 respectively. This can be compared to ILI values calculated by International Water Data Comparisons Ltd for 27 supply systems in 19 countries that range from 1.0 to 10.0 with an average value of 4.2.
- For South African conditions it would be unusual to achieve an ILI value of below 2.0 and values in the order of 5.0 are common and represent systems in a reasonable condition. For smaller systems one would expect that since these systems are smaller and easier to manage, it should be possible to achieve an ILI of 3.0 through improved management practices. This suggests that there is considerable scope for improvement in Groups 2 and 3, while Group 1 could probably achieve an ILI of about 4.0.

Based on the conclusions from this report, it is recommended that:

- The importance of leakage management should gain greater exposure and emphasis from water services institutions such as the Water Research Commission and the Department of Water Affairs and Forestry.
- Water services authorities and providers should be made aware of the existence of the leakage-benchmarking methodology in order to create an environment of cooperation when water services institutions embark on further case studies.
- The performance indicators used to benchmark different water suppliers should be chosen carefully in order to make benchmarking across different categories of service providers or demarcation areas meaningful.
- Users of the benchmarking model should familiarise themselves fully with the content of the BENCHLEAK User Guide, before embarking on applying the model.
- The benchmarking model should be compiled into a full database for the South African water supply industry to facilitate collection and collation of data for an ongoing annual national benchmarking exercise. The results can then be presented in a standard format and sent to all water suppliers participating in the exercise. Obviously some of the figures quoted in this case study are based on a number of broad assumptions and the true situation can only be established if all of the approximately 300 service providers complete the BENCHLEAK form. The figures do, however, indicate the possible magnitude of Real Losses throughout the country.

BENCHMARKING OF REAL WATER LEAKAGE IN SOUTH AFRICA: RESULTS AND ANALYSIS OF LOCAL AUTHORITIES DATA USING BENCHLEAK

Table of Contents

Page No.

1. INTRODUCTION

1.1. WHY BENCHMARK LEAKAGE?

There is a growing realisation that water resources in South Africa are becoming increasingly stressed in many parts of the country and careful water resources management is becoming more important. The development of the National Water Resources Strategy and the Water Conservation and Demand Management National Strategy by the Department of Water Affairs and Forestry (DWAF), are examples demonstrating the Government's commitment to water conservation and the efficient use of the available resources. As awareness grows internationally about issues such as sustainability of resources, economic efficiency and protection of the environment, the leakage from water distribution systems is becoming a topical issue worldwide.

Water losses from water distribution systems are inevitable and cannot be eliminated completely. Such losses may be due to infrastructure-related problems, administrative-related problems or theft and usually have financial implications. The volume of water lost from a system is an indicator of planning and construction efficiency, distribution efficiency, and operational and maintenance activities. The annual volume of water lost is therefore an important indicator of the performance of a water supply and distribution system.

Until recently (mid 1990's) no standard methodology or terminology for the calculation of water losses existed. Misunderstandings and problems often arose because of differences in the definitions and methods used by different people in different parts of the world to calculate and describe water losses. National and international comparisons of the performance of a system cannot be made in the absence of standard terminology and methodology to calculate and describe losses. The main issue to be addressed is how leakage and losses should be calculated to provide meaningful results and what Performance Indicators should be used to allow meaningful comparison of leakage between different systems.

1.2. PURPOSE OF THIS REPORT

The purpose of this report is to present the results of the benchmarking exercise that was carried out as part of this study. This created the opportunity to test the methodology on real data. It is not the purpose of this report to explain the concepts of the BENCHLEAK model in great detail. The reader is referred to the BENCHLEAK User Guide for more detailed information in that regard.

Apart from presenting the results of the benchmarking exercise carried out for various water suppliers, this report will also attempt to provide interpretation of the results and to report on the significance and meaning of the key performance indicators that are used to benchmark leakage.

This report contains three sections each of which is described below.

Chapter 1: provides background information to leakage benchmarking and the South African Water Supply Industry. It also describes the purpose of this report and the benchmarking exercise carried out as part of the project.

Chapter 2: provides a discussion of the results of the benchmarking exercise. The details obtained from the different water suppliers are documented and the key results from the analysis are presented.

Chapter 3: provides a brief summary of the results together with some concluding remarks regarding leakage benchmarking in South Africa.

1.3. BACKGROUND TO THE SOUTH AFRICAN WATER SUPPLY INDUSTRY

The South African Water Supply Industry has undergone some dramatic changes in recent years. Not only has the industry experienced numerous changes in the institutional arrangements, but the emphasis from supply management has also changed to one of Integrated Resource Planning in which demand management is given a very high priority. Local authorities have been empowered and encouraged to be more autonomous with the result that more of the responsibilities from the national government bodies are being transferred to the local authorities.

It is considered worthwhile to reflect briefly on the key elements of the institutional framework with regard to the provision of water services:

- **Central Government's** primary functions include the establishment of national policy guidelines and development strategies, formulating criteria for subsidies, and monitoring and regulating service provision and water-related institutions.
- **Provincial Government** has as its key activity the promotion of effective local government. Where local government does not have the capacity to carry out its service function, provincial government can take over.
- **Local Government:** Service provision is the primary responsibility of local authorities.

- **Water Boards:** The role of water boards has now expanded beyond their previous function of bulk water supply and can also include the provision of basic services.
- **Water Service Committees** have the function of providing water supply and sanitation services, generally in a rural context.

In metropolitan areas local government takes on two forms. Firstly, Metropolitan Councils have been established to manage large-scale functions and within them Metropolitan Local Councils are responsible for more local functions. Secondly, outside the metropolitan areas, urban local government has been established in the form of local councils. These local councils elect representatives to the district councils which are established to provide local government services to the rural areas.

Local Government has the primary responsibility of ensuring that people in their areas of jurisdiction are provided with water supply and sanitation services. In particular, local government is allocated the function of water service authority and in an urban context the local council is normally the obvious sphere of local government to take on this responsibility. In metropolitan areas, however, the allocation of the water services authority function may be made to the metro local council or the metro council.

Having the function of water service authority, the local government then decides whether it will be the water service provider itself or whether this function will be contracted out to others: the private sector, a neighbouring local authority or a water board, for example.

It is important to note that the study was carried out before the new 2001 municipal demarcation and the water suppliers therefore relate to the former municipal areas. The total number of forms that was sent out represented about 10% of the total number of water suppliers in South Africa. This included Transitional Local Councils (TLCs), Transitional Rural Councils (TRCs), Regional Councils (RCs), District Councils (DCs) and Metropolitan Local Councils (MLCs).

At present the great majority of service providers in South Africa are local authorities, many of who also run their own bulk service arrangements, both for water and wastewater. There are also many local authorities, however, particularly in larger centres, which secure their bulk services from other sources such as a water board, a metropolitan council or another local authority.

1.4. GATHERING OF DATA

1.4.1. General Methodology

The BENCHLEAK Model is simply a spreadsheet (in Microsoft-Excel format) comprising three forms that utilise certain basic information provided by the water supplier. The model can be run from anywhere on the users PC as long as the Excel program can be accessed. There is no sophisticated installation shield and the **BENCHLEAK.XLS** file is simply copied into a suitable directory and the model is used in the same manner as a normal Excel spreadsheet. Definitions of the various terms used in the BENCHLEAK Model and the Model installation are provided in the BENCHLEAK User Guide.

The information provided by the Water Supplier is processed in such a way that the leakage can be evaluated and compared between supply systems in a meaningful and realistic manner. The model contains three parts namely:

- **The Summary form** (1 sheet when printed)
- **The Detail-1 form** (3 sheets when printed)
- **The Detail-2 form** (1 sheet when printed).

The users are only required to complete the Detail-1 form, which utilises the following information:

- System name and contact details.
- System data: length of mains, number of connections, percentage of time that the system is pressurised and the average operating pressure of the system;
- Period to which the information refers i.e. calendar year, financial year;
- Details of water input to the system (i.e. water purchased from bulk supplier and water produced from own sources etc.);
- Details of water supplied to customers including estimates of all unmetered and unbilled water;
- Estimate of Apparent Losses as a percentage of the Total Losses.

To facilitate the capture of data from water suppliers, a data request form was created that includes the basic information required. The BENCHLEAK User Guide provides details of this form as well as the different sheets that make up the model. The data request form was specifically created for those water suppliers who would like to analyse their system using BENCHLEAK, but cannot use the model for some reason.

Various water suppliers were contacted and the purpose of the study explained to them. The water suppliers were then asked to complete the **Detail-1 form** and to send the completed form back to the study team. Some water suppliers indicated that they do not have access to the MS Excel program and in such cases the data request form was sent to them. The water suppliers were then contacted again after a period of about four weeks to request the completed forms.

Most water suppliers could not complete the form within the required four-week period due to the required information not being readily available and also due to a lack of capacity. Those water suppliers, who did not complete the form after the initial required four weeks, were contacted again after a second four-week period. A number of water suppliers to whom the form was sent never completed it, not even after a few months and despite numerous telephonic discussions and written requests, due to a lack of personnel and/or details of their supply network.

In order to validate the results, the data were thoroughly checked for any obvious anomalies. Numerous mistakes and incorrect data were identified during this screening process. Typical errors and mistakes identified included:

- Mistakes related to the units of the input data.
- Errors in the input data, e.g. Authorised Consumption equal to or more than the Input Volume.
- Where parts of the supply area are excluded from certain data, but included in other data, e.g. a certain area would be metered by one bulk meter only and would be included in the System Input Volume but not in the Authorised Consumption since individual consumers are not metered.
- Inaccurate or incorrect data leading to unrealistic results, e.g. where the inputs to Length of Mains and Number of Service Connections results in a Density of Service Connections of 200 connections/km of mains. This would suggest a property every 10 m on both sides of the road which is unrealistic in South Africa.

In case where dubious data were identified the water supplier was contacted again to verify the data. While most of the large errors were identified, there are still likely to be other less obvious errors, which can only be identified through thorough and regular completion of the BENCHLEAK form.

1.4.2. Participating Water Suppliers

Participation in the leakage benchmarking methodology was not limited to any water services provider groups or geographical regions. In fact, water services providers throughout South Africa were encouraged to participate through a series of presentations at national conferences. As indicated, mixed responses were received from water services providers with some who were enthusiastic and keen to participate and others who were negative and, in some instances, even suspicious. Eventually sufficient results were received from a range of water services providers covering the whole sphere of service provision: from metropolitan councils to district councils. The participants included those supplying systems in excess of 300 000 connections to those supplying systems of less than 300 connections.

The total number of forms that was sent out represented about 10% of the total number of water suppliers in South Africa. Of the total number of forms sent out, only about 60% was received back from water suppliers. Out of the total number of positive responses received, only 85% was finally used in the case study after detailed screening, while the other 15% was rejected due to anomalous data. The final selected entities represented about 4% of the total number of water suppliers in South Africa. It is interesting to note that all the MCs that were contacted responded positively to the request for data.

Appendix F provides the results from the benchmarking exercise that was carried out. Participating water suppliers were grouped into three groups based on the size of the system as dictated by the number of service connections. The groups are briefly described in **Table 1.1**. As can be seen from **Table 1.1** the groups are considered to be representative of the total sample group in terms of the number of water suppliers in each group. The total sample group is considered to be representative of South African water suppliers as it contains all of the Metropolitan Council areas in the country (which each have more than 100 000 connections in their systems), a number of smaller water suppliers, which each have less than 1 500 connections in their systems as well as water suppliers covering the range in between. The sample group represent about 4% of the total number of water suppliers in the country.

Table 1.1: Grouping for case study participants

Grouping	Criteria	Group Size	% of Total
1. Large	No of connections > 50 000	12	35
2. Medium	10 000 </= No of Connections </= 50 000	10	30
3. Small	No of Connections < 10 000	12	35

2. RESULTS FOR PARTICIPATING SOUTH AFRICAN WATER SUPPLIERS

2.1. PRESENTATION OF RESULTS

Before proceeding to document the results from the various domestic/urban water suppliers it is considered worthwhile to explain briefly how the results from the benchmarking exercise are presented. Various performance indicators are provided in graphical format for each Water Supplier within the various groups and these graphs are shown in **Appendix F**. Each Water Supplier is given a reference number in order to provide anonymity. Reference is made to the graphs in **Appendix F** throughout the discussions in **Sections 2.2** to **2.5**. At the start of each sub-section **Tables 2.1**, **2.2**, **2.5** and **2.7** provide a summary of the performance indicators as discussed under **Sections 2.2**, **2.3**, **2.4** and **2.5** respectively.

2.2. SYSTEM DATA

2.2.1. Summary of Results

Table 2.1 provides a summary of the system data for the sample group. As can be seen, the sample group has been split into three sub-groups based on the size of the system in terms of number of service connections (as explained in **Table 1.1**). Of the total sample group consisting of 34 Water Suppliers, 35% have more than 50 000 service connections (Group 1), 30% have less than 50 000 but more than 10 000 connections (Group 2) and 35% have less than 10 000 service connections (Group 3). In the respective groupings, 100% of cases in Group 1 have mains in excess of 1 000 km, 90% of cases in Group 2 have mains less than 1 000 km but more than 300 km, while in Group 3 80% of cases have mains less than 300 km. None of the sample cases have a total length of mains of less than 10 km.

Based on that distribution, it is accepted that each of the sub-groups is representative of the total sample group. The total sample group is considered to be representative of Water Suppliers in South Africa as it contains all of the Metropolitan Councils as well as some of the smallest systems (e.g. less than 1 500 connections). If the sample group is grouped according to the size of the system, as determined by the number of service connections in the system, it is clear that for that scenario, the size of the system is also proportional to the length of mains in the system i.e. there is a relationship between length of mains and number of service connections, although not a direct proportionality. This is evident through the density of connections where no specific distribution pattern is observed (refer to **Fig. F.2**), although the average density of connections for Group 1, Group 2 and Group 3 is 57, 52 and 38 respectively.

Table 2.1: System Data

Utility Ref No.	Length of mains	No of Service Connections	Density of service connections	Average Operating Pressure	System input volume	Authorised Consumption	
	(km)	(No)	(No /km of mains)	(m)	(Ml/yr)	(Ml/yr)	(l/conn /day)
Group 1 – Large (No of service connections > 50 000)							
1	6 544	315 911	48	45	285 276	238 360	2 067
2	2 900	278 000	96	45	123 220	94 108	927
3	2 050	161 000	79	45	87 152	73 453	1 250
4	3 000	160 000	53	50	100 000	87 700	1 502
5	2 251	106 000	47	70	75 369	54 392	1 406
6	1 331	105 000	79	40	54 836	49 642	1 295
7	3 600	80 000	22	75	122 846	82 946	2 841
8	1 073	70 000	65	45	27 952	19 600	767
9	1 352	69 000	51	50	29 477	24 300	965
10	1 400	68 500	49	60	41 080	31 610	1 264
11	1 600	60 000	38	60	44 831	23 423	1 070
12	1 085	58 031	53	45	24 713	20 175	952
Group Ave	**2 349**	**127 620**	**57**	**53**	**84 729**	**66 642**	**1 359**
Group 2 – Medium (10 000 < No of service connections < 50 000)							
13	834	46 700	56	45	19 565	17 200	1 009
14	761	42 000	55	35	29 020	25 550	1 667
15	320	35 530	111	40	26 426	19 040	1 468
16	677	34 200	51	50	16 324	12 950	1 037
17	722	32 087	44	55	26 818	22 624	1 932
18	717	31 200	44	60	22 039	17 440	1 531
19	380	18 000	47	45	17 694	13 603	2 070
20	456	17 264	38	40	9 799	9 061	1 438
21	255	10 500	41	40	12 845	8 700	2 270
22	300	10 400	35	55	13 505	6 700	1 765
Group Ave	**542**	**27 788**	**52**	**47**	**19 403**	**15 287**	**1 619**
Group 3 – Small (No of service connections < 10 000)							
23	260	9 620	37	45	3 774	3 034	864
24	329	9 197	28	34	14 869	13 549	4 036
25	215	8 737	41	30	6 162	5 858	1 837
26	103	5 872	57	50	4 459	3 902	1 821
27	114	4 226	37	57	4 160	2 750	1 783
28	450	4 000	9	30	2 648	2 227	1 525
29	43	2 661	62	37	1 556	1 238	1 275
30	45	1 844	41	40	1 715	1 322	1 964
31	60	1 650	28	40	2 904	2 750	4 566
32	28	1 429	51	35	1 433	1 135	2 176
33	22	962	44	60	271	240	684
34	13	275	21	45	994	836	8 329
Group Ave	**140**	**4 206**	**38**	**42**	**3 745**	**3 237**	**2 572**
Sample Ave	**1 038**	**54 700**	**49**	**47**	**36 933**	**29 159**	**1 863**

Considering the historical design of suburbs and towns in South Africa, it is typically the larger systems that would contain a large number of high-density, low-income suburbs. Smaller systems would typically contain one or two high-density suburbs where the average size of erven would be larger than those high-density suburbs located in the cities. However, no conclusive remarks can be made with regard to the density of connections in relation to the size of the distribution system until more data are collected and analysed for water suppliers in South Africa.

It is obvious that larger systems would rank higher with regard to System Input Volume. For Group 1, System Input Volume is typically more than 25 000 Mλ/yr, while for Group 2 it is typically more than 10 000 Mλ/yr. Water systems in Group 3 typically reported System Input Volume of more than 1 000 Mλ/yr, but less than 10 000 Mλ/yr. The distribution within the respective groups is much more erratic and displays a larger variance.

There are isolated cases where the smallest value for System Input Volume for a water supplier in a higher order group is less than the high values in a lower order group, e.g. the smallest value in Group 1 is 24 715 Mλ/yr. In Group 2 three water suppliers have values of System Input Volume of 26 426, 26 818 and 29 020 Mλ/yr. This is simply because System Input Volume is not directly proportional to system size.

The same is true for Authorised Consumption, where Groups 1, 2 and 3 typically reported values of more than 20 000 Mλ/yr, between 20 000 Mλ/yr and 6 000 Mλ/yr, and between 6 000 Mλ/yr and 200 Mλ/yr, respectively.

2.2.2. Average Operating Pressure

The frequency at which new leaks occur and the rate of flow of leaks are related to operating pressure. The exact relationship between operating pressure and leakage has not been established, but the weighted average relationship for large systems appears to be that leakage varies with pressure approximately to the power 1.15. The simplified assumption is that leakage varies linearly with pressure is often adopted and yields realistic results.

Operating pressure is constrained by local topography and minimum levels of service and will vary significantly between different water supply systems. As can be seen from **Fig. F.1**, the average operating pressure varies from about 30 m to about 75 m for the reference set with an average value of 47 m.

It is often assumed that the system is supplied continuously. This, however, is not the case in other countries (particular developing countries) and the percentage of time that the system is pressurised is an important parameter to be taken into account. All the water suppliers included in the reference data set indicated that their systems are pressurised 100 percent of the time. For this reason, this parameter is not discussed separately.

2.2.3. Density of Service Connections

Density of connections (number of connections per km of mains) is an important indicator and can vary significantly from one system to another. From **Fig. F.2** it can be seen that it varies from 9 service connections/km to 111 service connections/km. The average value for the reference set is approximately 50 service connections/km.

The density of connections can also be used as a quick check in the verification of data. For example, a low value of 5 connections per km of mains suggests that on average there is one connection for every 200 m of mains. In the South African context this is possible where the supply system consists mainly of large plots and smallholdings. On the other hand, high density of connections can be expected in some of the large urban centres in South Africa due to the existence of high-density low-income areas where erf sizes are relatively small.

It should be noted that care should be taken in cases where the person providing the information estimates the number of connections as being equal to the number of properties. It is not always the case that the number of connections is equal to the number of properties, since it is common practice to have one saddle connection branching to two or more erf connections. It is also often found that undeveloped properties are often not connected. For comparison purposes the number of service connections can usually be considered to be equal to the number of serviced erven.

2.3. SELECTED OPERATIONAL PERFORMANCE INDICATORS

2.3.1. Summary of Results

Table 2.2 provides a summary of the operational performance indicators for the sample group in terms of the sub-groups as explained in **Table 1.1**. Group 1 displays the largest Total Losses (more than 5 000 Mλ/yr) followed by Group 2 (more than 1 500 Mλ/yr) and Group 3 (less than 1500 Mλ/yr).

This distribution is expected, because Total Losses is simply a function of System Input Volume and Authorised Consumption. The same is true for Apparent Losses and Current

Annual Real Losses (CARL) expressed in terms of volume (Mλ/yr), as these two parameters have been estimated for the whole data set as 20% and 80% of Total Losses respectively.

Because System Input Volume and Authorised Consumption are not directly proportional to system size (in terms of number of connections) and Total Losses is a function of these two parameters, it is obvious that Total Losses is not directly proportional to system size.

Apparent Losses for Group 1 ranges from about 860 Mλ/yr to about 9 380 Mλ/yr with an average value of about 3 570 Mλ/yr. For Group 2 it ranges from a minimum of about 150 Mλ/yr to a maximum of 1 480 Mλ/yr with an average of 830 Mλ/yr. Group 3 reports Apparent Losses of minimum, maximum and average of about 6 Mλ/yr, 280 Mλ/yr and 100 Mλ/yr respectively.

The BENCHLEAK Model allows the water supplier to provide an estimate of losses associated with bulk meter error, but this does not include the losses associated with the consumer accounts, which, in turn, are based on the consumer meters. The individual components of the Apparent Losses are not listed separately in the model since few, if any, of the water suppliers will be in a position to supply reliable information in this regard. Instead, the Apparent Losses are simply considered to be a percentage of the Total Losses. A value to the order of 20% is normally considered to be appropriate, although it can vary from system to system.

The Apparent Losses represent a component of the water that escapes the revenue system and any reduction in Apparent Losses will result in a greater income to the water supplier at the effective selling price of the water. In some South African situations the Apparent Losses can be very high and can even exceed the physical losses (or real losses), especially in cases where levels of payment are low and the payment is based on a flat tariff rather than measured consumption.

CARL for Group 1 ranges from about 3 700 Mλ/yr to about 37 500 Mλ/yr with an average of about 14 500 Mλ/yr. For Group 2 it ranges from a minimum of about 600 Mλ/yr to a maximum of 6 000 Mλ/yr with an average of 3 300 Mλ/yr. Group 3 reports CARL of minimum, maximum and average of about 25 Mλ/yr, 1 100 Mλ/yr and 400 Mλ/yr respectively. The median (or 50^{th} percentile) value of CARL for Group 1, 2 and 3 is approximately 10 700 Mλ/yr, 3 300 Mλ/yr and 300 Mλ/yr respectively.

Table 2.2: Selected Operational Performance Indicators

Utility Ref No.	Total Losses (Mλ/yr)	Ratio of Total Losses to Authorised Consumption	Ratio of Authorised Consumption to System Input Volume	Apparent Losses (Mλ/yr)	Current Annual Real Losses (Mλ/yr)	Current Annual Real Losses (λ/conn/d)	Current Annual Real Losses (λ/ km of mains/ d)	CARL per conn per metre of pressure (λ/conn/d/ m of press)
Group 1 – Large (No of service connections > 50 000)								
1	46 916	0.20	0.84	9 383	37 533	325	15 713	7.23
2	29 112	0.31	0.76	5 822	23 289	230	22 002	5.10
3	13 699	0.19	0.84	2 192	11 507	196	15 379	4.35
4	12 300	0.14	0.88	2 460	9 840	168	8 986	3.37
5	20 977	0.39	0.72	4 195	16 781	434	20 425	6.20
6	5 194	0.10	0.91	1 039	4 155	108	8 553	2.71
7	39 900	0.48	0.68	7 980	31 920	1 093	24 292	14.58
8	8 352	0.43	0.70	1 670	6 682	262	17 060	5.81
9	5 177	0.21	0.82	1 035	4 142	164	8 393	3.29
10	9 470	0.30	0.77	1 894	7 576	303	14 826	5.05
11	21 408	0.91	0.52	4 282	17 126	782	29 326	13.03
12	4 538	0.22	0.82	862	3 676	174	9 282	3.86
Group Ave	**18 087**	**0.32**	**0.77**	**3 568**	**14 519**	**353**	**16 186**	**6.21**
Group 2 – Medium (10 000 < No of service connections < 50 000)								
13	2 365	0.14	0.88	473	1 892	111	6 215	2.47
14	3 470	0.14	0.88	694	2 776	181	9 994	5.17
15	7 386	0.39	0.72	1 477	5 909	456	50 589	11.39
16	3 374	0.26	0.79	709	2 665	214	10 787	4.27
17	4 194	0.19	0.84	839	3 355	286	12 732	5.21
18	4 599	0.26	0.79	920	3 679	323	14 059	5.38
19	4 091	0.30	0.77	818	3 273	498	23 599	11.07
20	738	0.08	0.92	148	590	99	3 547	2.47
21	4 145	0.48	0.68	829	3 316	865	35 626	21.63
22	6 805	1.02	0.50	1 361	5 444	1 434	49 717	26.08
Group Ave	**4 117**	**0.32**	**0.78**	**827**	**3 290**	**447**	**21 686**	**9.51**
Group 3 – Small (No of service connections < 10 000)								
23	740	0.24	0.80	148	592	169	6 238	3.75
24	1 319	0.10	0.91	264	1 055	314	8 789	9.25
25	304	0.05	0.95	61	243	76	3 099	2.54
26	557	0.14	0.87	111	446	208	11 862	4.16
27	1 410	0.51	0.66	282	1 128	731	27 109	12.83
28	421	0.19	0.84	84	336	230	2 048	7.68
29	318	0.26	0.80	64	255	262	16 224	7.09
30	393	0.30	0.77	79	314	467	19 123	11.67
31	154	0.06	0.95	31	123	255	5 607	6.37
32	298	0.26	0.79	60	238	457	23 335	13.06
33	31	0.13	0.89	6	25	71	3 088	1.18
34	158	0.19	0.84	32	126	1 259	26 639	27.98
Group Ave	**509**	**0.20**	**0.84**	**102**	**407**	**375**	**12 763**	**8.96**
Sample Ave	**7 774**	**0.28**	**0.80**	**1 538**	**6 236**	**388**	**16 596**	**8.16**

Expressing Real Losses as a percentage of System Input is often used as a benchmarking parameter. This parameter is discussed under **Section 2.3**, but is presented in **Table 2.5** as it also forms part of the Financial Performance Indicators. From **Table 2.5** and **Fig. F.3**, it can be seen that the distribution of percentage losses varies within all three groups. The average for Groups 1, 2 and 3 is 18%, 18% and 16% respectively. Out of the 34 water suppliers 29% reported Real Losses of 1-10%. In the categories of 11-20%, 21-30% and 31-40% Real Losses, the distribution is 47%, 18% and 6% respectively. None reported Real Losses in excess of 40%.

However, throughout the development of BENCHLEAK, concern has been expressed over the use of percentages as a benchmarking parameter as it can be misleading and could provide a skewed picture. This is illustrated by means of the information in **Table 2.3**. Here the Current Annual Real Losses (CARL) or simply Real Losses is given in units of λ/conn/d and as a percentage of the System Input Volume together with the Authorised Consumption (also in units of λ/conn/d). This is the same data as given in **Table 2.1**, **2.2** and **2.5**, except that the data has been sorted according to the CARL in λ/conn/d.

Two examples of how percentages can be misleading can be taken from the data presented in **Table 2.3**:

1. Water supplier No. 22 and 11 reported Real Losses of 40% and 38% respectively. Although the percentage losses in this case are virtually the same, the Real Losses per connection for No. 22 and 11 are 1434 and 782 λ/conn/d respectively, which is a considerable difference.
2. In the case of water supplier No. 8 and 31 the percentage Real Losses is 24% and 4% respectively. However, the Real Losses per connection is virtually the same (262 and 255 λ/conn/d respectively).

In both these cases the consumption per connection is quite different and clearly influences the percentage losses.

One of the recommended performance indicators is to express losses per service connection per day. The average CARL per service connection per day for Groups 1, 2 and 3 is 353, 447 and 375 λ/conn/d respectively. The minimum and maximum for the three respective groups are 108 and 1093, 99 and 1434, and 71 and 1259 λ/conn/d respectively.

From these figures it is evident that expressing Real Losses per connection shows no definite trends with regard to grouping, which proves that it is not biased in terms of system size, system input, unit consumption, etc. As in the case of CARL per connection/ day, expressing Real Losses per kilometre of mains or per connection per meter of pressure also shows no definite trends or distribution patterns. This is proof of the successfulness of the BENCHLEAK Model as a benchmarking tool.

Table 2.3: Illustrating the problem with percentages

Ref No.	Current Annual Real Losses (λ/conn/d)	Current Annual Real Losses (% of System Input)	Authorised Consumption (λ/conn/d)
22	1 434	40.3	1 765
34	1 259	12.7	8 329
7	1 093	26.0	2 841
21	865	25.8	2 270
11	782	38.2	1 070
27	731	27.1	1 783
19	498	18.5	2 070
30	467	18.3	1 964
32	457	16.6	2 176
15	456	22.4	1 468
5	434	22.3	1 406
1	325	13.2	2 067
18	323	16.7	1 531
24	314	7.1	4 036
10	303	18.4	1 264
17	286	12.5	1 932
29	262	16.4	1 275
8	262	23.9	767
31	255	4.2	4 566
28	230	12.7	1 525
2	230	18.9	927
16	214	16.3	1 037
26	208	10.0	1 821
3	196	13.2	1 250
14	181	9.6	1 667
12	174	14.9	952
23	169	15.7	864
4	168	9.8	1 502
9	164	14.1	965
13	111	9.7	1 009
6	108	7.6	1 295
20	99	6.0	1 438
25	76	3.9	1 837
33	71	9.2	684

2.3.2. Current Annual Real Losses as Percentage of System Input Volume

The use of Current Annual Real Losses expressed as a percentage of System Input Volume as an indicator of leakage can often be misleading. This is due to the fact that the percentage leakage is heavily dependent upon the total consumption, which, in turn, varies significantly from one system to another. The same leakage can result in significantly different percentage losses, and for this reason percentage losses are not recommended as a comparative performance indicator.

In South Africa, this is particularly important due to the extreme conditions encountered in various parts of the country. In many parts of the country there are areas of great affluence where the water consumption per capita is very high. Adjoining these affluent areas are areas of extreme poverty where the per capita consumption is very low and often closer to 25 λ /head/day. If the two systems have similar levels of real leakage, the water supplier to the affluent area will be able to show a percentage leakage of less than 10% while the supplier to the low-income area may struggle to achieve leakage levels of below 20%. In reality, however, the supplier to the low-income area may be more efficient in reducing leakage than its counterpart in the affluent area, although this is not indicated by the percentage losses.

From **Fig. F.3** it can be seen the “Current Annual Real Losses” as percentage of System Input Volume range from about 4% to about 40% for the reference data set with an average value of 16%.

2.3.3. Current Annual Real Losses per Kilometre of Mains

The length of mains in a system provides an indication of the size of the system. “Length of mains” is defined as the total length of supply and distribution mains in the system. “Current Annual Real Losses by Volume” is the total “System Input Volume” minus the “Authorised Consumption” and the “Apparent Losses” (Refer to the BENCHLEAK User Guide for more detail).

This parameter is also closely linked to the size of the system and will depend largely on the “System Input Volume”, the basis of estimating “Apparent Losses” and the distribution of the “Authorised Consumption”.

The parameter provides an indication of the real water losses that are occurring in the system and the accuracy of this value depends on the reliability of the estimates of “System Input” and “Authorised Consumption”. An individual water supplier can rate the performance of his own system on an annual basis by using the “Annual Real Losses by

Volume". This parameter, however, can't be used to benchmark performance against other systems, since "System Input Volume", "Authorised Consumption" and "Apparent Losses by Volume" are different for each system.

The distribution of "Current Annual Real Losses by Volume" for the reference set ranges from approximately 25 M λ/yr to approximately 37 500 M λ/yr. Expressing "Current Annual Real Losses" as losses per kilometre of mains per day provides a more meaningful performance indicator and allows a direct comparison between different systems.

From **Fig. F.4**, it can be seen the "Current Annual Real Losses per Kilometre of Mains" ranges from approximately 2 000 λ/km of mains/d to approximately 50 000 λ/ km of mains/ day with an average value in the order of 17 000 λ/ km of mains/ day.

2.3.4. Current Annual Real Losses per Connection

As discussed in the previous section for the "Current Annual Real Losses per Kilometre of Mains", expressing the "Current Annual Real Losses" as losses per connection per day also helps to remove the influence of the size of the system, and allows a more direct comparison between different systems.

From **Fig. F.5** it can be seen the "Current Annual Real Losses per Connection" range from approximately 70 λ/conn/d to approximately 1 400 λ/conn/d with an average value in the order of 400 λ/conn/d.

2.3.5. Current Annual Real Losses per Connection per metre of Pressure

Different systems operate under different average operating pressures, as can be seen in **Section 2.2.2**. It is also known that leakage is influenced directly by pressure and in order to remove this influence the previous indicators of Real Losses can be divided by the average operating pressure.

Fig. F.6 shows the "Current Annual Real Losses per Connection per Metre of Pressure" and it can be seen that the values range from approximately 1.0 λ/conn/d /m pressure to almost 30 λ/conn/d/m pressure with an average value of approximately 10 λ/conn/d/m pressure.

2.4. SELECTED FINANCIAL PERFORMANCE INDICATORS

2.4.1. Summary of Results

Table 2.5 provides a summary of the financial performance indicators for the sample group. Real Losses as a percentage of the System Input Volume is discussed under **Section 2.3**. The total Non-Revenue water as percentage of System Input Volume ranges from about 6% to about 52%. Again, no definite trends can be picked up between the different groupings and the distribution seems to be irregular. The average percentage for the groups is almost uniform with 26%, 23% and 21% for Groups 1, 2 and 3 respectively.

Little confidence is attached to the data with regard to Non-Revenue water as a percentage of Running Cost. The reason for this is simply because it was evident that Water Suppliers found it difficult to provide a reasonably accurate break-up between the components of Non-Revenue water, which are:

- Unbilled Authorised Consumption,
- Apparent Losses, and
- Real Losses.

It is even more difficult for Water Suppliers to provide a break-up of the components of the Unbilled Authorised portion of Non-Revenue water. 9% of Water Suppliers could not provide an estimate of the average annual operating cost of the system. To this end, the distribution of Non-Revenue Water as a percentage of Running Cost is as given in **Table 2.4**.

Table 2.4: Distribution of Non-Revenue Water as % of Running Cost

Non-Revenue Water as % of Running Cost	% of Water Suppliers in this category
No data	9
1 – 10 %	15
11 – 20 %	31
21 – 30 %	15
31 – 40 %	15
41 – 50 %	6
51 – 60 %	0
61 – 70 %	3
71 – 80 %	3
81 – 90%	3
91 – 100%	0

Table 2.5: Selected Financial Performance Indicators

Utility Ref No.	Non-Revenue Water components as % of System Input Volume			Total Non-revenue water as % of	Non-Revenue Water components as % of Cost of Running System			Total Non-Revenue Water as % of
	Unbilled Consumption	Apparent Losses	Real Losses	System Input Volume	Unbilled Consumption	Apparent Losses	Real Losses	Annual Running Cost
Group 1 – Large (No of service connections > 50 000)								
1	18	3	13	34	19	4	8	31
2	0	5	19	24				0
3	0	3	13	16	0	3	10	13
4	5	2	10	17	5	2	5	12
5	0	6	22	28	2	27	56	86
6	10	2	8	20	19	4	8	31
7	0	6	26	33	1	8	15	24
8	0	6	24	30	0	9	17	26
9	0	4	14	18	0	6	10	16
10	2	5	18	25	2	6	11	19
11	4	10	38	52	10	21	38	69
12	0	3	15	18	0	5	11	16
Group Ave	**3**	**5**	**18**	**26**	**5**	**9**	**17**	**28**
Group 2 – Medium (10 000 < No of service connections < 50 000)								
13	0	2	10	12	0	4	7	11
14	0	2	10	12	0	3	7	10
15	0	6	22	28	0	8	22	30
16	0	4	16	21				0
17	0	3	13	16				0
18	0	4	17	21	0	7	12	19
19	6	5	18	29	10	8	17	35
20	0	2	6	8	0	3	14	18
21	2	6	26	35	5	14	24	42
22	0	10	40	50	0	31	41	72
Group Ave	**1**	**4**	**18**	**23**	**2**	**10**	**18**	**24**
Group 3 – Small (No of service connections < 10 000)								
23	0	4	16	20	0	6	12	18
24	0	2	7	9	0	1	5	6
25	9	1	4	14	23	2	3	28
26	18	3	10	30	14	2	9	25
27	0	7	27	34	0	14	18	32
28	24	3	13	40	35	5	7	46
29	0	4	16	20	0	5	7	11
30	7	5	18	30	10	7	18	35
31	0	1	4	6	1	4	3	8
32	0	4	17	21	0	0	1	1
33	0	2	9	11	0	2	9	11
34	0	3	13	16	0	0	1	1
Group Ave	**5**	**3**	**12**	**21**	**7**	**4**	**8**	**19**
Sample Ave	**3**	**4**	**16**	**23**	**5**	**7**	**14**	**24**

2.4.2. Real Losses as a Percentage of Running Cost

"Real Losses" are generally valued in terms of the purchase price of the water by the water supplier or the cost of producing the water in the case of suppliers who abstract and purify their own water rather than purchasing from a bulk supplier. In order to express the "Real Losses" in financial terms they are often given as a percentage of the total running cost of the system. Expressing the losses in such terms often serves as an incentive for water suppliers to play a more active role in leakage management. The "Real Losses as a percentage of Running Cost" are shown in **Fig. F.7** and range from approximately 1% to 55% with an average value in the order of 15%.

2.4.3. Non-Revenue Water as a Percentage of System Input Volume

Non-Revenue water comprises the following components:

- Unbilled Authorised Consumption,
- Apparent Losses,
- Real Losses.

Apparent losses represent direct loss of income to the water supplier and are therefore usually expressed in terms of the selling price of the water and not the purchase price, as was the case for the "Real Losses". The "Unbilled Authorised Consumption" would also normally be expressed in terms of the selling price of water by the supplier. It is sometimes useful to express the total "Non-Revenue Water" as a percentage of the total volume of water going into the system in order to gauge the performance of the system from year to year. "Non-Revenue Water as Percentage of System Input Volume" is shown in **Fig. F.8** and range from approximately 6% to more than 50% with an average value of almost 25%.

2.4.4. Non-Revenue Water as a Percentage of Running Cost

A more meaningful performance indicator for the non-revenue water is to express it as a percentage of the annual system operating cost. The results form the sample data sets are shown in **Fig. F.9**, and as can be seen, the values range from approximately 1% to more than 80% with an average value of almost 25%.

2.5. KEY PERFORMANCE INDICATORS

2.5.1. Summary of Results

Table 2.6 provides a summary of the key performance indicators for the sample group, which is the Unavoidable Annual Real Losses (UARL) and the Infrastructure Leakage Index (ILI). These two parameters are the ultimate measure of the BENCHLEAK Model as an unbiased tool that successfully removes various influential factors when benchmarking the performance of one system against that of another.

Table 2.6: Key Performance Indicators

Utility Ref No.	Unavoidable Real Losses		Infrastructure Leakage Index
	(Mλ/yr)	(λ/conn/d)	
Group 1 – Large (No of service connections > 50 000)			
1	6 086	53	6.2
2	4 510	44	5.2
3	2 722	46	4.2
4	3 322	57	3.0
5	3 202	83	5.2
6	1 576	41	2.6
7	3 526	121	9.1
8	1 237	48	5.4
9	1 452	58	2.9
10	1 752	70	4.3
11	1 682	77	10.2
12	1 083	51	3.4
Group Ave	**2 679**	**62**	**5.1**
Group 2 – Medium (10 000 < No of service connections < 50 000)			
13	860	50	2.2
14	604	39	4.6
15	499	38	11.8
16	722	58	3.7
17	776	66	4.3
18	829	73	4.4
19	349	53	9.4
20	305	51	1.9
21	190	49	17.5
22	275	73	19.8
Group Ave	**541**	**55**	**8.0**
Group 3 – Small (No of service connections < 10 000)			
23	203	58	2.9
24	165	49	6.4
25	119	37	2.0
26	120	56	3.7
27	113	73	10.0
28	124	85	2.7
29	39	40	6.5
30	33	50	9.4
31	28	58	4.4
32	21	40	11.3
33	26	73	1.0
34	7	74	17.0
Group Ave	**83**	**58**	**6.4**
Sample Ave	**1 134**	**59**	**6.4**

No definite trends are evident with regard to the distribution of the UARL or the ILI for the three groups. The average value for the UARL for Groups 1, 2 and 3 are 62, 55 and 58 λ/conn/d respectively. For the ILI it is 5.1, 8.0 and 6.4 for Groups 1, 2 and 3 respectively.

The distribution of the UARL and ILI for the total sample group is given in **Table 2.7**.

Table 2.7: Distribution of UARL and ILI

UARL Category (λ/conn/d)	% in this category	ILI Category	% in this category
31 – 40	15	1 – 5	62
41 – 50	24	6 – 10	23
51 – 60	28	11 – 15	6
61 – 70	6	16 – 20	9
71 – 80	18	> 20	0
81 – 90	6		
91 – 100	0		
> 101	3		

2.5.2. Unavoidable Annual Real Losses per Connection

It is impossible, even in well-managed systems, to eliminate leakage completely. It is clear that there is some minimum level of leakage that can be considered as the "Unavoidable Annual Real Losses" for any given system. The method for calculating the unavoidable leakage is provided in the BENCHLEAK User Guide and is not repeated in the current document. The volume of unavoidable leakage for any system is directly related to the size of the system (length of mains and number of service connections) together with the average operating pressure.

The "Unavoidable Annual Real Losses" by volume is on its own a meaningless parameter, unless it is divided by the length of mains or number of service connections. The "Unavoidable Annual Real Losses per Connection" is the preferred performance indicator. The "Unavoidable Annual Real Losses" per connection for the reference data set are shown in **Fig. F.10** and vary from approximately 40 λ/conn/d to almost 120 λ/conn/d with an average value in the order of 60 λ/conn/d.

2.5.3. Infrastructure Leakage Index (ILI)

The Infrastructure Leakage Index (ILI) is the most recent and preferred performance indicator for comparing leakage from one system to another. It is a non-dimensional index representing the ratio of the current real leakage and the "Unavoidable Annual Real Losses" (UARL). A high ILI value indicates poor performance with large potential for improvement while a small ILI value indicates a well-managed system with less scope for improvement.

Fig. F.11 shows the distribution of the Infrastructure Leakage Index for the reference data set. From the graph it can be seen that the ILI values range from 1.0 to approximately 20.0 with an average value in the order of 6.4. This can be compared to ILI values calculated by International Water Data Comparisons Ltd for 27 supply systems in 19 countries that range from 1.0 to 10.0 with an average value of 4.2.

2.6. TERMS NOT TO BE INCLUDED FOR COMPARING SYSTEMS

The following parameters are useful indicators of the size of a system or of the water used in a system, but cannot be used as performance indicators:

- **Length of mains**
- **System Input Volume**
- **Authorised Consumption by Volume**

The following terms can be used as performance indicators, but are normally not regarded as meaningful indicators and are rarely used for comparing systems:

- **Authorised Consumption per Connection:** The "Authorised Consumption per Connection" is simply calculated by dividing the "Authorised Consumption" by the number of service connections in the system. From **Fig. F.12** it can be seen that the "Authorised Consumption per Connection" ranges from approximately 700 λ/conn/d to more than 8 000 λ/conn/d.

- **Ratio of Authorised Consumption to System Input Volume:** The ratio of the "Authorised Consumption" to the "Total System Input Volume" can be seen in **Fig. F.13** and ranges from approximately 0.50 to 0.95.

- **Ratio of Total Losses to Authorised Consumption: Fig. F.14** shows the distribution of the Ratio of "Total Losses" to "Authorised Consumption" for the reference data set. Expressing the "Total Losses" as a ratio of "Authorised Consumption" enable water suppliers to rate the volume of water that is lost in terms of the volume of water that is consumed. Although this is not one of the preferred performance indicators, it can be of interest to water suppliers. For the reference data set, the highest ratio was found to be 1.02, indicating that the “Total Losses” were slightly more than the “Authorised Consumption” (clearly a situation of concern). The smallest ratio of 0.05 indicates that the “Total Losses” are only 5% of the “Authorised Consumption by Volume”.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1. CONCLUSIONS

From the information gathered during the leakage-benchmarking case study, several conclusions can be drawn:

- The South African water supply industry is generally lagging best international practices with respect to leakage management in potable water distribution systems. It was only during 1996 that the Water Research Commission (WRC) identified the need to control the level of unaccounted-for water in South Africa with the result that the development of a standard methodology or terminology for the calculation of water losses was only initiated in the late 1990's.
- The information required to calculate the various performance indicators used in this case study is often not available from the water suppliers, despite the fact that the information is very basic. For example, many water suppliers have difficulties in providing information such as the total length of mains and number of service connections in their system.
- While the benchmarking procedure was initially developed for complete water distribution systems, the same approach can easily be used for individual management zones within a single supply system. In this manner this approach can be used to identify problem management zones within a system as well as to compare one system with another.
- Water supply systems in South Africa are poorly metered with regard to both bulk and consumer metering.
- The ILI values for the sample group range from 1.0 to approximately 28.0 with an average value in the order of 7.0. The average values are 5.1, 8.0 and 6.4 for Groups 1, 2 and 3 respectively. This can be compared to ILI values calculated by International Water Data Comparisons Ltd for 27 supply systems in 19 countries that range from 1.0 to 10.0 with an average value of 4.2.
- For South African conditions it would be unusual to achieve an ILI value of below 2.0 and values in the order of 5.0 are common and represent systems in a reasonable condition. For smaller systems one would expect that since these systems are smaller and easier to manage, it should be possible to achieve an ILI of 3.0 through improved management practices. This suggests that there is considerable scope for improvement in Groups 2 and 3, while Group 1 could probably achieve an ILI of about 4.0.

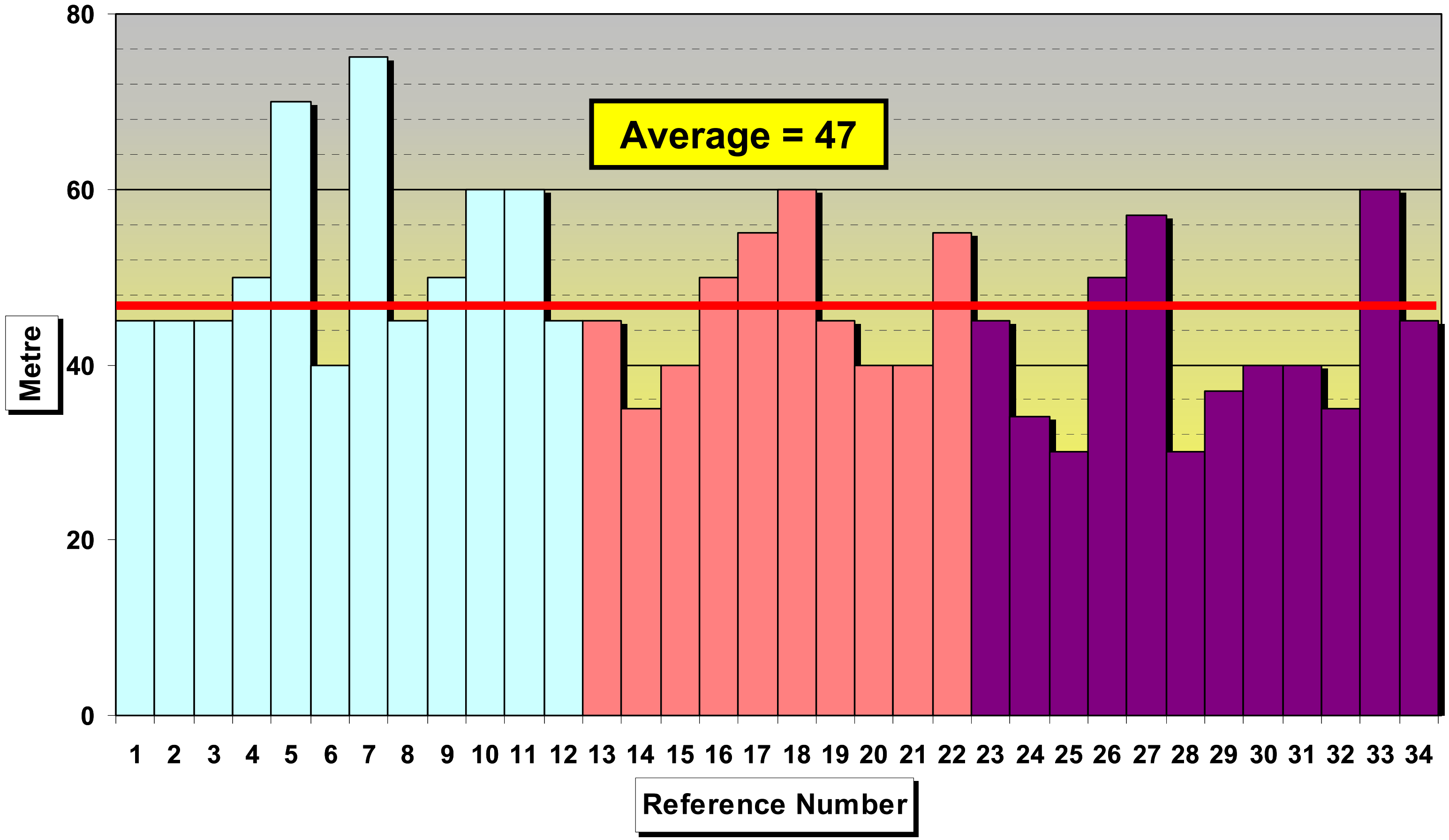
3.2. RECOMMENDATIONS

Based on the conclusions from this report, it is recommended that:

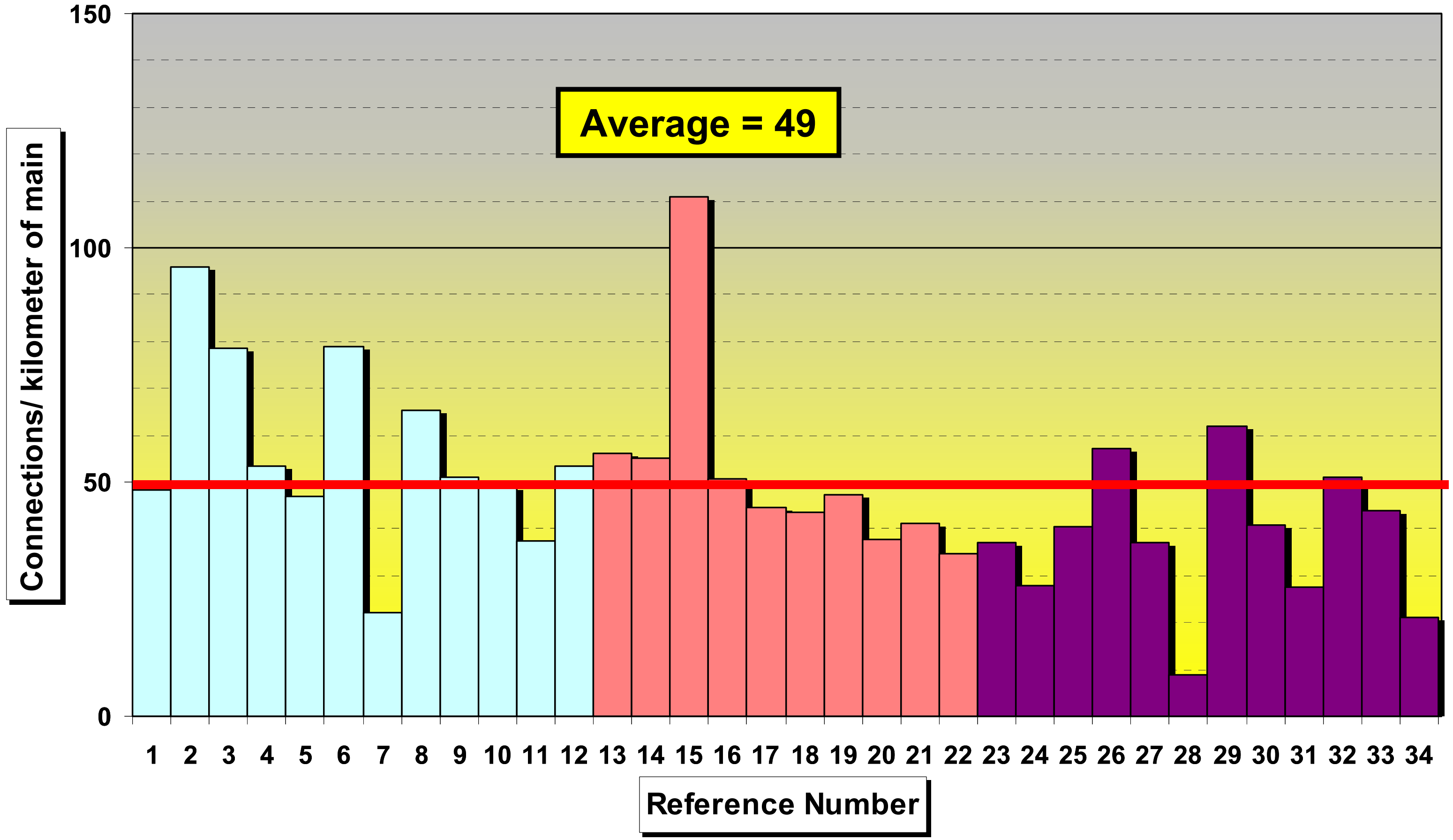
- The importance of leakage management should gain greater exposure and emphasis from water services institutions such as the Water Research Commission and the Department of Water Affairs and Forestry.
- Water services authorities and providers should be made aware of the existence of the leakage-benchmarking methodology in order to create an environment of cooperation when water services institutions embark on further case studies.
- The performance indicators used to benchmark different water suppliers should be chosen carefully in order to make benchmarking across different categories of service providers or demarcation areas meaningful.
- Users of the benchmarking model should familiarise themselves fully with the content of the BENCHLEAK User Guide, before embarking on applying the model.
- The benchmarking model should be compiled into a full database for the South African water supply industry to facilitate collection and collation of data for an ongoing annual national benchmarking exercise. The results can then be presented in a standard format and sent to all water suppliers who will participate in the exercise. Obviously some of the figures quoted in this case study are based on a number of broad assumptions and the true situation can only be established if all of the approximately 300 service providers complete the BENCHLEAK form. The figures do, however, indicate the possible magnitude of Real Losses throughout the country.

APPENDIX F

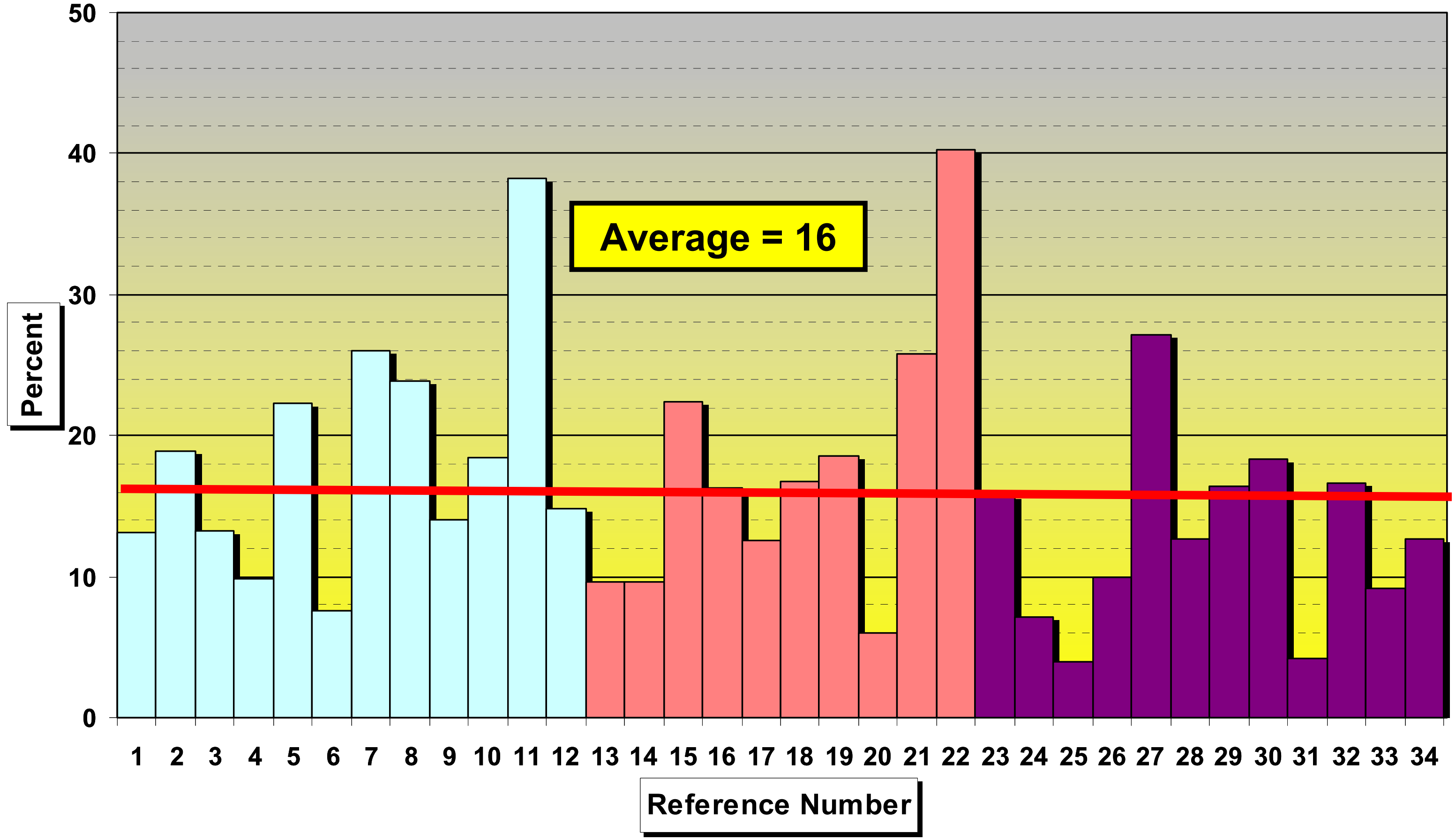
Results for Participating Water Suppliers



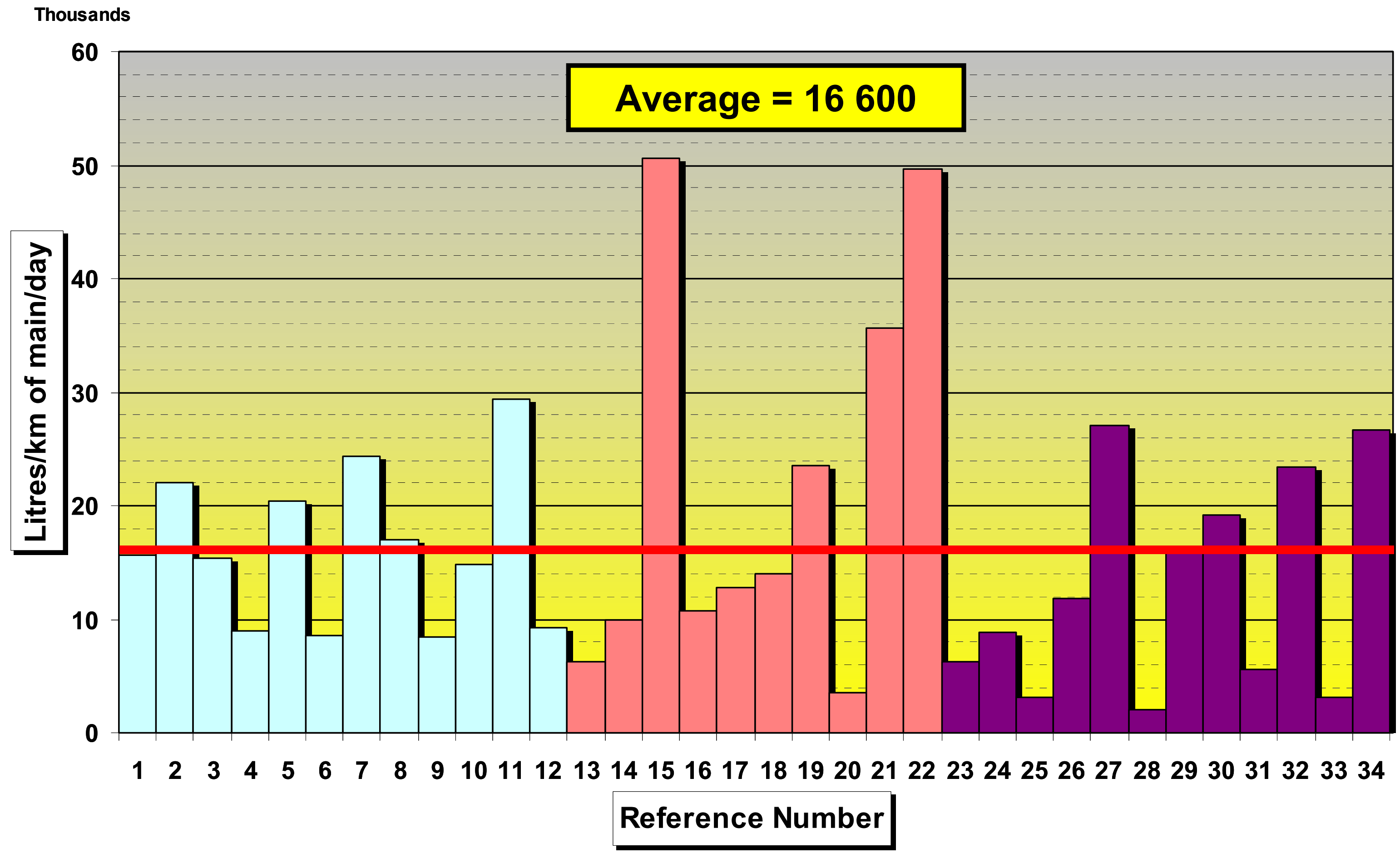
	wrp	Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Average operating pressure	**Fig. F.1**



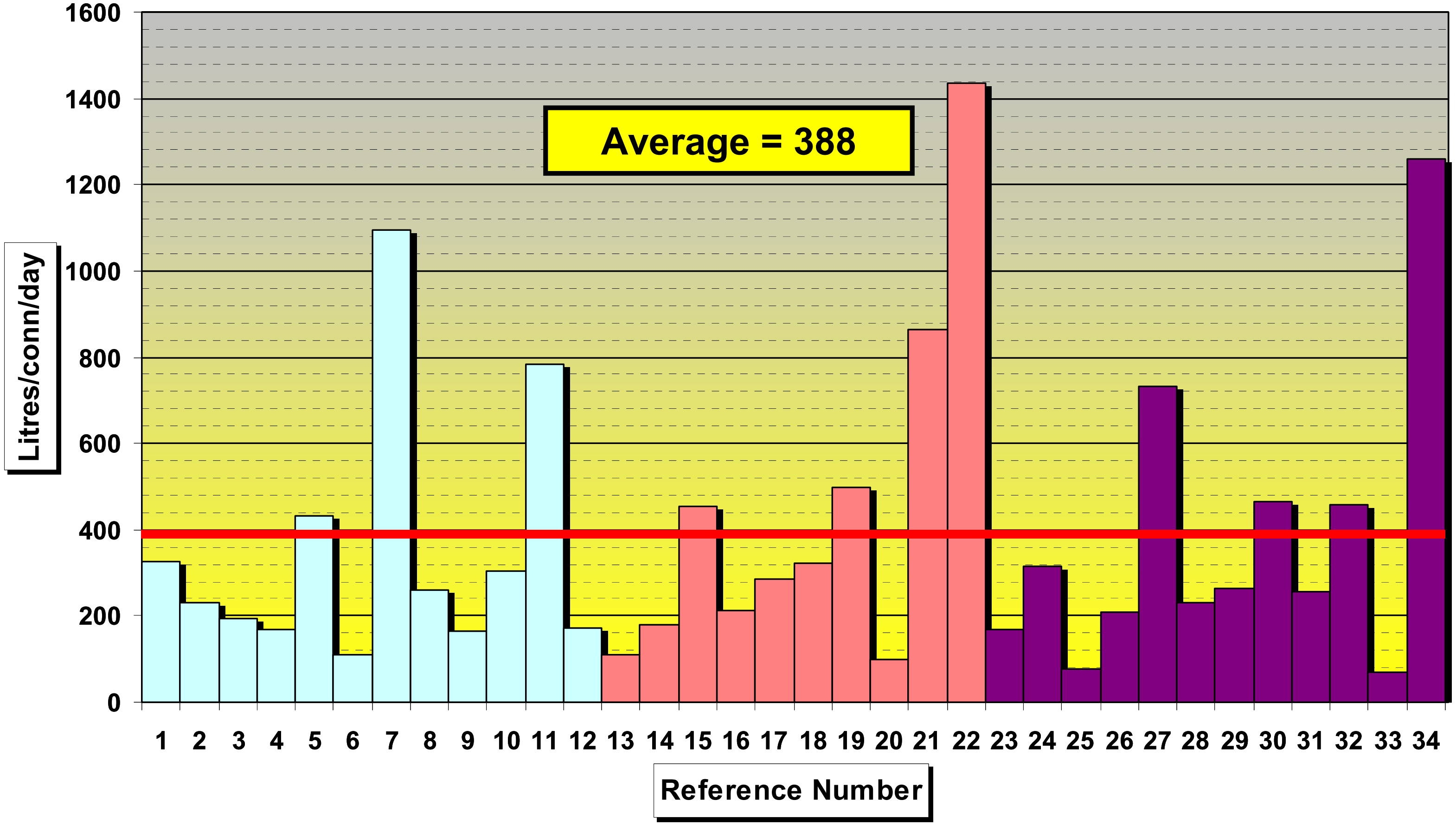
		Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Density of connections	**Fig. F.2**



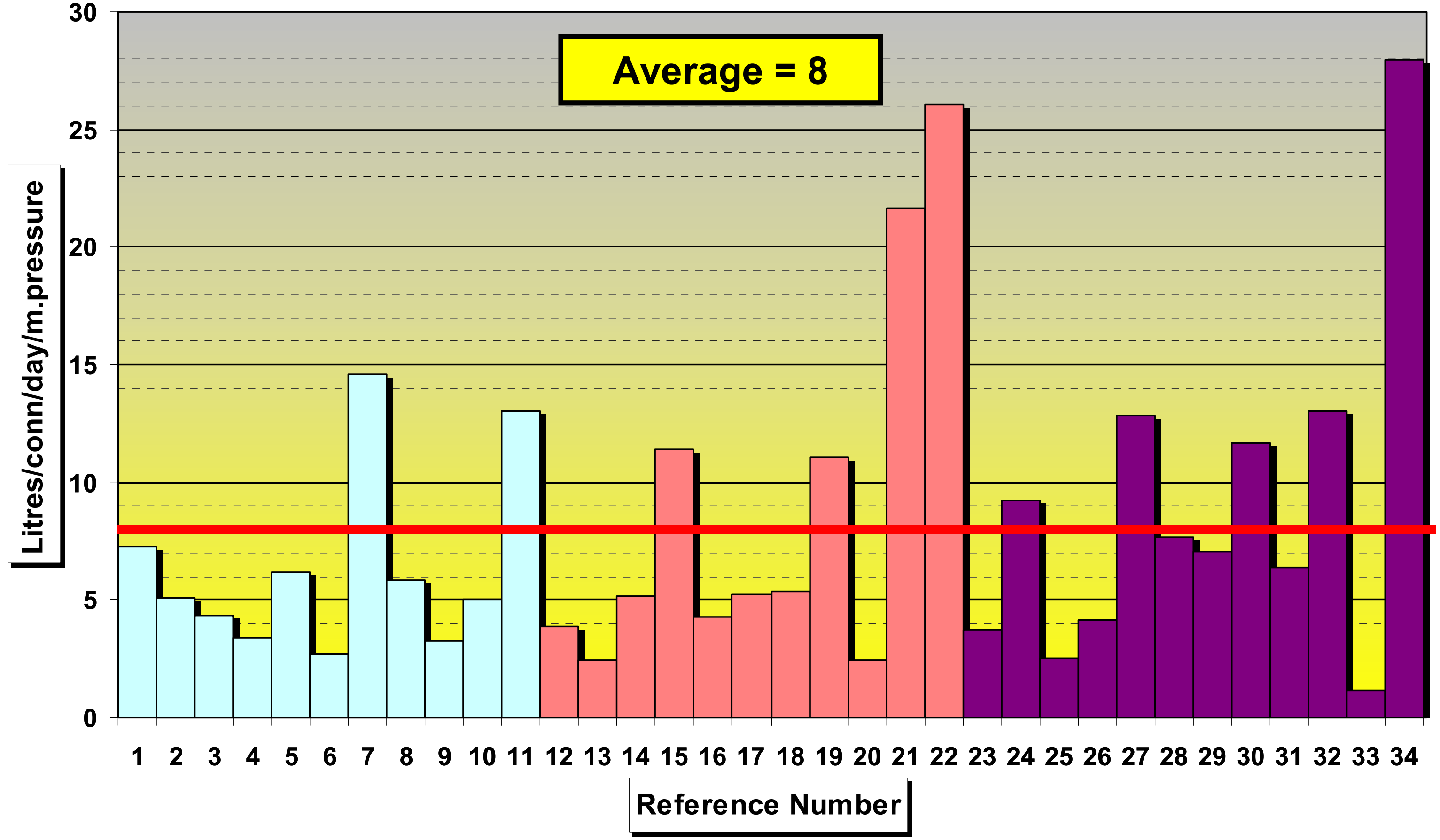
wrp	Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Current Annual Real Losses as a percentage of the System Inout Volume	**Fig. F.3**



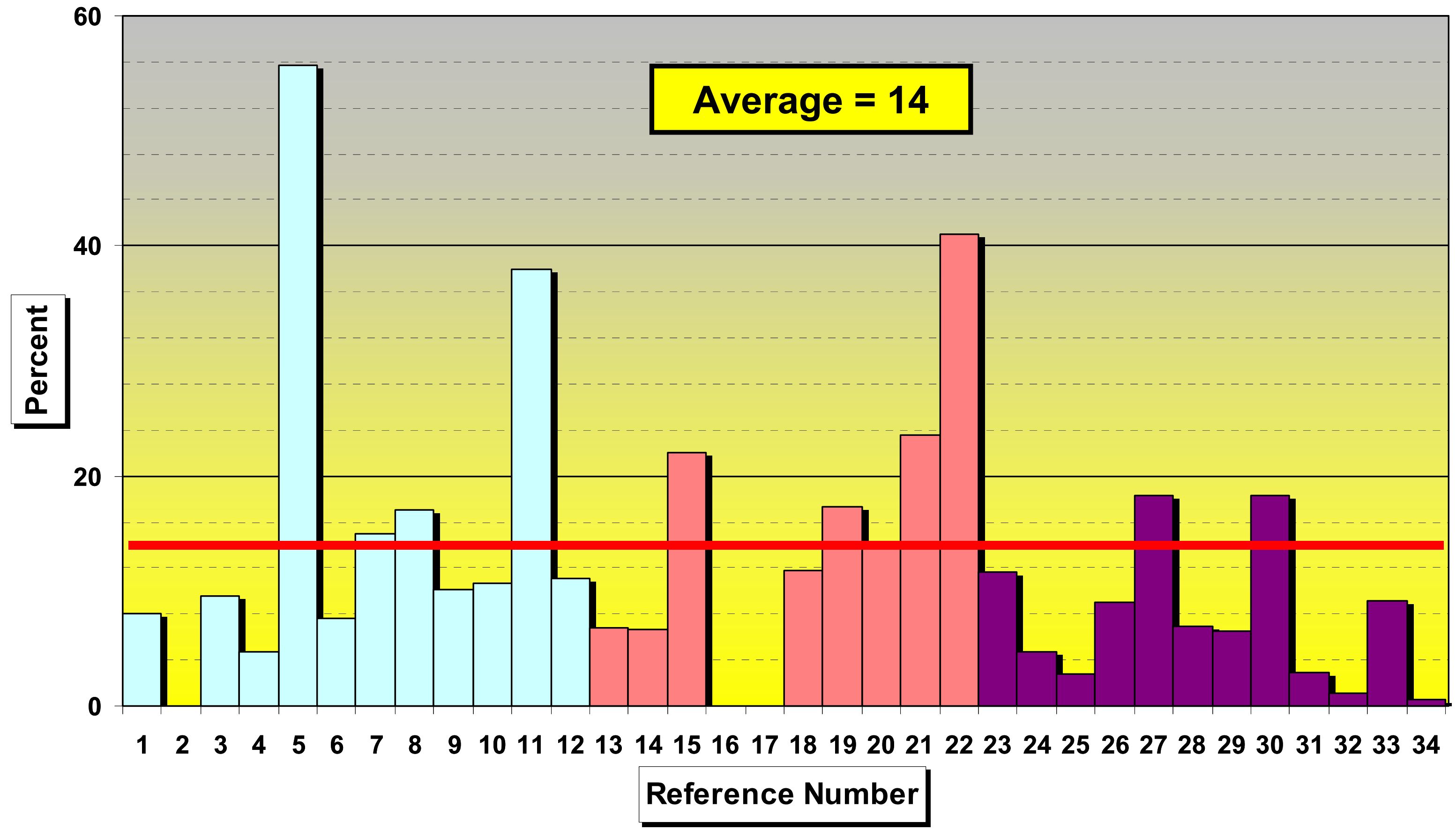
	wrp	Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Current Annual Real Losses per km of mains per day	**Fig. F.4**



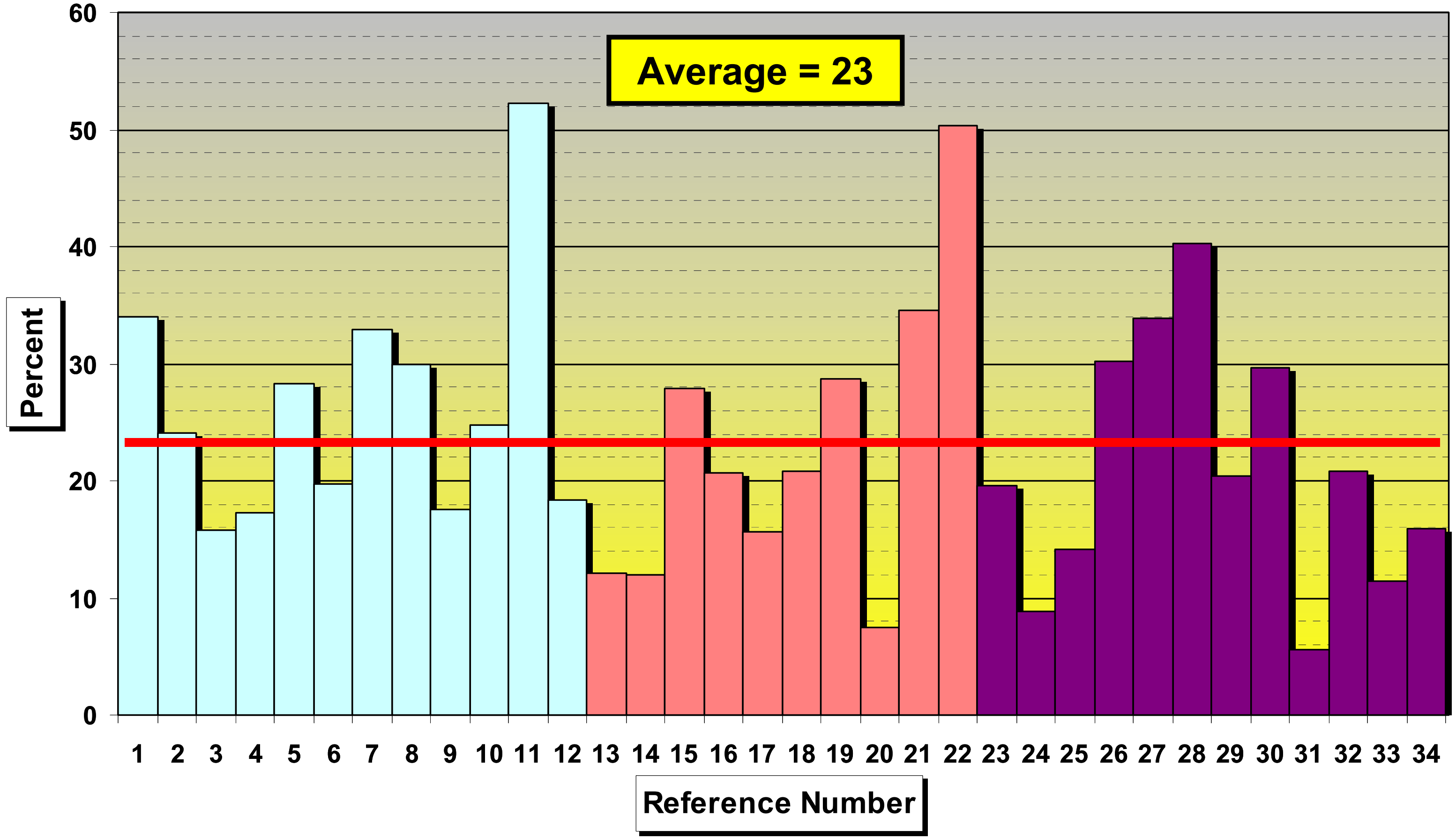
	wrp	Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Current Annual Real Losses in litres per connection per day	**Fig. F.5**



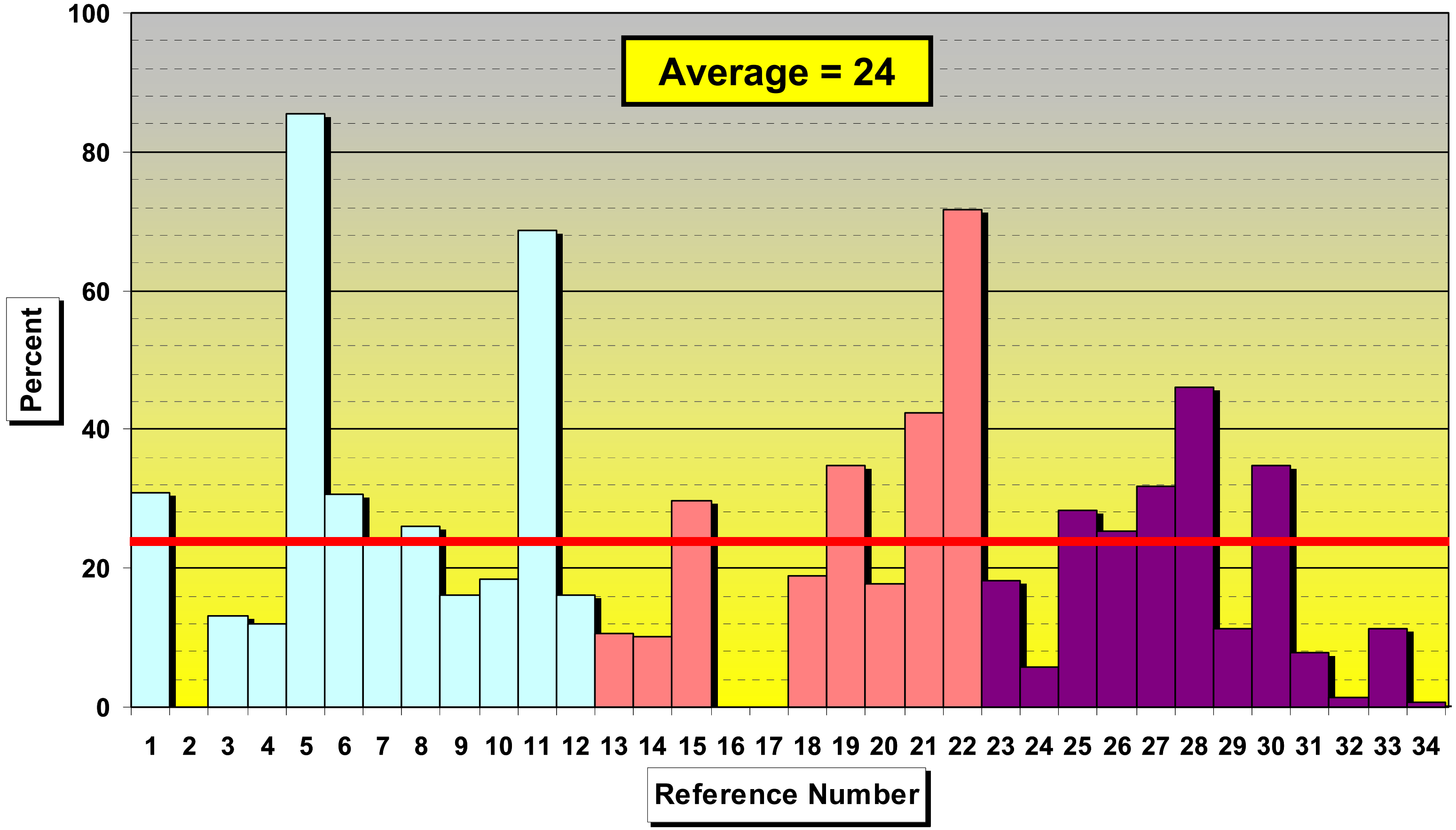
		Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Current Annual Real Losses in litres per connection per day/ metre of pressure	**Fig. F.6**



		Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Real Losses as a percentage of the annual Running Cost	**Fig. F.7**



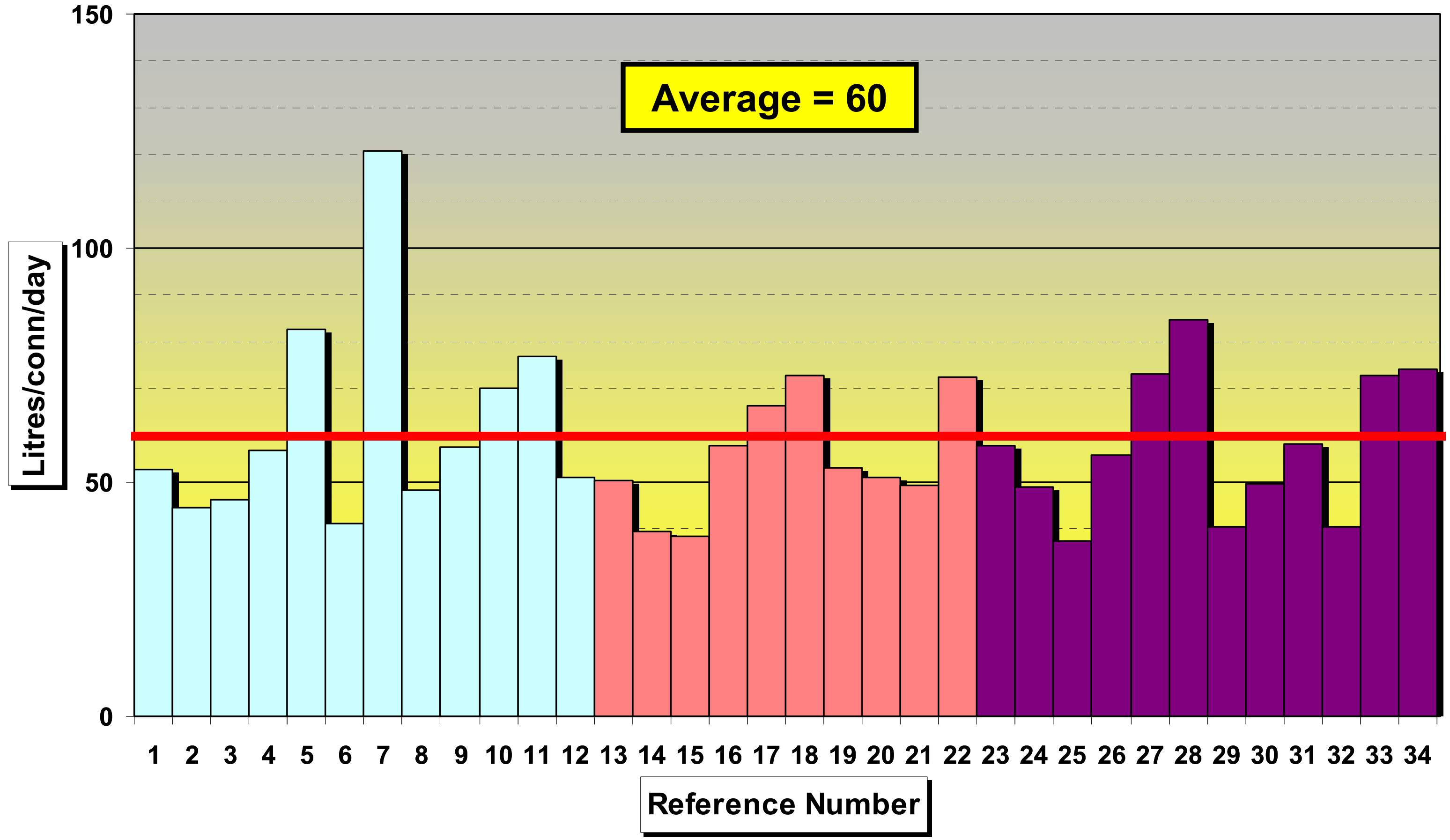
Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Non-Revenue water as a percentage of the System Input Volume	**Fig. F.8**



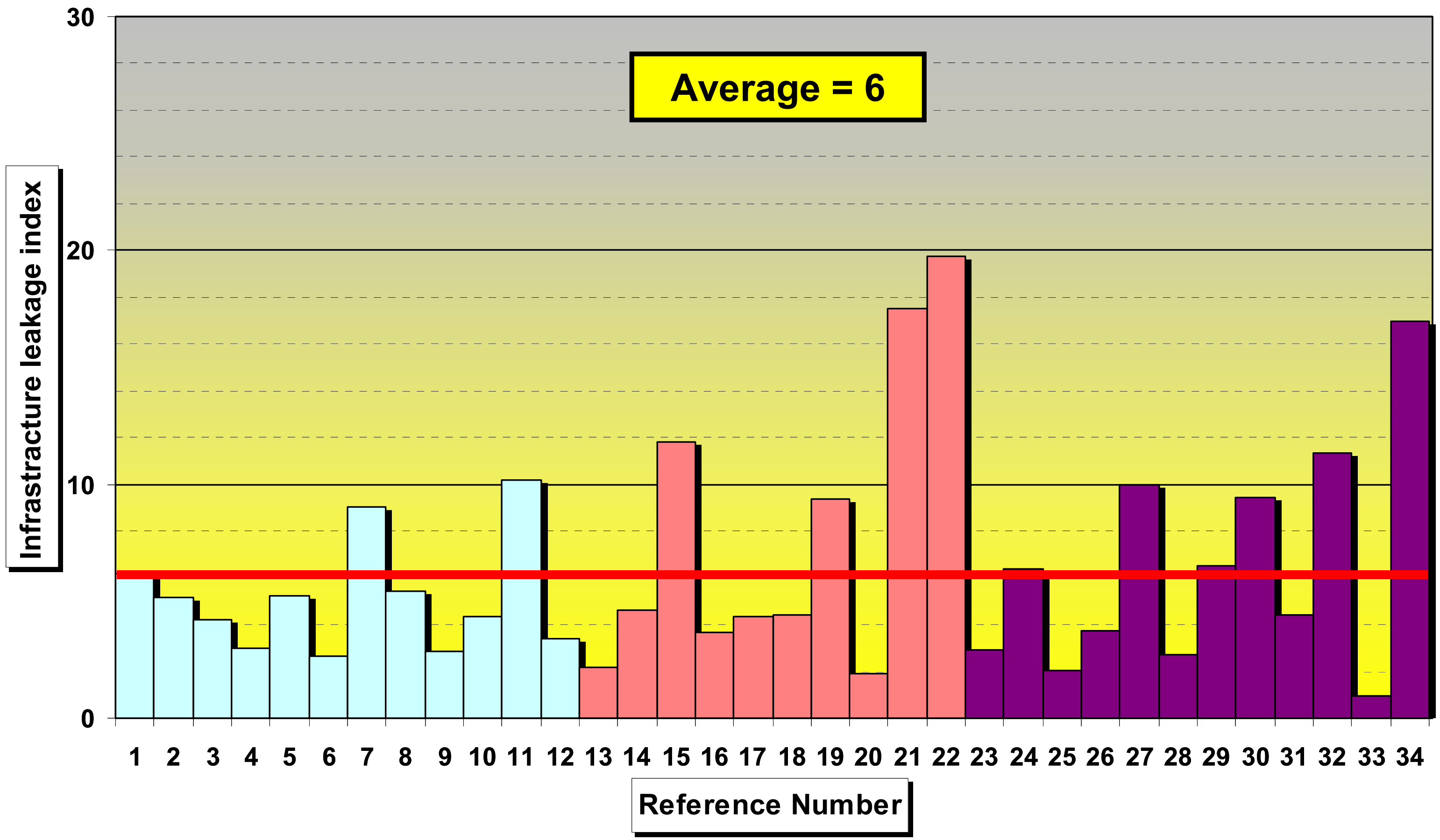
Benchmarking of Real Water Leakage in South Africa
Results and Analysis of Local Authorities Data Using BENCHLEAK

Non-Revenue water as a percentage of the annual Running Cost

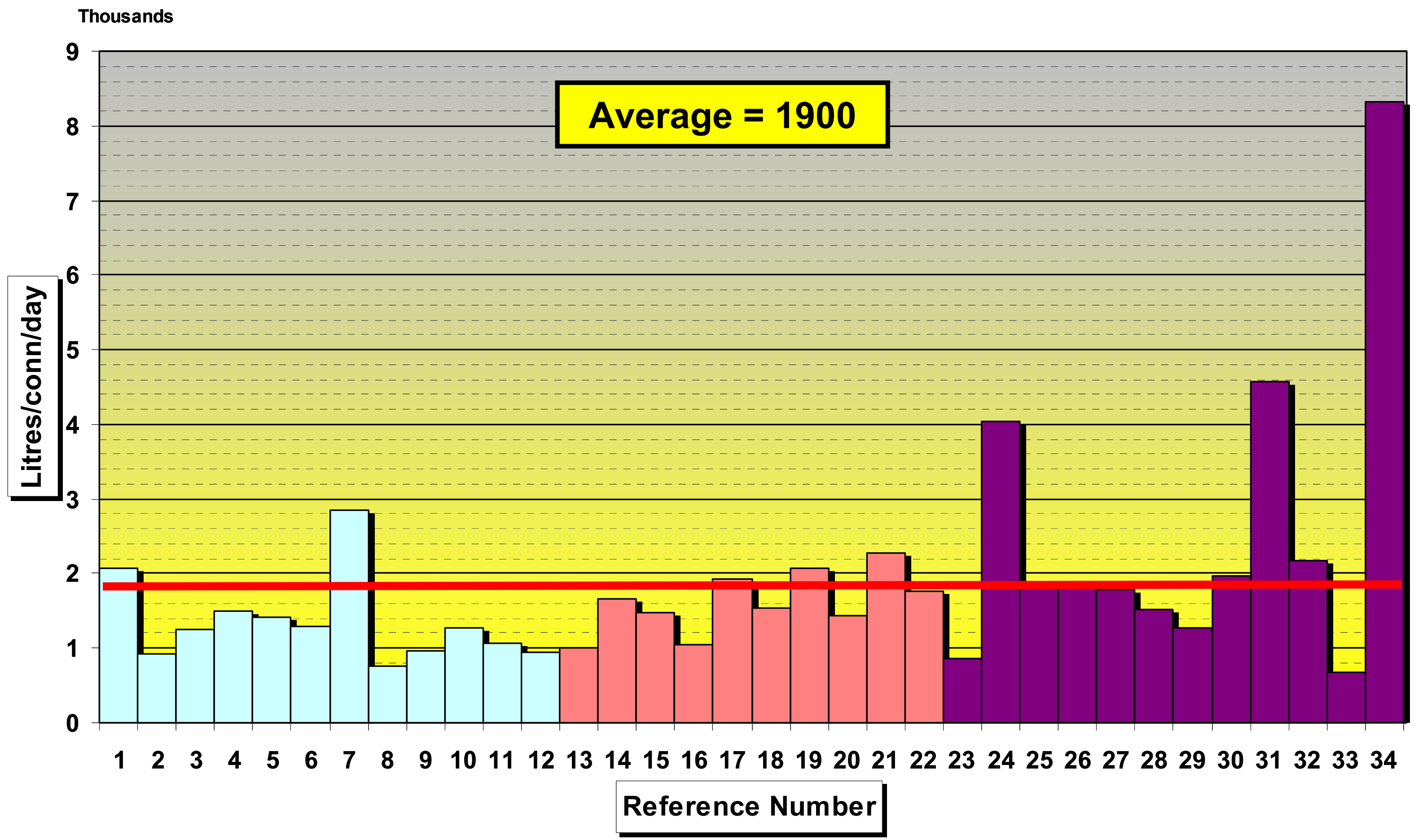
Fig. F.9



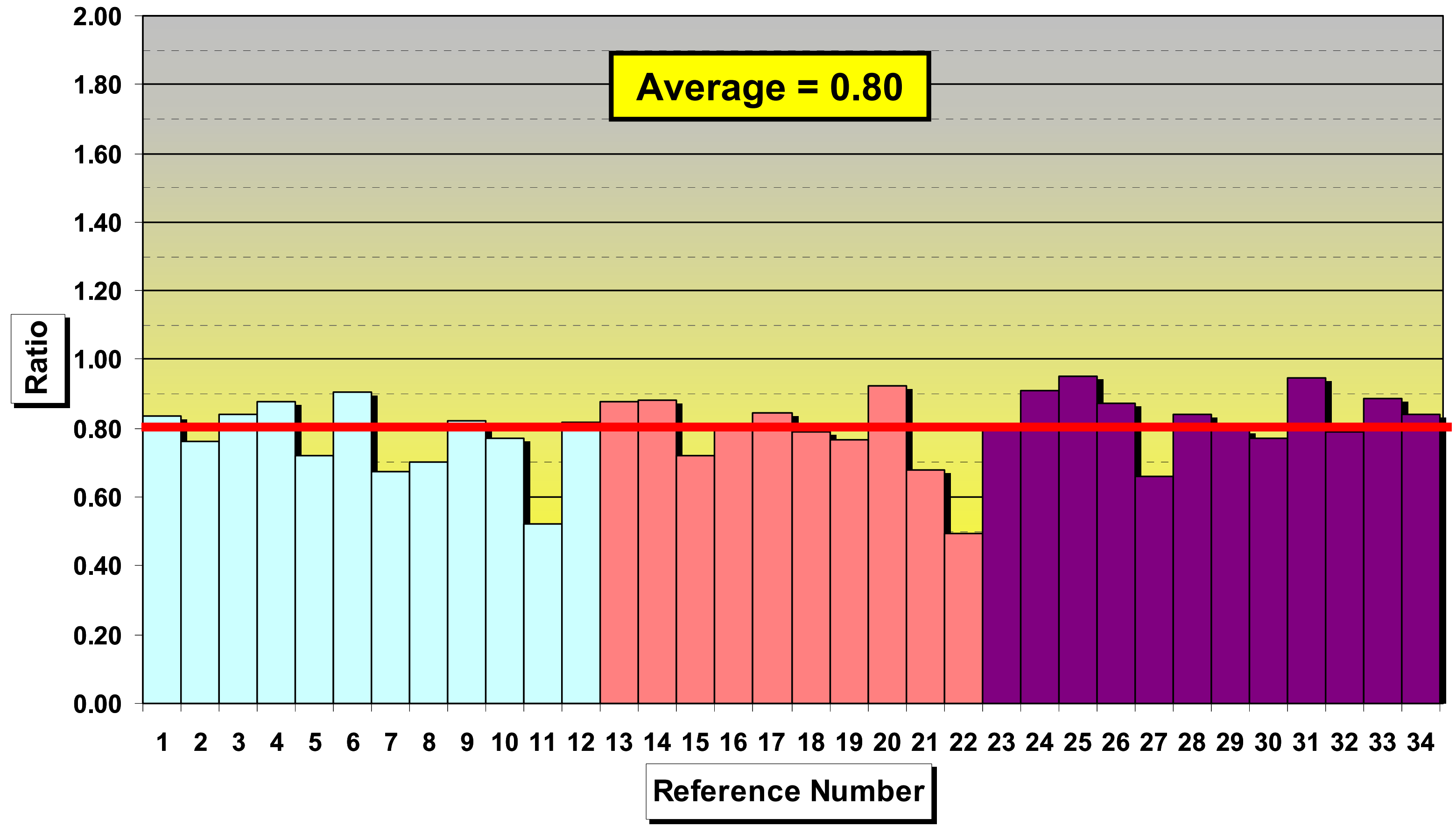
wrp	Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Unavoidable Annual Real Losses in litres per connection per day	**Fig. F.10**



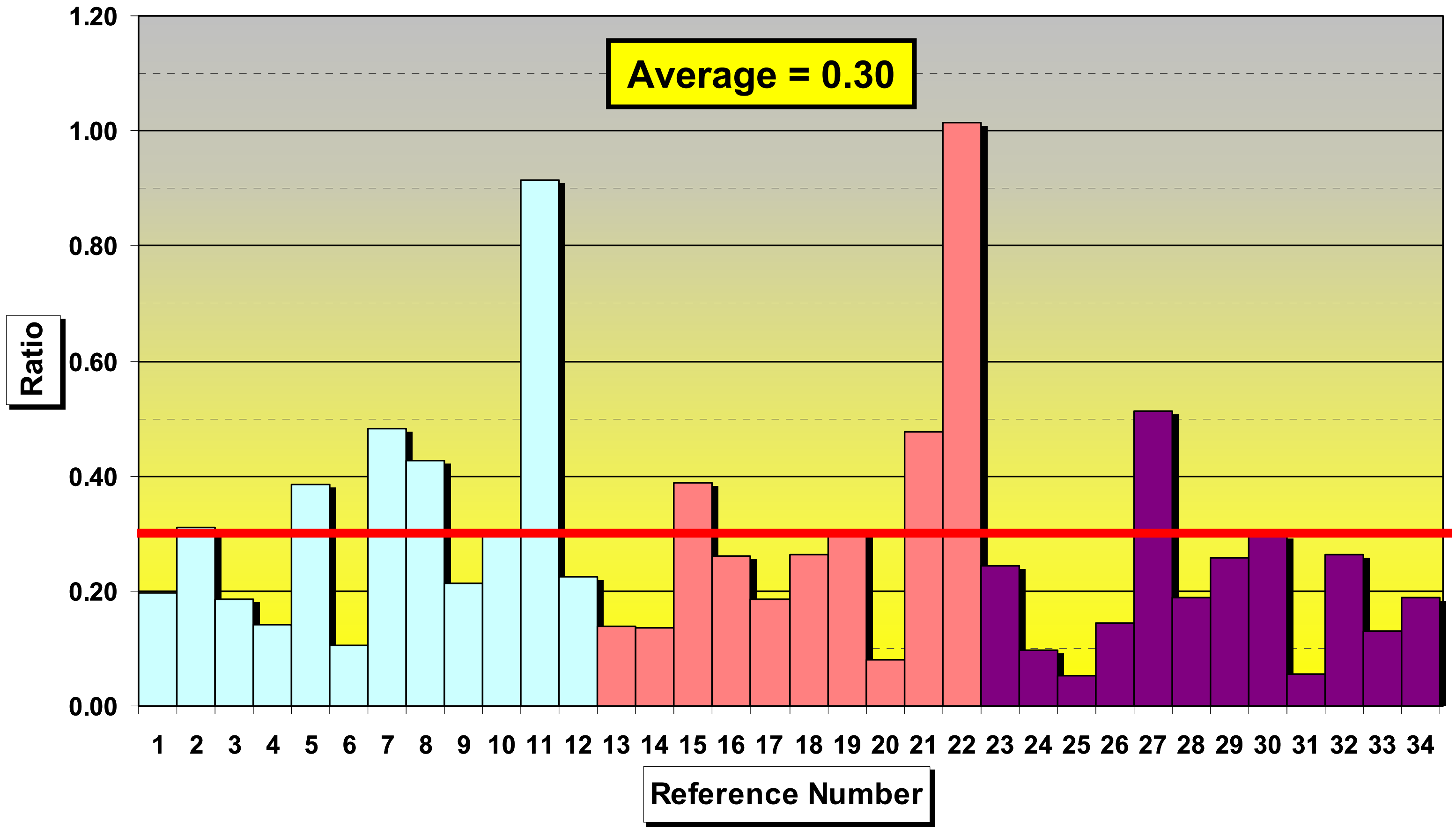
	wrp	Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Infrastructure Leakage Index	**Fig. F.11**



Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Authorised Consumption in litres per connection per day	**Fig. F.12**



		Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Ratio of Authorised Consumption to System Input Volume	Fig. F.13



	Benchmarking of Real Water Leakage in South Africa Results and Analysis of Local Authorities Data Using BENCHLEAK	Ratio of Total Losses to Authorised Consumption	**Fig. F.14**