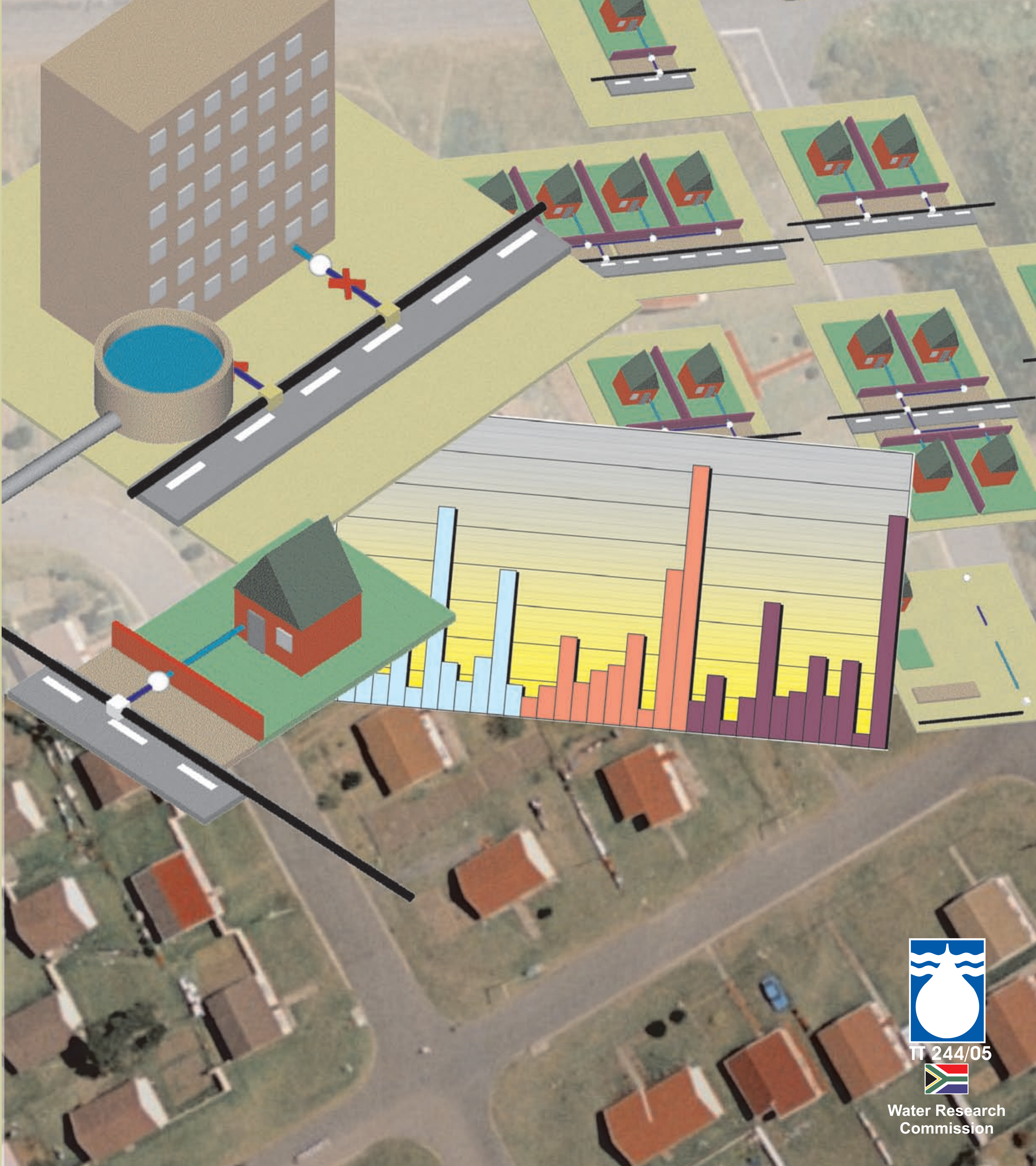
Benchmarking of Leakage from Water Reticulation Systems in South Africa

R McKenzie and C Seago



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Water Research Commission

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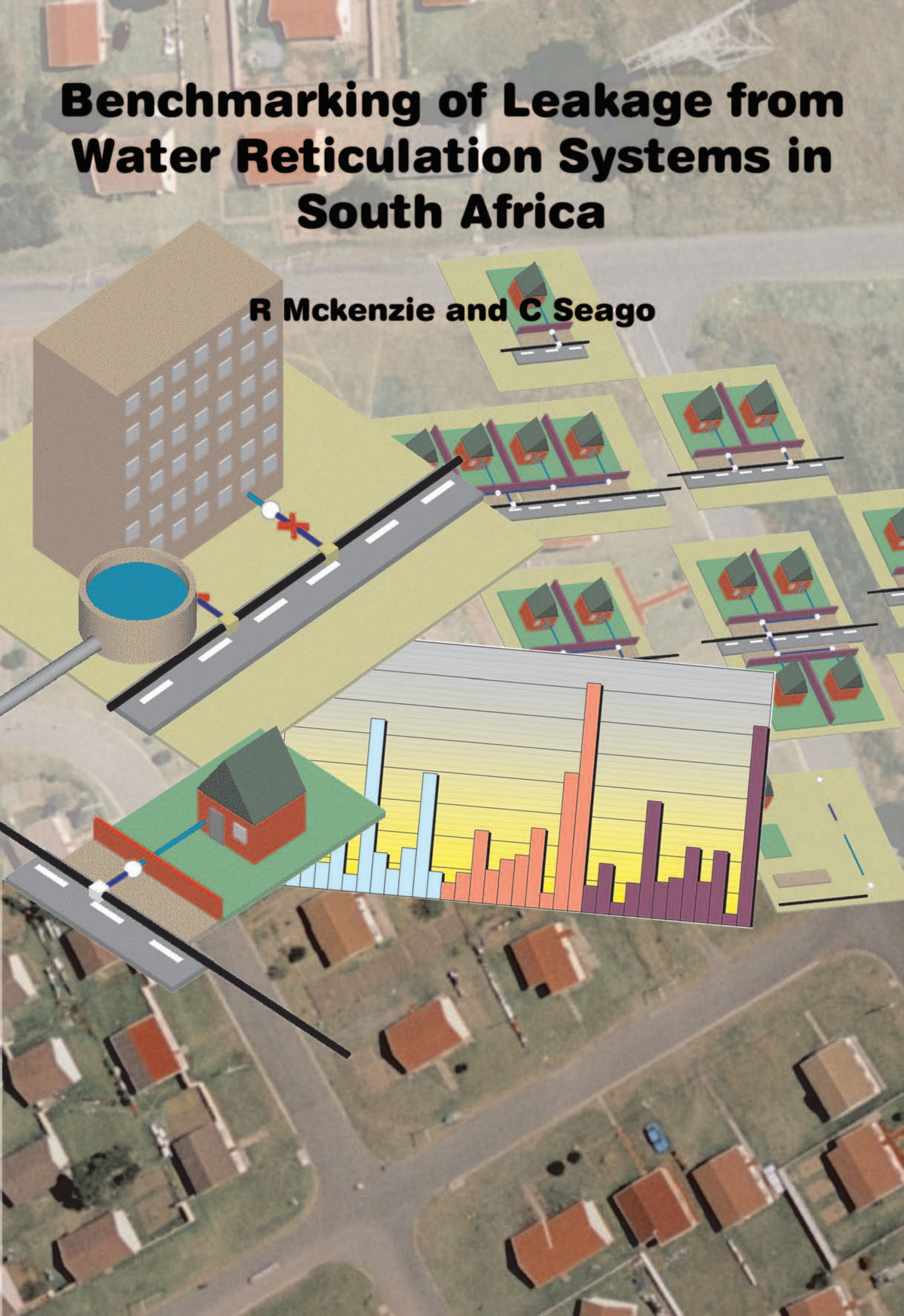

Benchmarking of Leakage from Water Reticulation Systems in South Africa

Report to the Water Research Commission

by

R. Mckenzie and C. Seago

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Water Research Commission
Private Bag X03
Gezina
0031

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EXECUTIVE SUMMARY

A study was undertaken through the WRC in order to assess the levels of leakage in various water utilities throughout South Africa. The study was effectively an extension to a previous study in which the standard water auditing model BENCHLEAK, was developed through the WRC. The BENCHLEAK model was developed to evaluate levels of leakage and non-revenue water in potable water distribution systems. The first study involved developing the model with a limited budget for checking the various data sets used to test the model. The main objective of the follow-on study was therefore to use the model to evaluate the levels of leakage in approximately 30 water utilities throughout South Africa. The BENCHLEAK model is relatively simple to use and is based on the standard IWA water auditing methodology.

Data from approximately 60 water suppliers were obtained and after careful screening the sample data set was reduced to 30 suppliers. For each supplier, various performance indicators were evaluated which are presented in the report. For the purpose of leakage evaluation, it was agreed that the most reliable and meaningful indicator is the Infrastructure Leakage Index (ILI) which is presented in Figure 1 for 27 of the water utilities considered in the analyses. This relatively new PI is the ratio of the Current Annual Real Losses (CARL) to the Unavoidable (Technical Minimum) Annual Real Losses (UARL) and is discussed in detail in the paper by Lambert et al (1999). The ILI provides an indication of how effectively a utility is managing real losses under the current operating pressure regime.

A clearly defined water balance is the first essential step in the assessment of volumes of Non-revenue water and the management of water losses in potable water distribution systems. The standard IWA water balance provides a breakdown of the water that enters a particular system into various components and in so doing allows the system manager / operator to establish the quantities of water is being used or lost.

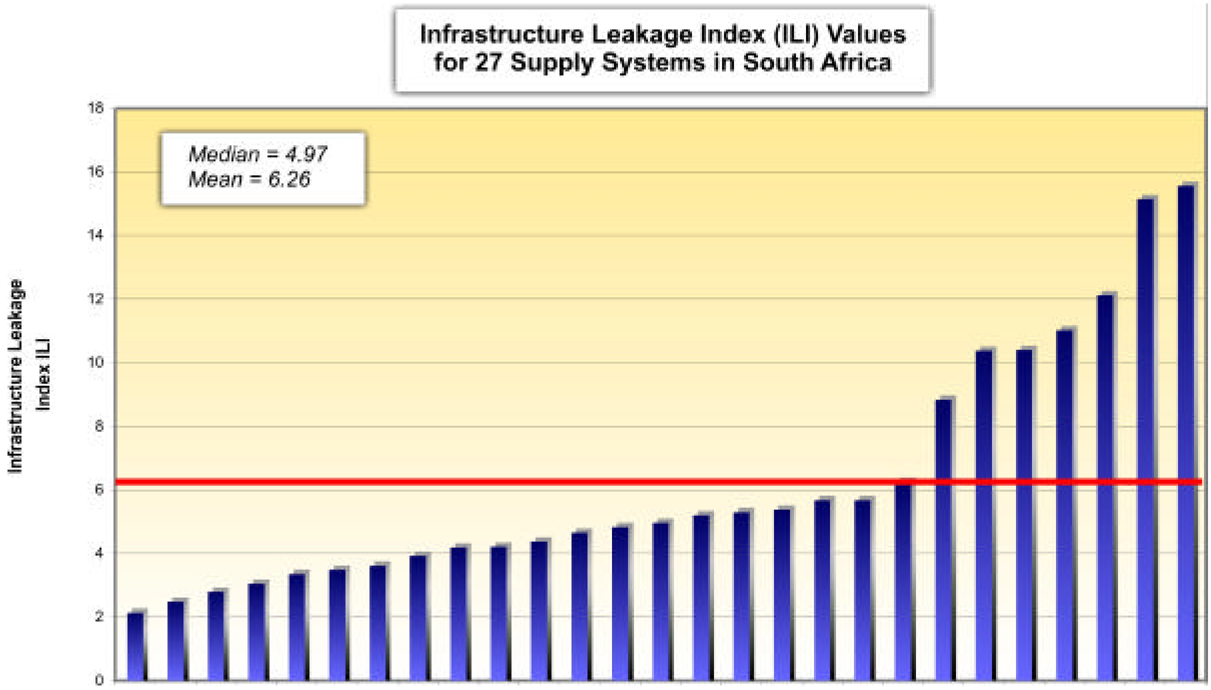

Figure 1: ILI results for 27 systems in South Africa

From Figure 1 it can be seen that the ILI values for the South African data range from 2.0 to approximately 15.5 with an average value in the order of 6.0. An ILI value of 6 indicates that if 1 litre of water is considered to be unavoidable leakage on mains and service connections, 6 litres is actually physically being lost and therefore 5 litres could theoretically be saved through some form of intervention. Having said this however, experience shows that it is not normally economically viable to target a leakage below a certain level, and for this reason an ILI value of 2 to 3 would generally be considered very efficient for South African water utilities. In the case of the system with an ILI of 6, as mentioned above for example, it would not be economically viable to try and target an ILI of below 3. This in turn, would suggest that a realistic leakage reduction of 3 could be achieved from each 6 litres of leakage.

The data set shown in **Figure 1** can now be compared to several other international data sets compiled by various WDM specialists from around the world and some results from the UK, North America and Australia are provided in the main report for comparison purposes.

From the results of the project it was concluded that:

- 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. It is also often very difficult to get the water utilities to fill out the data request forms as they are either too busy or are unwilling to assist.
- 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 if there are more than 2 000 connections and the zone is relatively homogeneous. 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.
- 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.
- The final data set documented in the report suggests an average ILI value of 5.5 for South African systems with more than 50 000 connections, 7.8 for systems with between 10 000 and 50 000 service connections and 5.0 for systems with less than 10 000 connections. There is no apparent correlation between the size of the system and the ILI value.

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.
- 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.

In conclusion, it appears that most of the South African water supply systems are currently in relatively good condition, however, very few of the utilities have sufficient funds to carry out the normally accepted level of maintenance and renewal. While the ILI values for the South African water utilities are lower than for most other developing countries they are also higher than in the more developed countries. An average ILI value in the order of 6 remains very high and indicates significant room for improvement, particularly in a country which has very limited water resources. If the water supply systems are not maintained properly due to lack of resources and funds, they will quickly deteriorate and the ILI's will steadily increase to levels experienced in other developing countries.

ACKNOWLEDGEMENTS

The authors of this report would like to acknowledge the support from the South African Water Research Commission for funding the project and to all the water suppliers who took the time and effort to provide suitable data sets for inclusion in the analyses.

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1 INTRODUCTION

1.1 WHY BENCHMARK LEAKAGE

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.

1.2 INTRODUCTION TO THE STUDY

There is an increasing awareness in South Africa that water is limited and that careful management should be applied when dealing with this scarce resource. Water lost from potable water distribution systems remains a major issue when examining the overall water wasted throughout the country. It is unclear as to the actual extent of water lost due to leakage in South Africa, and many assumptions have been made in this regard. No figures can be quoted with absolute confidence and for this reason a project was initiated by the Water Research Commission in order to gain a clearer understanding of the extent of leakage in South Africa. The BENCKLEAK software (Mckenzie and Lambert 2002) was developed through the Water Research Commission in a previous project entitled "Development of a simple and pragmatic approach to benchmark real losses in potable water distribution systems in South Africa" (WRC project number K1145). It was developed to provide a simple yet pragmatic approach to the evaluation of leakage from potable water distribution systems. The model is used to assist water utilities to evaluate the levels of leakage and non-revenue water in their water distribution systems.

The previous project was initiated by the Water Research Commission in order to develop a standardised software package (BENCHLEAK) and undertake some initial evaluations on selected water utilities in South Africa. The results from approximately 30 water suppliers were processed as part of the project (K1145). The main objective of the project was to develop the software and the data obtained from the 30 water suppliers were used mainly to test the software. It was not possible within the limited time-frame to screen the data thoroughly with the result that the South African data set could not be included as part of the larger worldwide data set. As the software has now been available for some time in South Africa, a second project was commissioned to build on the previous work and prepare reliable water audits for selected suppliers throughout the country.

The project was initiated to compare the levels of leakage for at least 30 water utilities in South Africa and to check the results carefully so that they could be included in the larger International Water Association (IWA) initiative to gather leakage information from around the world. By creating an international data, it will allow comparisons to be made of leakage levels between various countries.

A number of water utilities (approximately 60) in South Africa were requested to provide data on their respective systems including length of mains, number of service connections, average operating pressure, systems input volume and the components of authorised consumption. The data were processed through the BENCHLEAK model and the results screened for errors.

While the main aim of the project was to gather a data set of water suppliers in South Africa and to determine the levels of leakage being experienced, it was also necessary to investigate certain issues in depth to ensure that a standard approach was being used. Some confusion had been experienced by some water utilities in the previous project with regard to certain of the input parameters for the model, namely, the number of service connections and the estimation of apparent losses. It was therefore important to ensure that the results from the project were all based on the same assumptions with regard to key elements of the benchmarking calculation.

For this reason, standard drawings were developed to assist users in assessing the number of service connections in their systems as well as the levels of apparent losses. The apparent loss figure was previously very subjective and open to interpretation. In this project a more detailed and pragmatic approach to evaluating apparent losses was used. The age of the meters and the number of illegal connections are the main factors influencing the apparent losses in South Africa. The apparent losses for each individual water utility have been assessed according to these factors where information was available.

This report presents the main findings of the project. Results from the various water utilities included in the data set are presented and discussed. Standard approaches for dealing with various inputs required for the model have been developed and are presented.

1.3 THE BENCHLEAK MODEL

The BENCHLEAK model was the first detailed water audit model to be developed based on the IWA methodology as documented by Lambert et. Al. (1999). The model was developed through the Water Research Commission in order to facilitate the evaluation of leakage levels and, in particular, non-revenue water, in potable water distribution systems (Mckenzie and Lambert, 2002). It is a simple, user friendly model that is based on an excel spreadsheet and provides various performance indicators for non-revenue water and real losses. The model was used in the evaluation of 30 water utilities throughout South Africa, which were then compared to international water utilities. The input to the model was provided by the water utilities and some details of the key input variables are provided in **Section 1.2.1**.

1.3.1 BENCHLEAK Input

Length of mains: The length of mains is the total length of the bulk and distribution mains in a particular system. All pipes excluding the connection pipes are considered to be mains. This value can sometimes cause confusion in that water utilities are often unsure as to what it includes. It is in fact the total length of bulk and distribution mains. It should be noted that most recent models (e.g. Aqualibre:- Liemberger and Mckenzie, 2002) consider bulk and distribution mains separately. BENCHLEAK, however, does not differentiate between the two types of water main and a single 'lumped' variable is used.

Number of service connections: This value has been a topic of debate amongst many water demand management specialists, and is discussed in more detail later in this document. It is defined as the number of connections to the mains although a more practical definition is recommended in **Section 3.2**.

Operating pressure: The average operating pressure for the whole system over the period in question. This is sometimes a contentious issue and continues to attract considerable debate on the issue. In most systems, however, it is possible to estimate the average pressure at the Average Zone Point (AZP) to the nearest 5m or even 10m. The pressure is used in various calculations and in particular to calculate the Unavoidable Annual Real Losses (UARL).

Population: The population that is served by the water utility in question. This parameter plays no real role in the model and is simply used for general information and to enable the user to calculate the per capita consumption (if appropriate for the specific system) which can often highlight a problem with the base data. The per-capita consumption has not been included in the model since most systems usually have a mixed user profile which will produce misleading results if the water supplied to the system and population figures are used without some adjustment.

System input volume*:* The total volume input into the water supply system, allowing for known errors such as bulk meter under-registration . It can be supplied as a single value or split into various components if more detailed information is available.

Authorised consumption*:* This represents the authorised water use which can be metered or unmetered. If unmetered, the supply is estimated based on local knowledge or from test measurements. The authorised consumption can also divided into various sections namely, billed metered, billed unmetered, unbilled metered and unbilled unmetered. Examples of each type of water use are provided in **Table 1.1**. which is neither complete nor rigid in the sense that some components of water use may be allocated to different categories by some suppliers. The main issue concerns whether or not the water is paid for and in this regard all suppliers should be able to select an appropriate category.

Table 1.1. Examples of the various components of authorised consumption.

Billed metered	Domestic consumers Industrial consumers Commercial consumers Municipal buildings and Government buildings
Billed unmetered	Consumers charged on a flat rate tariff basis Consumers below the 6kl free monthly allowance
Unbilled metered	Some schools (should now all be metered) Recreational parks (should now all be metered) Some government buildings (should now all be metered) Police stations (should now all be metered) Municipal swimming pools (should now all be metered)
Unbilled unmetered	Fire fighting Mains flushing Some building site supplies

Costs of real and apparent losses*:* In order to estimate the value of the non-revenue water it is necessary to know both the buying price and average selling price of the water. The buying price is usually the lower of the two prices and is applied to the real losses (i.e. physical leakage) since if this can be reduced, the water purchased by the supplier will be lower. If the apparent losses can be reduced, the selling price of the water is considered appropriate since in most cases the 'recovered' apparent losses will often be converted into revenue water. The annual cost of running the system is also required to enable the model to calculate the value of Non Revenue Water as a percentage of the running costs for the system.

1.3.2 BENCHLEAK output

The BENCHLEAK model carries out a number of calculations providing the user with useful output that can be used to compare various water utilities. The main outputs from the model include:

Unavoidable Annual Real Losses (UARL)*:* This represents 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 the system is operated very efficiently and all practical measures are taken to minimise leakage. The UARL is generally not an achievable target for most water suppliers, since it is well below the economic level of leakage in most cases.

Apparent Losses (AL)*:* The apparent losses include all unauthorised consumption (theft or illegal use) as well as all technical and administrative inaccuracies associated with customer metering and billing. In the BENCHLEAK model, the user is required to provide an estimate of the apparent losses as a simple percentage of the total losses (calculated from the water input to the system minus water supplied to consumers) – the remainder being the real losses. This simplistic approach has been superseded in more recent models using a more pragmatic and defendable approach in which the various components of the apparent losses are estimated separately in some form of scientific manner. For the BENCHLEAK model, however, the relatively simplistic approach of a single percentage is used. To ensure that the results are realistic, it is recommended that the apparent losses are based on some realistic estimate of the various components (i.e. meter error, illegal use, reservoir overflows etc). 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 which can then be converted to a percentage value as required by the model.

Current Annual Real Losses (CARL)*:* The current annual real losses represent the physical water losses from the system up to the point of measurement of customer use – i.e. the consumer meter. The current annual real losses are calculated as the difference between the total water losses minus the estimated apparent losses. This variable is of importance as a key performance indicator and is used to calculate the Infrastructure Leakage Index (ILI) as discussed below.

Infrastructure Leakage Index (ILI)*:* The infrastructure leakage index (ILI) is a relatively new performance indicator used to measure the extent of leakage in a particular system. It is normally used for systems with over 5 000 connections but can be used for smaller systems if they are known to be homogeneous (systems down to 1 000 connections can often considered). The ILI is a non-dimensional index which provides an indication of the relative level of leakage in a particular area when compared to the theoretical minimum level of leakage that can be achieved (i.e. the UARL). It is a ratio of the current annual real losses (CARL) to unavoidable annual real losses (UARL as discussed in Lambert *et. al,* 1999).

1.4 METHODOLOGY

The basic leakage benchmarking methodology used in the project was not altered from that used in the previous study and is documented in the BENCHLEAK Manual (Mckenzie and Lambert, 2002). The main focus of this subsequent project was to carefully screen the data from several water utilities in order to develop a reasonably reliable data set for approximately 30 utilities. The project was split into a series of tasks as discussed below:

- **Task 1**: Select suitable water suppliers for Leakage Benchmarking throughout SA – approximately 60 suppliers were identified.
- **Task 2**: Discuss the selected suppliers with WRC to create short list of 30;
- **Task 3**: Develop leakage benchmarking forms for the 30 water suppliers;
- **Task 4**: Check the results and repeat the analyses where necessary;
- **Task 5**: Document results in project report;
- **Task 6**: Present and discuss the results with WRC/Steering Committee;
- **Task 7**: Finalise report;
- **Task 8**: Disseminate findings and transfer of technology.

The bulk of the work was completed by March 2004 and a technical paper was presented by Mrs Seago at the WISA conference held in Cape Town at the beginning of May 2004. A copy of the paper presented is included in **Appendix F**.

1.5 LAYOUT OF THIS REPORT

This report contains 6 sections and 6 appendices, as described below.

Section 1: Introduction

Section 1 provides an introduction to the project and purpose of the study as well as a brief explanation of the methodology used to collect, collate and process the data used in the analyses.

Section 2: The IWA Water Balance and ILI

Section 2 provides some background information on the International Water Association (IWA) water balance on which the analyses are based. It also provides some information on performance indicators (PIs) used to measure real and apparent losses in potable water distribution systems. This section concludes with an overview of the Infrastructure Leakage Index (ILI) which is considered to be one of the most useful and reliable PIs for assessing Real Losses in potable water distribution systems.

Section 3: Using BENCHLEAK

While the BENCHLEAK Model is already documented in previous reports, the basic operation of the model and the data requirements are repeated in **Section 3** for completeness and reference purposes. Since the original model was developed, several issues have been identified which caused confusion in previous studies. The key problem issues are discussed together with recommendations on how they should be addressed when undertaking a water audit. The section concludes with a description of the density of connections which is a useful indicator for assessing the reliability of the basic input data from the water utilities.

Section 4: Results from the Study

Section 4 contains the main tabulated results from the study from the various water utilities included in the assessment. The results from the South African utilities are also compared to several international data sets which have been obtained from similar work being undertaken in Europe, Canada, USA and Australia.

Section 5: Conclusions and Recommendations

Section 5 provides a summary of the work undertaken and how it can be used in South Africa to assist Water Service Providers in assessing their own levels of leakage and/or wastage. Recommendations are also made in connection with the use of the ILI as an indicator which can be used by a regulator to initiate water demand management measures in areas where the leakage/wastage is above acceptable norms.

Section 6: References

Section 6 provides references to all publications used during the course of the study as well as a few additional references for users wishing to gain more in-depth knowledge of the subject of leakage benchmarking.

Appendix A: Glossary of Terms

Appendix A provides a short glossary of terms to assist readers with the standardised terminology used throughout the report.

Appendix B: Derivation of the UARL Parameters

Appendix B provides further detail on the derivation of the parameters used to calculate the Unavoidable Annual Real Losses (UARL) which is used in the calculation of the ILI.

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 in **Appendix C**.

Appendix D: Graphic Results from Participating Water suppliers

Appendix D summarises the results presented in **Section 4** in a graphical format.

Appendix E: Sample Printout of the BENCHLEAK Worksheets

An example of the five sheets of the BENCHLEAK model are listed in **Appendix E** together with 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 F: Paper presented at the WISA conference of May 2004

A copy of the paper presented by Mrs Seago at the 2004 WISA conference held in Cape Town is provided in **Appendix C** and is a key deliverable from the project.

2 IWA WATER BALANCE AND USE OF ILI

2.1 BASIC IWA WATER BALANCE

A clearly defined water balance is the first essential step in the assessment of volumes of Non-revenue water and the management of water losses in potable water distribution systems. In July 2000, the IWA Task Forces on Performance Indicators and Water Losses published a standard international 'best practice' water balance as shown in **Figure 2.1** (Mckenzie and Lambert, 2004). This water balance has since been recognised and adopted as international 'best practice' by a steadily increasing number of countries and water utilities throughout the world.

System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Water Exported	Revenue Water
			Billed Metered Consumption	
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorised Consumption	
			Customer Meter Inaccuracies	
		Real Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows at Storage Tanks	
			Leakage on Service Connections up to point of Customer Meter	

Figure 2.1: The IWA 'best practice' standard water balance

2.2 PERFORMANCE INDICATORS FOR LEAKAGE

In addition to the standardised water balance, the task force also proposed several key 'best practice' PIs for :

- Non-Revenue Water;
- Water Losses;
- Apparent Losses and;
- Real Losses.

Of particular significance is the use of the term 'Non-Revenue Water' in place of the widely used 'Unaccounted-for Water' due to the scope for misinterpretation and manipulation associated with the latter term. One only has to examine publications from around the world to see how the definitions and calculations of 'Unaccounted-for Water' vary from one country to another. The term 'Non-revenue Water' is clear and unambiguous, even to non-specialists.

While some healthy debate still continues around the world, the IWA approach of selecting different PIs for different purposes - namely: Financial, Operational, and Water Resources – is a clear step forward. In each case, PI's have been recommended for both basic and detailed levels within each category. (Intermediate PIs have also been proposed in some cases, however, to avoid confusion only a few of the key and most useful PIs relating to water losses and non-revenue water are provided in **Table 2.1.**

Table 2.1: Details of Selected Key PI's

Component	Type	Basic PI	Detailed PI
Non- Revenue Water	Financial	Volume of NRW as % of System Input Volume	Value of NRW as % of cost of running system
Real Losses	Water Resources	Volume of real losses as % of System Input Volume (It should be noted that there was some dissagreement among the IWA Task Team members with regard to the use of percentages. It has been recommended that this indicator be reviewed to establish a more meaningful PI.	
Real Losses (In each case, this PI is calculated per day 'when the system is pressurised to allow for the effect of intermittent supply).	System Operational	litres/service connection/day for systems with 20 or more services/km mains (32 per mile) Use m^3/km mains/day for systems with fewer than 20 services/km of mains	The Infrastructure Leakage Index: defined as the Ratio of the Current Annual Real Losses to the Unavoidable Annual Real Losses = CARL/UARL This indicator is fully explained by Lambert et. al.
Apparent Losses	Operational		m^3/service connection/year
Water Losses	Operational	m^3/service connection/year	

Some discussion on each of the PIs listed in **Table 2.1** is provided below.

2.2.1 Non-Revenue Water: Financial PI

Although "% by volume" has traditionally been widely used as a PI for many components of the water balance (including Non-revenue Water), it can be very misleading as it is strongly influenced by:

- differences and changes in the volume of consumption,
- intermittent supply,
- the presence or absence of customer storage tanks (which usually result in significant

under-recording of customer meters see Thornton & Risso, 2003).

While "% by volume" is still recommended as a basic financial PI for Non-revenue Water, and a basic PI for Real Losses from a Water Resources viewpoint, it should definitely not be used for assessing any aspect of operational performance management of Water Losses; (other components of the water balance and where possible the recommended PI's given in **Table 2.1** should be used).

The detailed financial PI for Non-revenue Water is based on the **% by value** of the water rather than the **% by volume**. A simple example of a typical calculation is provided in **Table 2.2** which highlights the differences between the two PI's for Non-revenue Water.

Table 2.2: Comparison of basic and detailed NRW Financial PIs for a Canadian System **(from Mckenzie and Lambert, 2004)**

NRW Component	Volume as % of System Input Volume	Marginal Cost ($\$/m^3$)	Value as % of Annual System Running Cost
Unbilled Authorised Consumption	1.06	0.0440	0.08
Apparent Losses	1.25	0.2550	0.57
Real Losses	17.72	0.0447	1.41
Non-Revenue Water	20.03		2.06

2.2.2 Real Losses: Water Resources PI

The **basic** Water Resources PI recommended by Alegré et.al. (2000) is:

Real Losses by volume' = Volume of Real Losses as % of System Input Volume

No further work has been done on this PI by the Water Losses Task Force since 2000. As previously mentioned, %'s by volume are strongly influenced by differences and changes in consumption, and various members of the Task Force has expressed their reservations concerning the use of percentages even for a water resources PI. If improvements to this PI are to be considered, it would be useful to assess whether or not the 'Real Losses' become available for re-use.

2.2.3 Real Losses: Operational PI

The IWA Best Practice Report (Alegré et.al., 2000) clearly states that "%'s by volume" are unsuitable for assessing the efficiency of operational management of Real Losses. This conclusion has been endorsed by many organisations throughout the world including;

Ofwat in England/Wales, the national regulator in Malta, AWWA in N. America, WSAA in Australia, NZWWA in New Zealand and last but not least DWAF in South Africa.

As comparatively few systems have a density less than 20 service connections/km, **'litres per service connection per day'** is the preferred basic operational PI for most distribution systems. This basic PI is the best of the 'traditional' PIs but has certain limitations, as it does not allow for the following:

- density of connections (per km of mains);
- length of service pipe between the main and the customer meter, and;
- average pressure (leakage rates vary approximately linearly with pressure for systems with mixed pipe materials).

To address these deficiencies, a detailed operational PI for real losses was developed and is referred to as the Infrastructure Leakage Index (ILI). This relatively new PI is the ratio of the Current Annual Real Losses (CARL) to the Unavoidable (Technical Minimum) Annual Real Losses (UARL) and is discussed in detail by Lambert et al (1999).

The ILI provides an indication of how effectively a utility is managing real losses under the current operating pressure regime. It is important to note, however, that this does not imply that the pressure management is optimal, and it is usually possible to reduce the volume of real losses (but not the ILI) through improved active pressure management. This 'twin track' approach to leakage management directly addresses comments that the ILI somehow favours water utilities that operate at high pressures and discriminates against those that implement strict pressure management measures. Once again, this is the subject of considerable debate, however, the speed at which water utilities throughout the world have adopted the ILI as their preferred PI for real losses is clear testament to its value in the water industry. The ILI has in fact been the subject of many workshops and is included in many water balance models including, BENCHLEAK (Mckenzie and Lambert, 2002)), BENCHLOSS (Mckenzie and Lambert, 2000), BENCHLOSSNZ(Lambert and Mckenzie, 2002)), AQUALIBRE (Liemberger and Mckenzie, 2003), FASTCALC(Lambert: Personal Communication), as well as many other similar models developed and used throughout the world by various water utilities or water distribution specialists.

Since the ILI was first introduced in 1999, it has been calculated in an increasing number of countries. Theory and experience both show that it can be used with confidence for comparisons at international, national, state and within-system levels for systems with:

- more than 5000 service connections;

- more than 25 metres pressure on average throughout the system, and have;
- more than 20 service connections per km of mains.

2.2.4 Apparent Losses: Operational PI

The operational PI for Water Losses (i.e. the sum of Real and Apparent Losses) and Apparent Losses in the 2000 PIs Report (Alegré et.al., 2000) was m^3/service connection/year (to provide consistency with the basic PI for Real Losses). However, numerous international applications of the Water Balance since 2000 have identified a need for more specifically focused practical operational PIs for Unbilled Authorised Consumption (UAC), and the components of Apparent Losses (AL). When auditing and comparing volumes attributed to UAC and AL, it's necessary to check that these components are not excessive.

A practical approach undergoing further testing by the Performance Indicators Team of the WLTF is to use '% of Water Supplied' as a PI for checking the Unbilled Authorised Consumption (metered and unmetered), and the Unauthorised Consumption. The most meaningful practical PI for the remaining component of Apparent Losses – mainly customer meter error – is likely to be '% (+/-) of registered metered consumption', as this is the usual basis for presenting results from systematic testing of randomly selected customer meters.

Further details on the assessment of apparent losses are provided in the paper by Thornton and Risso (2002).

2.3 INTRODUCTION TO BABE

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

In order to support the government legislation and encourage efficient use of the available water resources in South Africa, the Water Research Commission (WRC) has initiated and supported numerous projects since the mid 1990's to provide low cost software solutions to assist water suppliers in understanding and managing their Non-Revenue Water.

The new models are all based on the Burst and Background Estimate (BABE) methodology which was first developed for the UK Water Industry in the early 1990's. The BABE philosophy has since been accepted and adopted in many parts of the world as it provides a simple and pragmatic approach to the very complex and often confusing problem of leakage from water distribution systems. The approach was so successful that it is now recommended by many international water associations as the most systematic and pragmatic approach to Leakage Management. The methodology and concepts have been widely accepted by most water suppliers throughout the country and through the efforts and initiatives of the WRC, South Africa is now regarded as one of the key players in this field worldwide.

The BABE methodology is based on the concept that leakage in a water reticulation system can be considered 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.

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 upon factors such as minimum depth of pipes, type of ground and surface, etc. In the UK a threshold limit of 500 litres/hour was used in the 1994 Managing Leakage Reports, but advances in technology and other factors suggest that a figure of around 250 litres/hour would be more appropriate in South Africa. In other words:

Events	***>***	***250 litres/hour***	***=***	***Bursts***

Events	**<**	**250 litres/hour**	**=**	**Background Leaks**

In the development of the BABE techniques, it was agreed that the following four principal issues concerning leakage management shown in **Figure 2.2**) should be addressed:

In order to address the four key components of the BABE methodology, four models were developed through the WRC over a period of approximately four years as shown in

Figure 2.3 and described in **Table 2.3**. Each model is a small self contained program which addresses one specific issue. It was decided to adopt this simple and straightforward approach in order to avoid confusion and allow water suppliers to use one or all of the models as they consider appropriate.

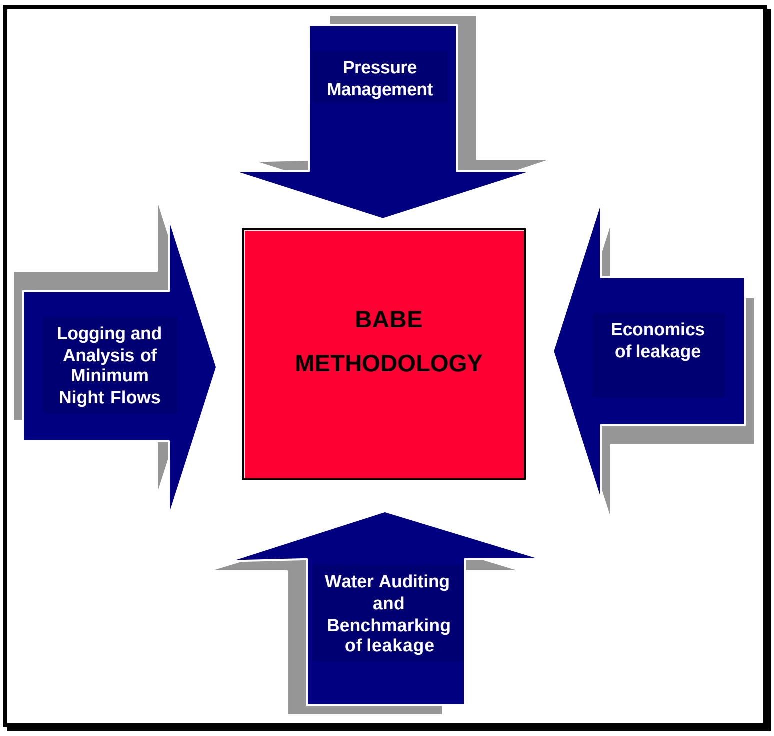


Figure2.2: Four Main Elements of the BABE Methodology

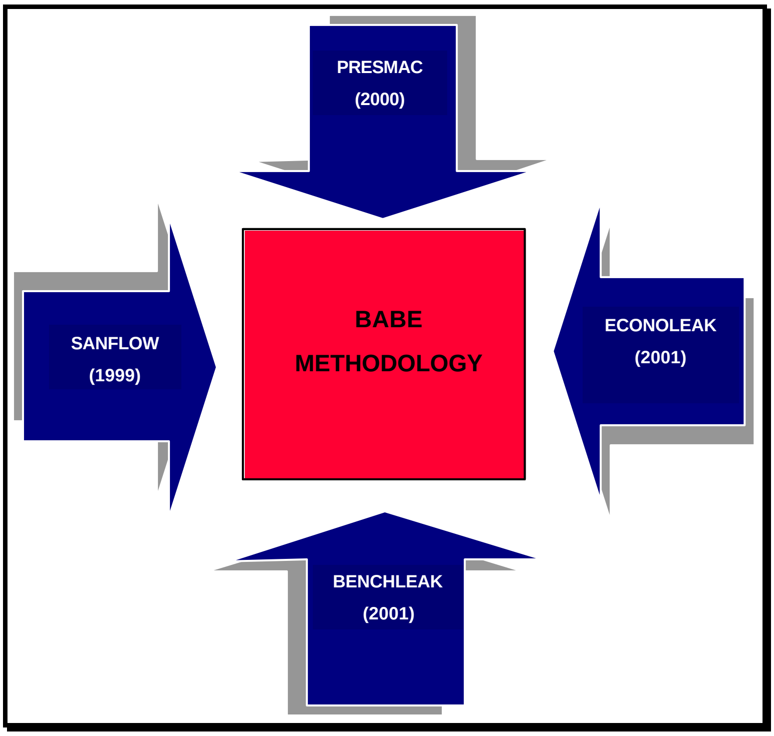


Figure 2.3 : Models Developed through the WRC

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

Table 2.3: Details of the various WRC BABE based models

Model	Details	ISBN Reference	WRC Reference	Release
SANFLOW	Model designed to provide an indication of the unexplained burst leakage in a zone from the analysis of the minimum night flow.	186845 4908	TT 109/99	1999
PRESMAC	Model designed to estimate the potential for Pressure Management in a pressure zone based on logged flow and pressures over a representative 24-hour period.	186845 7722	TT 152/01	2001
BENCHLEAK	Model designed to establish the levels of non-revenue water in a water utility or zone metered area based on the latest IWA recommendations regarding the Minimum Level of Leakage.	186845 7737	TT 159/01	2001
ECONOLEAK	Model to evaluate the most appropriate frequency for undertaking Active Leakage Control	186845 8326	TT 169/02	2002

2.4 CALCULATION OF THE UARL

One of the key developments originating from the BABE methodology over the past few years has been the concept of Unavoidable Annual Real Losses (UARL) together with a new performance indicator referred to as the Infrastructure Leakage Index (ILI). These two new variables were first introduced by Lambert et. al. (1999) and have now become widely accepted throughout the world.

The equation for the UARL is based on BABE (Background and Bursts Estimates) 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.

The methodology is described in the paper (**Lambert et al, 1999**) 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 2.4**. 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 etc.

Each of the elements in **Table 2.4** 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 2.5.**

Table 2.4: Parameters required for 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*

Table 2.5: Parameter values used to calculate UARL

Component of Infrastructure	Background Losses	Reported Bursts	Unreported Bursts
Mains	20*L/km/hr	• 0.124 bursts /km/year at • 12 m^3/hr per burst* • average duration of 3 days	• 0.006 bursts /km/year at • 6 m^3/hr per burst* • average duration of 50 days
Service connections to street/property line	1.25*L/conn/hr	• 2.25/1000 connections/year at • 1.6 m^3/hr per burst* • average duration of 8 days	• 0.75/1000 conn/yr at • 1.6 m^3/hr per burst* • average duration of 100 days
Unmetered Service connections after street/property line	0.50*L/conn/hr per 15m length	• 1.5/1000 connections/year at • 1.6 m^3/hr per burst* • average duration of 9 days	• 0.50/1000 conn/yr at • 1.6 m^3/hr per burst* • average duration of 101 days

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

The parameter values indicated in **Table 2.5** 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 2.6**. 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 2.6.**

Table 2.6: 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	L/km mains/day per m of pressure
Service connections to street/property line	0.60	.04	0.16	0.8	L/connection/day/ m of pressure
Unmetered Service connections after street/property line	16.0	1.9	7.1	25	L/km underground. pipe/day/metre of pressure

NOTE: the UARL losses 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 South Africa, except at low density of connections (less than 20 per km of mains).

Based on the figures provided in **Table 2.6** the calculation of the UARL can therefore be expressed as follows:

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

Where:

UARL	=	Unavoidable annual real losses (L/day)
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 (metres)

Example: A system has 121 km of mains, 3975 service connections all located at the street property boundary edge and an average operating pressure of 48 metres.

UARL = (18 * 121 + 0.80 * 3975 + 25 * 0) * 48 Litres/day
104 544 + 152 640 Litres/day
257 184 Litres/day
257.2 m^3/day
93 872 m^3/year
65 Litres/connection/day

3 USING BENCHLEAK

3.1 OVERVIEW OF THE BENCHLEAK MODEL

The BENCHLEAK model is a simple, user friendly model based on an Excel spreadsheet. Its objective is to assist Water Utilities to determine their levels of leakage by performing a number of calculations based on data input by the Water Utility. As with all models, its effectiveness is based on the input data and the accuracy thereof. The model is fully described in the original user guide (Mckenzie and Lambert, 2002) and a few key issues are repeated in this section for completeness.

3.1.1 Hardware and software requirements

To run the BENCHLEAK software the user requires a basic PC with the Windows operating system and the EXCEL spreadsheet program, preferably Excel 97 or higher. There are no special requirements as the software is a basic Excel spreadsheet with no restrictive features or links to other programs.

3.1.2 Installing BENCHLEAK

The BENCHLEAK software is available as a downloadable file from the WRC website and can be found under the link software. It is a relatively small file at approximately 130Kb and can be run as long as the Excel program can be accessed. There is no sophisticated installation shield and it is suggested that the software be installed as follows:

- Set up a directory called Benchleak;
- Save the **BENCHLEAK.XLS** file into this directory from the website;
- Each time a new calculation is required, rename the BENCHLEAK file with a more specific name, and over-write the yellow cells and boxes with new data.

3.1.3 Overview of the software

The BENCHLEAK software is an Excel Workbook that processes basic information entered by the user in such a way that:

- Unavoidable Annual Real Losses are calculated for any individual system;
- Components of the standard Water Balance are calculated for any system and year;

3.1.4 The Individual Worksheets

The BENCHLEAK Model comprises three worksheets 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.

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.

- Estimate the **unavoidable annual real losses (UARL)** that will occur from the system based on the methodology developed by A Lambert et. al. (**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 3.0 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 **Figure 3.1**.

3.1.5 Input Data Requirements

Cells in the BENCHLEAK Worksheets are colour-coded as follows:

Example	Input	Calculation

- Blue cells (example data) are protected and cannot be accessed;
- Yellow cells and blocks (data entry) must be completed by the user;
- Green cells (calculated values) are protected and cannot be accessed

Notes are provided throughout the Worksheets to assist the user and he/she is only required to complete the yellow cells.

The information required is as follows:

Section D1: General

- Name of Water Undertaking;
- Name of Water Supply System;
- Contact details (Name, Address, Telephone, Fax, e-mail).

Section D2: System Data

- Length of Transmission and Distribution mains (km);
- Number of Properties;
- Number of Service Connections;
- Percentage of time system is pressurised during year (%);
- Average operating pressure, when system pressurised (metres)
- Population (not used in the calculations)

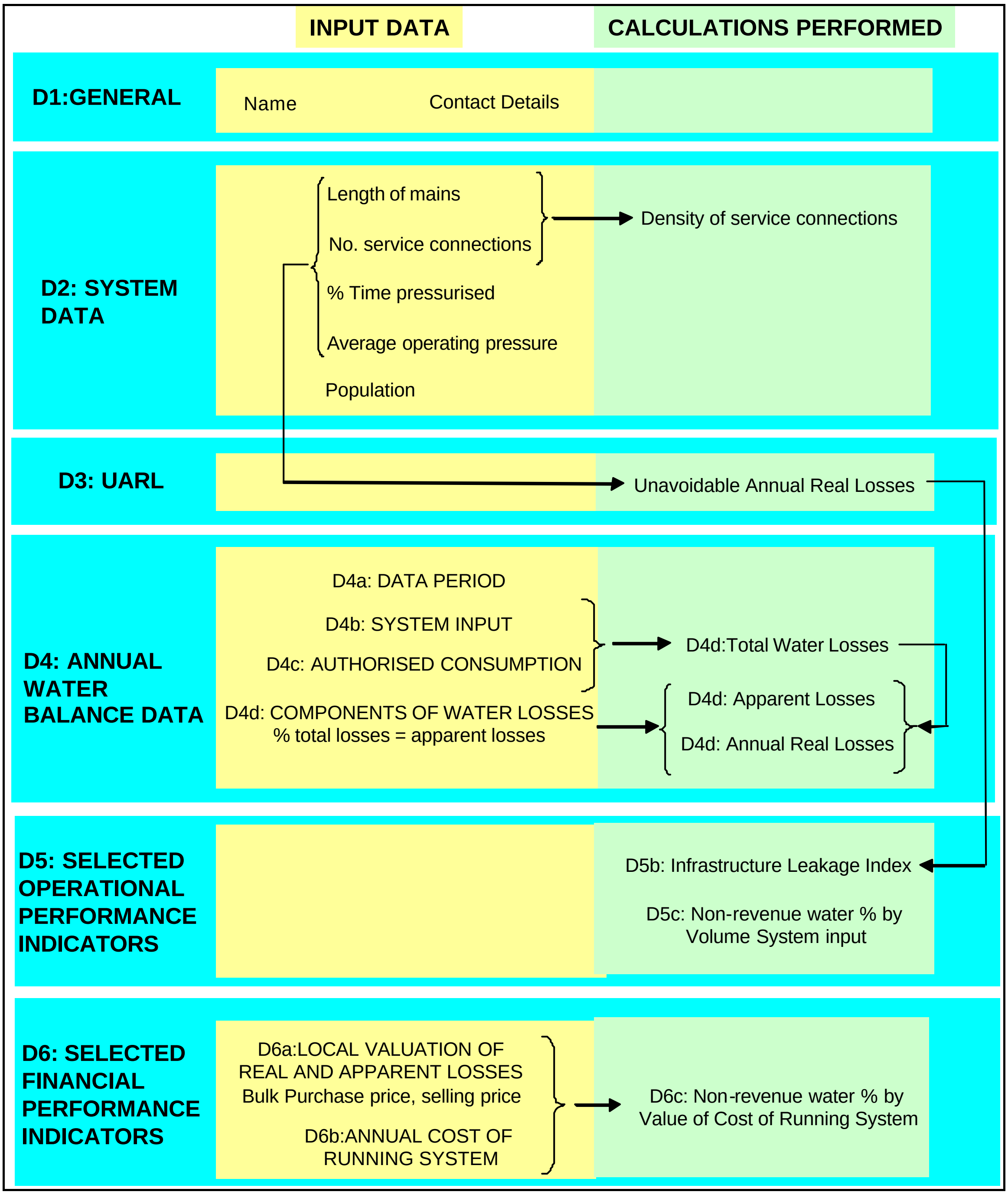


Figure 3.1: Procedure for using BENCHLEAK

Section D4: Annual Water Balance Data

- Data Period;
- System Input Volume;
- Components of Authorised Consumption;

Section D6: Selected Financial Performance Indicators

- Bulk purchase price, selling price;
- Annual Cost of running System;

3.2 CONNECTIONS AND FIRE HYDRANTS

The IWA Manual of Best Practice 'Performance Indicators for Water Supply Services' (Alegre *et. al.*, 2000) clearly defines a service connection as "*the authorised pipe connecting the main to the measurement point or the customer stop-valve, as applicable. Where several registered customers or individually occupied premises share a physical connection or tapping off the main, e.g. apartment buildings, this will still be regarded as the one connection for the purposes of the applicable Performance Indicator, irrespective of the configuration and number of customers or premises*". The "number of service connections" Ns variable is used to calculate the UARL in a system, by taking into consideration the unavoidable leakage expected to occur on service connections between the main and the stop-valve or property line. It is then added to the other components of UARL (on mains, and on pipes between the stop-valve / property line and the customer meter) to calculate the total UARL as seen in **Section 2.4**.

Experience shows that most water suppliers do not know how many saddle connections they have and what proportion support one, two, four or eight properties. However, they do usually have information on the numbers of billed accounts, customer meters, or stands (the South African term for defined plots of land). It is also usually possible to count the number of stop-valves sited outside the stands, typically in the pavement. By considering a representative sample of service connection layouts for a particular system, it is usually possible to produce a correlation between one of these parameters (billed accounts, customer meters or stop-valves) and the number of service connections Ns (physical connections to the mains) for that particular system.

If all service connection layouts were as simple as
Figure 3.2 and **Figure 3.3** that follow, there would be no uncertainty in calculating Ns from one of the other parameters, the ratio would be one to one. However, there is a wide variety of different layouts in South Africa and an even wider range internationally. In practice the situation in most reticulation systems is not clear-cut and defining the number of service connections can sometimes be confusing.

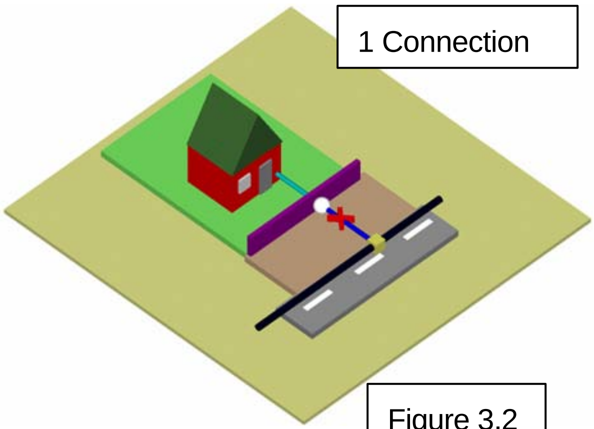


Figure 3.2

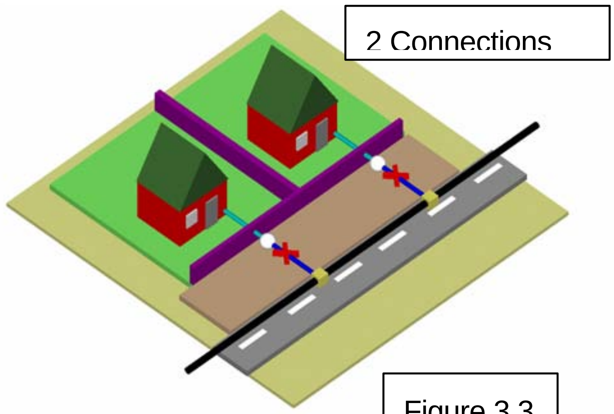


Figure 3.3

Figure 3.2 depicts a single billed metered property on a street, situated on a single stand. There is one physical connection from the main that goes to the stop-valve, on to the external meter in the pavement and then on to the stand/property.

Figure 3.3 depicts two single billed metered properties on a street, each situated on a separate stands. There are two physical connections onto the main, one for each property, and therefore also two stop-valves and two meters.

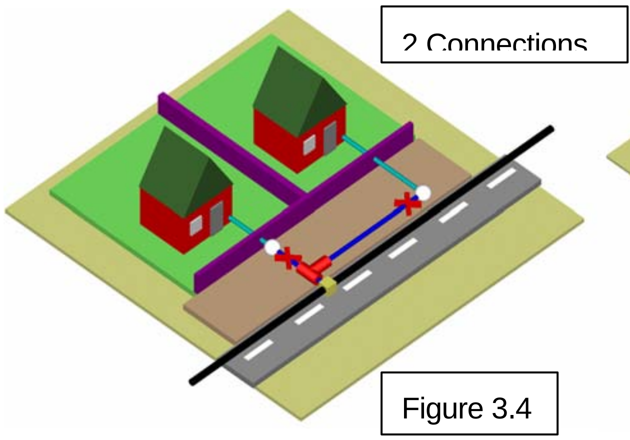


Figure 3.4

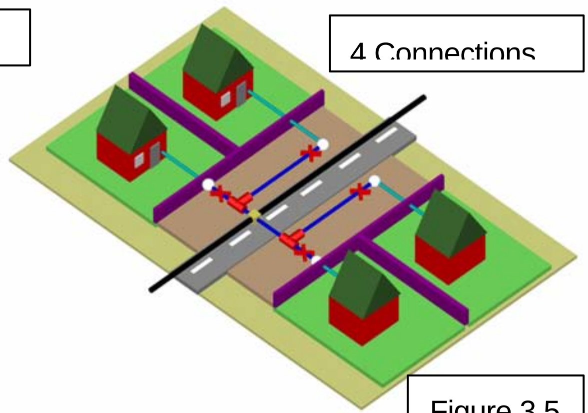


Figure 3.5

Figure 3.4 depicts two billed metered properties on a street, each situated on their own stand. There is only one physical connection onto the main, with a T-piece on the connection pipe to the second house. There are two meters.

Figure 3.5 depicts two properties on one side and two on the other side of a street. There is only one physical connection onto the main, with two connection pipes, one to each side of the street. Each connection pipe then branches at a T-piece to two stop-valves, each with its own meter.

According to the current IWA definition of a service connection, **Figure 3.3** would represent two service connections. In contrast, the layout for two separate properties in **Figure 3.4** would only represent one service connection since there is only one physical connection to the main. The main question to be answered, however, is whether or not the system layout in **Figure 3.3** produces double the leakage of the system shown in **Figure 3.4.** The number of "fittings" (here defined as points breaking the pipe's continuity, excluding the meter) where background leakage and detectable leaks are most likely to occur, is four for **Figure 3.3** and also four for **Figure 3.4** (**Figure 3.3** being at the two physical connections to the main and the two stop-valves; **Figure 3.4** being the one physical connection onto the main, the T-piece and the two stop-valves). Therefore, theoretically the unavoidable leakage resulting from the system shown in **Figure 3.4** should be similar to that from the system shown in **Figure 3.3**.

After considerable discussion with experts from around the world it was eventually agreed that for the purpose of the BENCHLEAK model (and other similar models), the configuration shown in **Figure 3.4** should be considered as two connections. Similarly, **Figure 3.5** would represent four connections, even though there is only one mains tapping. This is considered to be a practical and realistic approach to the issue of defining the number of connections as part of the UARL calculation. It may still be criticised by some specialists who consider the IWA definitions inflexible.

After the various discussions it was proposed that the number of services connections used in the UARL calculation should be taken as the number of properties, or stop valves, which is in many cases the same as the number of customer meters. This will obviously vary from area to area and even country to country and it will often be necessary to examine the actual network configuration and adopt some value which can be motivated based on the physical installation. This approach may in some cases contradict the standard IWA definition in cases where more than one property is supplied from a single connection or tapping off the main.

A main concern when using the number of properties or meters was in situations where a block of flats is served by one tapping off the main. Some apartment blocks in parts of Europe contain only one service connection serving numerous customer meters each adjacent to its own stop-valve. Normally such meters are read at regular intervals for billing purposes and any leaks at the stop-valve or meter will normally be quickly detected as part of the meter reading process. In such cases it would be over-generous to use the number of stop-valves as a surrogate for Ns when calculating the UARL. This issue led to considering the merits of standardising on using the number of stop-valves, but reducing the '0.80' coefficient for Ns (in the UARL calculation) in situations where the ratio of “number of stop-valves to number of physical connections to mains” is large (Lambert, personal communication, 2004).

For the UARL calculation, the coefficient of 0.8 l/service conn/day/metre of pressure used in the equation was based on one service connection to one customer. Rather than changing the way Ns is calculated for different situations, it was decided that it would be more practical to change the coefficient applied to Ns for some situations. The equation was proposed, relating the coefficient (0.8) to the ratio of number of stop-valves to number of physical connections to the main (Nm).

Ns Coefficient = 0.8 (1.0 – a * log (Ns/Nm)

The value of ‘a’ could be adjusted to give coefficients which tied in with theoretical calculations based on number of joints.

Perhaps one of the most significant sources of confusion occurs when the 'number of billed accounts' is used as a surrogate for Ns when calculating UARL. If the 'number of billed accounts' is the only indicator readily available, then it is suggested that the number of billed accounts be multiplied by a factor (less than 1) which takes into account the numbers of billed accounts served by a single service connection.

For example, consider a utility with 500 000 billed accounts, of which 400 000 have their own separate service connection; the remaining 100000 billed accounts are in multi-residential blocks. If the average number of multi-residential accounts per multi-residential block is 10, and each multi-residential block has one service connection, then the number of service connections used in the UARL calculation is:

400 000 + 1 x (100 000/10) = 410,000.

It is important to try and adopt a realistic estimate of the number of service connections for each area when using the BENCHLEAK model. As can be seen, it is a complicated issue and each system should be evaluated on its own merits and a decision taken regarding how the number of connections should be calculated in order to tie into the original methodology behind the UARL calculation.

3.3 DENSITY OF CONNECTIONS

While the density of service connections is not part of the data requested directly from the Water Utility itself, it forms a useful check to determine whether or not the number of service connections and length of mains figures are realistic. Density of service connections is defined by the following equation:

$$Ds = Ns / Lm$$

Where Ds = density of service connections
Ns = number of service connections
Lm = length of mains (km)

If the area being considered is an upmarket residential area, and the information supplied suggests a density of 142 connections per kilometre of mains then there is clearly a problem with either the length of mains or the number of connections (or both). Similarly, if a township area has 30 connections per kilometre of mains it is also likely to be incorrect as most townships are fairly densely populated with a density of connections of between 50 and 130 per km of mains. Since this parameter is so often found to be incorrect, it has been examined in some detail as part of the project in order to provide some guidance to the user of the BENCHLEAK model. Some details and typical examples are provided in the remainder of this section.

In order to investigate the density of service connections in various areas it has been assumed that the length of mains (Lm) is approximately equal to the length of roads in the system. While this is not always the case, it is a realistic approach in most parts of South Africa and is sufficiently realistic to derive the density of connections in a range of areas using ærial photographs (in cases where proper reticulations plans were not readily available). It is often easier to visualise properties situated on a street than along a length of pipe. For the purpose of the comparisons it has also been assumed that properties on both sides of a street are supplied by a single main running along the street – normally on one side of the street.

Table 3.1 provides some initial estimates of connection for single stands along a street edge.

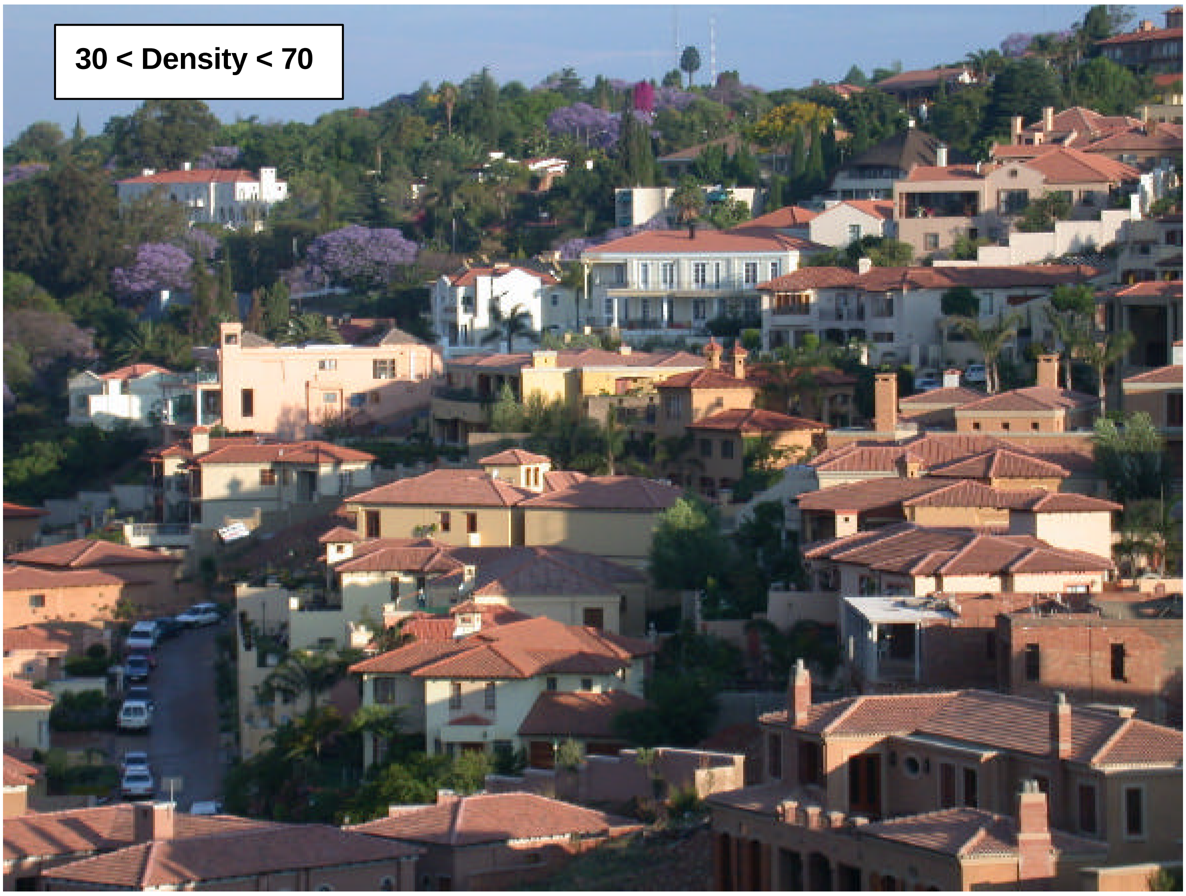
Table 3.1: Density values for various stand widths

Density	No. houses on one side of road in a kilometre	Width of stand
< 30	< 15	> 67 m
30 - 70	35 - 15	29 – 66 m
71 - 100	50 - 36	20 - 28 m
101 - 134	67 - 52	15 - 19 m
> 135	> 71	< 14 m

The following pictures provide some visual indications of the various densities of connections and the types of houses that can be expected with a particular width of stand.

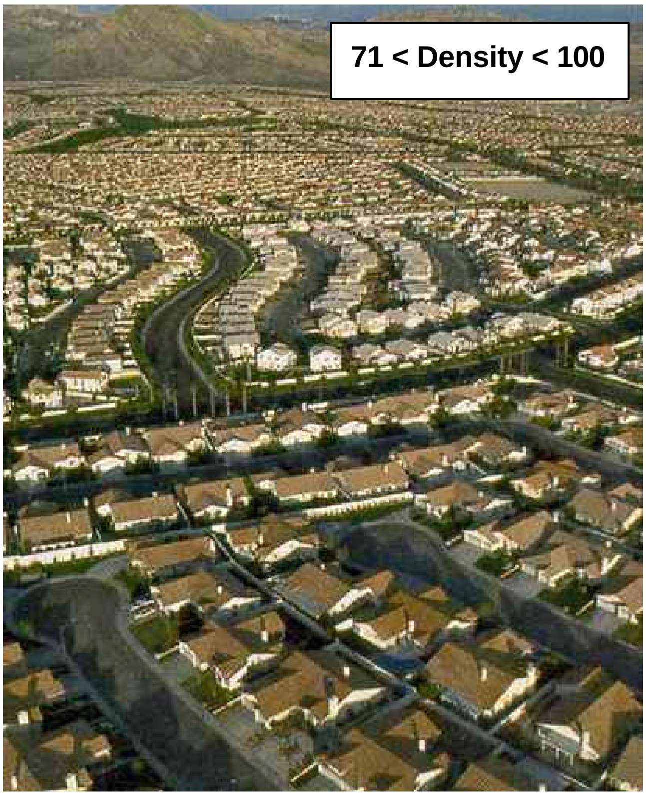
Width more than 67 m, less than 15 houses per km of road, Density less than 30

Width between 29 m and 66 m, between 15 and 35 houses per km of road, Density between 30 and 70

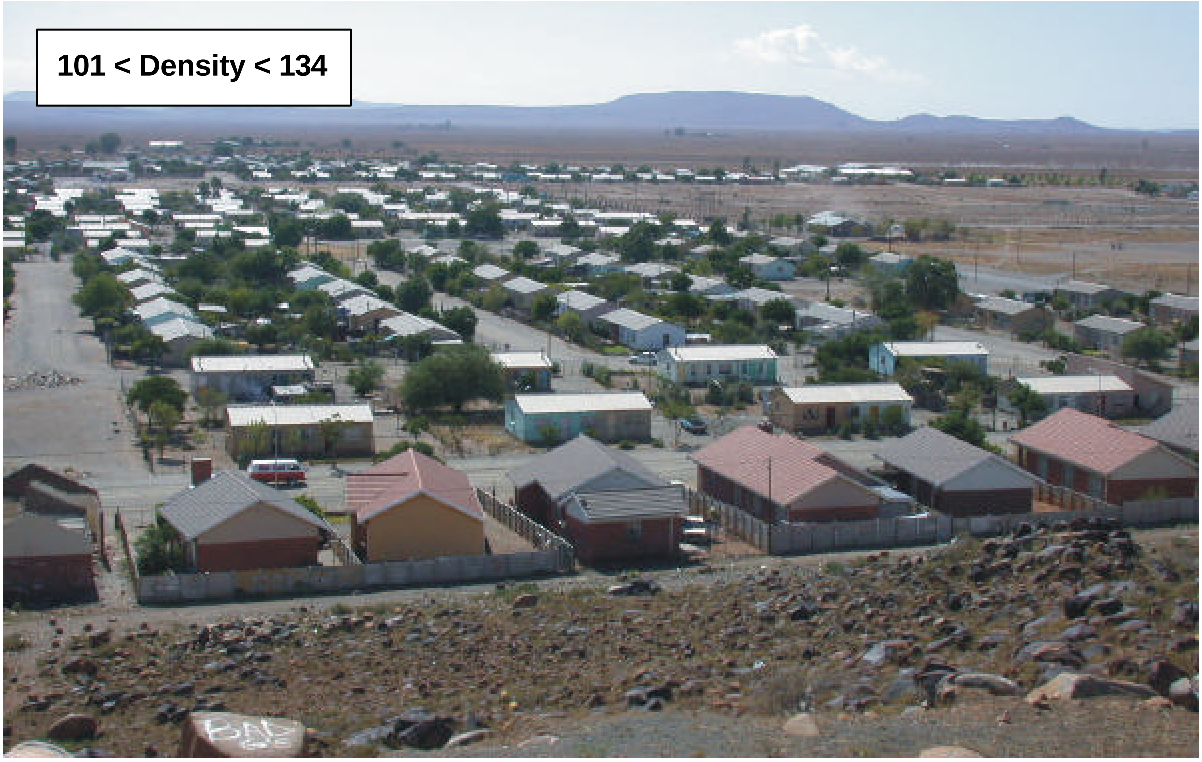

30 < Density < 70


30 < Density < 70

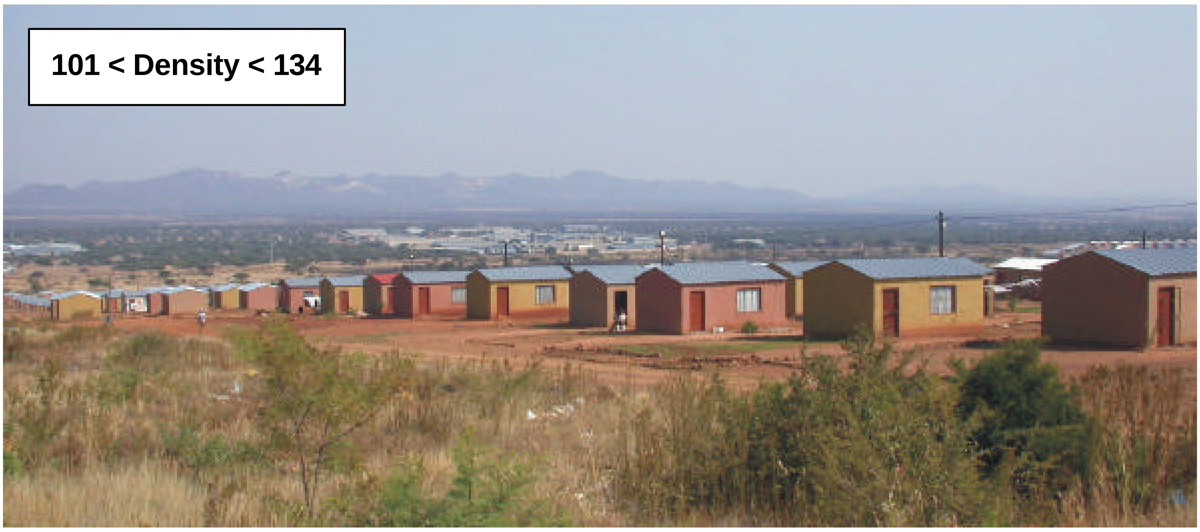
Width between 20 m and 28 m, between 36 and 50 houses per km of road, Density between 71 and 100



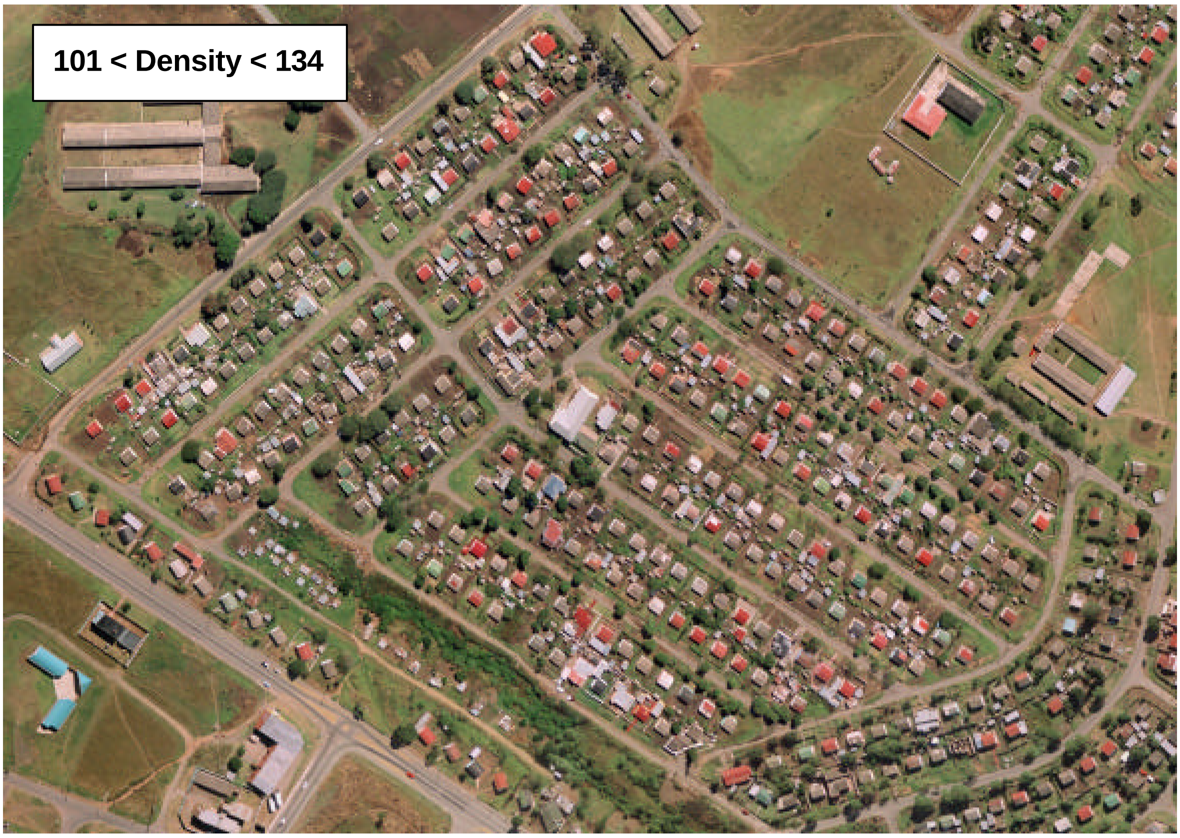
Width between 15 m and 19 m, between 67 and 52 houses per kilometer of road, Density between 101 and 134



101 < Density < 134

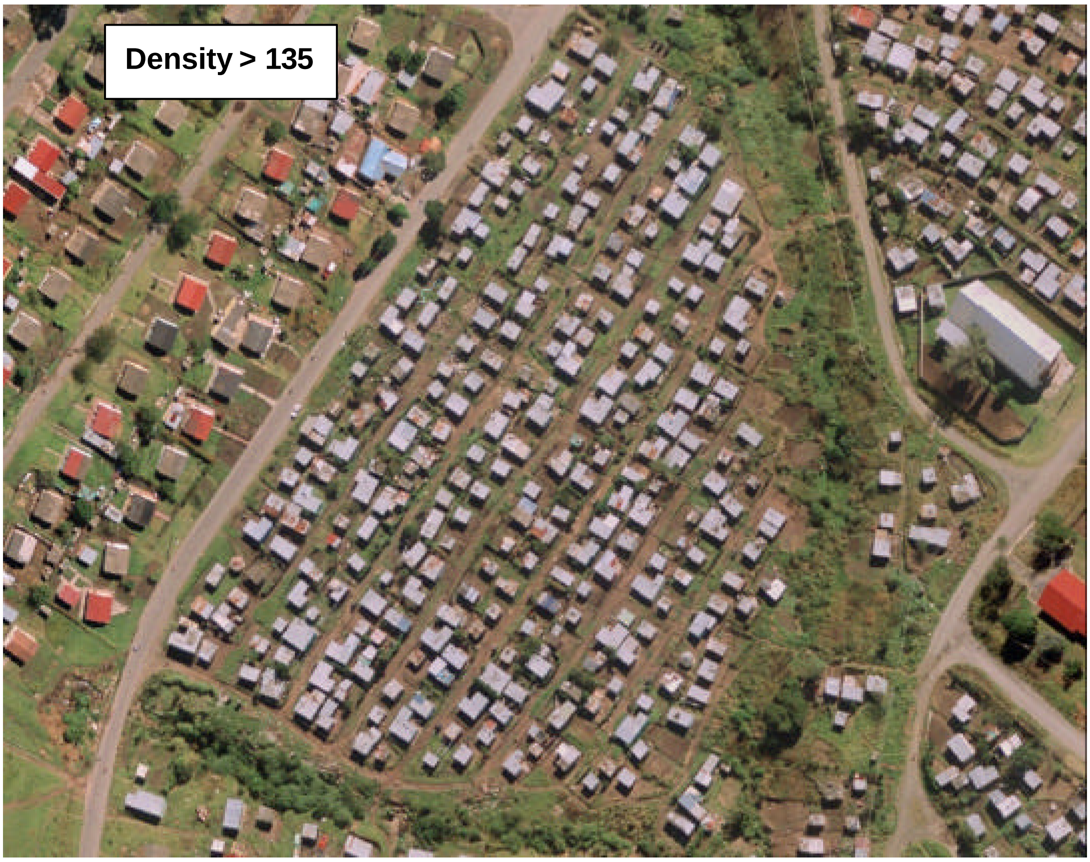


101 < Density < 134


101 < Density < 134


101 < Density < 134

Width less than 14 m, more than 71 houses per km of road, Density more than 135


Density > 135


Density > 135

3.4 APPARENT LOSSES

Apparent losses, often referred to as non-physical or paper losses, are in many cases the most expensive water losses to occur from a system since they represent a direct loss of revenue to the water supplier. In cases where the water bills are based on the metered consumption, any losses occurring due to meter error or data handling and/or processing, will result in reduced sales revenue (Thornton and Rizzo, 2002).

Meter error is often thought to be the main cause of apparent losses in a water system and can be due to wear and tear, incorrect meter installation, lack of maintenance, incorrect meter type or incorrect sizing. Data transfer errors can also contribute to the apparent losses. These can include merely recording an incorrect reading, incorrect interpretation of a decimal point or incorrect calibration of the meter. Estimated readings are often used to generate water accounts when a meter is situated in such a manner that it is difficult to read, and such assumed figures are often inaccurate.

Another contribution to apparent losses in South Africa and other developing countries is theft or illegal connections. Water may be stolen from a number of points in the system, but most commonly it is stolen from the customer supply point or fire hydrants. Customers have been known to tamper with water meters, by placing a magnet close to the register magnets to interfere with the correct rotation of the register and therefore causing lower readings. Hydrants are often abused by construction workers, street cleaners, taxi drivers who wash their vehicles and others who merely use the water for drinking or bathing. In addition to blatant theft, many accounts go unnoticed in the system. An example may be a temporary construction feed, which eventually becomes a permanent supply point but is never metered, billed or included on the billing database.

In the original BENCHLEAK model a simple lump sum was used to express apparent losses in terms of the total losses and a default value of 20% was suggested but could be changed by the user. This is a very simple approach, however, and is not scientific. In South Africa for example, an area such as Sandton in Johannesburg is unlikely to experience the same level of water theft as an informal township for example. To assume that the apparent losses in both areas are the same at 20% would clearly be unrealistic. To overcome this problem in the current water auditing project a simple and pragmatic approach was adopted.

Water utilities were asked to classify their expected illegal connections as very high, high, average, low and very low. They were also asked to provide information on their water meters in terms of accuracy and age. They were also asked to provide an estimate on the accuracy of their billing data in terms of good, average and poor. The apparent loss estimates shown in **Table 3.3** were suggested to provide a more pragmatic and realistic approach to estimate the apparent losses in a particular system. The figures should only be used in cases where flat rate tariffs are not used and can be adjusted if necessary to reflect more reliable information. The values shown in the table are based on limited information and are provided to demonstrate the approach rather than to provide a final solution to this complex issue.

Table 3.2: Suggested apparent loss percentages for a typical system.

Illegal connections		**Meter age and accuracy**			**Data transfer**	
			Good water quality	Poor water quality		
Very high	10 %	Poor > 10 years	8 %	10 %	Poor	8 %
High	8 %					
Average	6 %	Average 5- 10 years	4 %	8 %	Average	5 %
Low	4 %					
Very low	2 %	Good < 5 years	2 %	4 %	Good	2 %

For example, in a non flat rate tariff area, if a water utility has a high occurrence of illegal connections (8 %), the meters in place are more than 10 years old but the water quality of the area is fairly good (8 %) and the data transfer side is average (5 %), the apparent loss estimate would be 21 %.

The information on the meters was estimated from the fact that Europe has a compulsory replacement programme on all meters every five years. Most of the domestic meters in place in South Africa are similar to the European meters. Many factors play a role in the accuracy of a meter, but were excluded in order to minimise complexity, with the exception of the water quality factor which has a major influence on the lifespan of a water meter.

The flat rate tariff ratio is to include areas, such as townships, where the flat rate charged is less than the amount actually being used, which can have a major impact on apparent losses. The following example can be used to illustrate the problem. If an area with 43 000 connections is charged on a flat rate of 10 kl / month. This value may not necessarily be recovered by the users, however, it is billed and is therefore considered to be part of the billed authorised component of the water balance. This amounts to 5.16 mill m^3 / year. However, the water utility measures the water supplied to be 25 mill m^3 / year. The sewerage return flow measured to be 18 mill m^3 / year and garden irrigation is estimated to be 2 mill m^3 / year. The quantity of water flowing through the 43 000 properties is in fact 20 mill m^3 / year (18 mill m^3 / year + 2 mill m^3 / year), however, they are only billing 5.16 mill m^3 / year. The apparent losses becomes 14.84 mill m^3 / year (20 mill m^3 / year – 5.16 mill m^3 / year) and the real losses are then 5 mill m^3 / year (25 mill m^3 / year – 5.16 mill m^3 / year – 14.84 mill m^3 / year). **Figure 3.6** shows a pie cart of the example area.

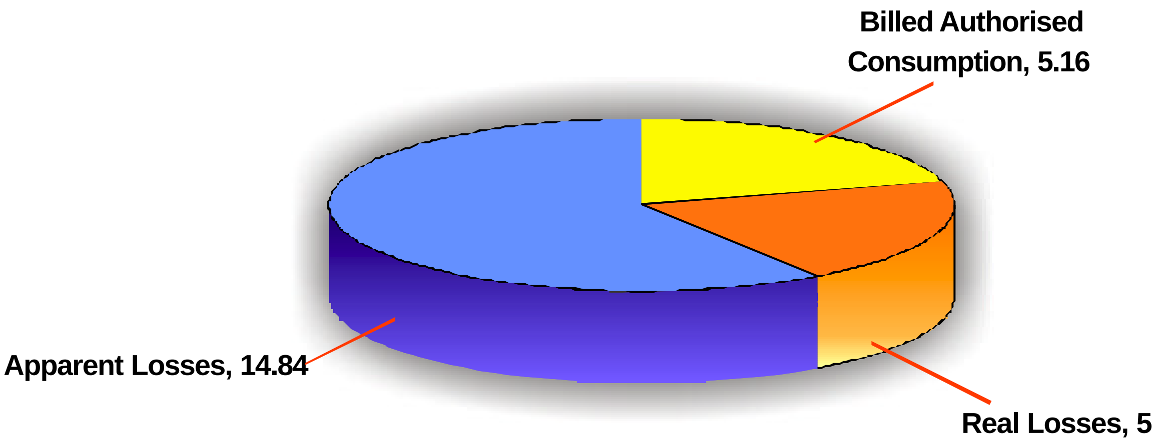


Figure 3.6: Components of the example area.

One of the assumptions regarding apparent losses when analysing a system is that they can be converted to revenue water since the water is effectively being used but not paid for. In many areas, this assumption is valid where customers do not abuse water and have sufficient income to pay for the water without having to alter their lifestyle. In many parts of South Africa, however, it is a fact that the level of consumption will decrease significantly if the consumer is required to pay for all water used. In such cases the apparent losses cannot simply be converted to revenue water by proper metering and billing. This is contrary to the normal assumption that reduction of apparent losses will result in greater revenue water and in such cases the normal practice of multiplying the apparent losses by the selling price of water may not be appropriate. In such cases it may be more realistic to use the purchase price (or product price) of water when assessing the value of the apparent losses rather than the selling price.

3.5 LENGTH OF UNDERGROUND PIPE

While this component is generally not included in the UARL calculation for South African systems, it is described in this report for completeness. The length of underground pipe is the third term in the UARL calculation and there is often confusion regarding what should be included in the UARL calculation and what is already taken into account as part of the service connection component.

If the meters are located at a street edge as shown in F**igure 3.7,** then it is assumed that a particular length of pipe has already been included in the connection component of the UARL calculation – even if the properties are on both sides of the road and supplied from a main running along one side of the road.. In such cases, no additional allowance is made for the length of underground pipe in the UARL calculation and the equaltion effectively has only the mains and connection component. The length of underground pipe is only included in the UARL calculation when the meter is located beyond the property boundary in which case the average length of underground pipe from the property boundary to the meter is used – this is shown in **Figure 3.8**.

The section after the street /property line can be ignored in the South African context, as most meters are located close to the street / property line, and this length has already been included in the Ns part of the UARL calculation.

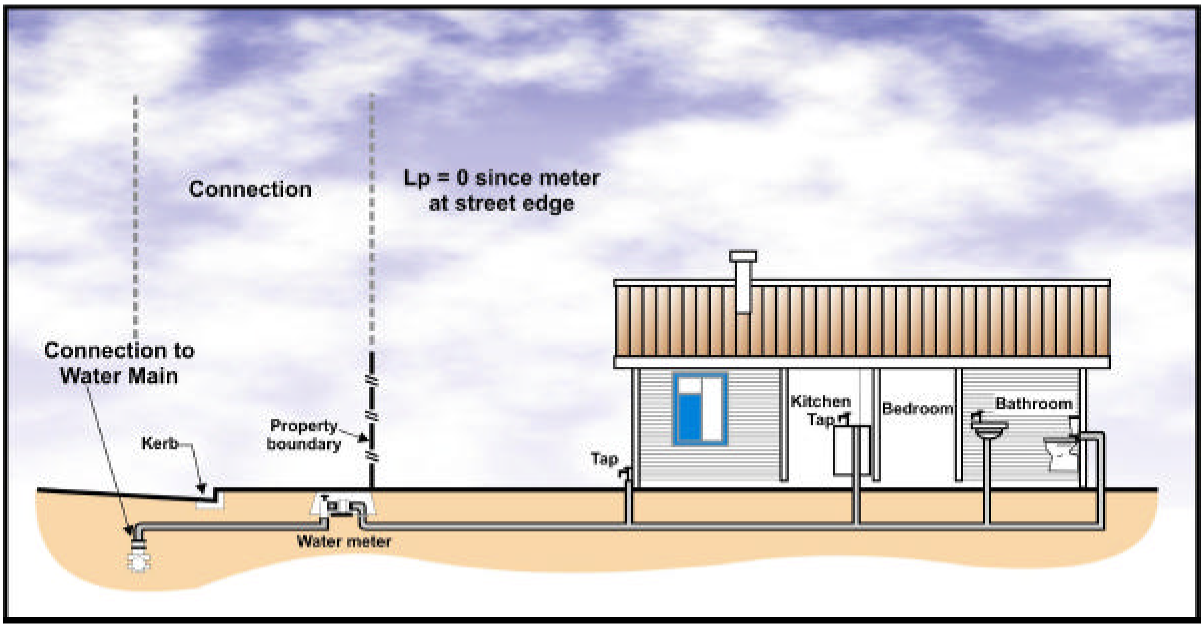


Figure 3.7: Typical house connection: Meter at street edge

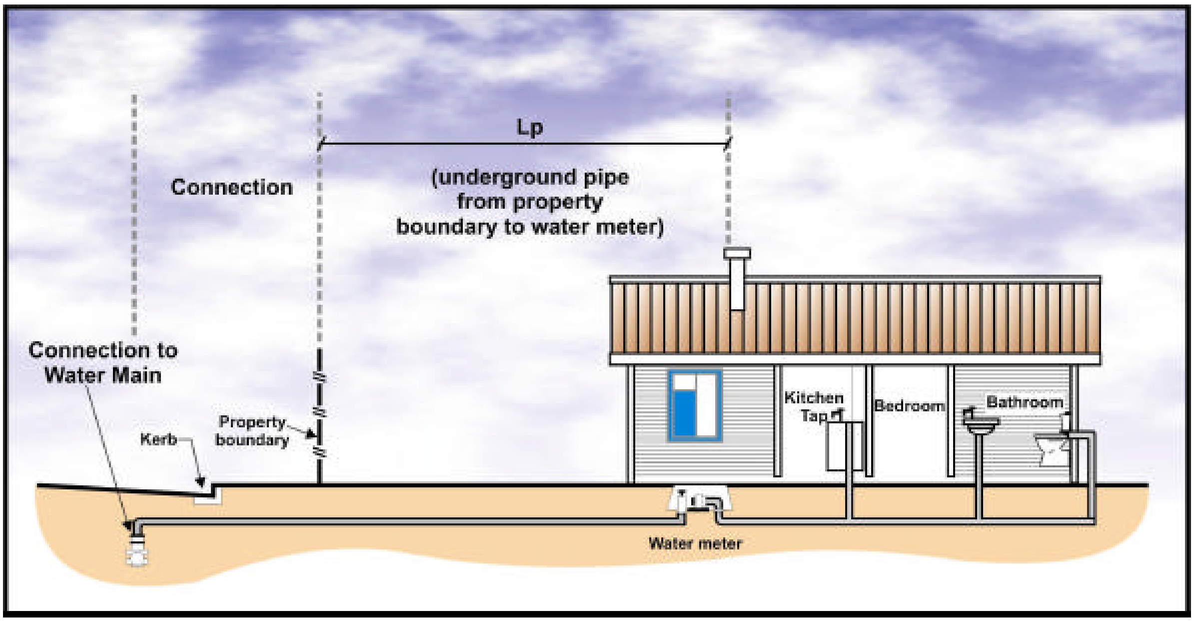


Figure 3.8: Typical house connection: Meter inside property

4 RESULTS FROM THE PROJECT

4.1 WHY BENCHMARK LEAKAGE?

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.

4.2 PURPOSE OF THIS SECTION

The purpose of this section is to present the results of the benchmarking exercise that was carried out as part of a project undertaken and supported by the WRC. Apart from presenting the results of the benchmarking exercise carried out for various water suppliers, this section also provides interpretation of the results and reports on the significance and meaning of the key performance indicators used to benchmark leakage.

4.3 GATHERING OF DATA

4.3.1 General Methodology

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. 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 wish to analyse their system using BENCHLEAK, but cannot use the model for some reason.

Approximately 60 water suppliers were contacted by the project team and the purpose of the study discussed with them. The details of the 60 suppliers can be seen in **Appendix D**. The water suppliers were then asked to complete the **Detail-1 form** and to send the completed form back to the study team. The forms were sent electronically by email except in a few cases where the suppliers did not have access to e-mail in which case the forms were faxed. The water suppliers were contacted again after a period of four to six weeks to request the completed forms.

It was found that most water suppliers could not complete the form within the six week period due to the required information not being readily available and also due to a lack of capacity within the utility. Those suppliers who did not complete the form after the initial period, were contacted again after a second six-week period. Some water suppliers never completed the form even after many months and numerous telephonic 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.

In case where dubious data were identified that could not be corrected, the water supplier was excluded from the final data set. While most of the large errors were identified, there may be other less obvious errors which can only be identified through thorough and regular completion of the BENCHLEAK form.

4.3.2 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. As indicated, mixed responses were received from water services providers with some enthusiastic and keen to participate and others who were very negative. Most suppliers indicated their willingness to participate over the telephone, however, never completed the forms even after numerous requests. A number of forms were obtained from areas where the research team had previously worked and therefore had a relationship with the water suppliers or had access to the information required to complete the forms. Eventually sufficient results (approximately 30, indicated in **Appendix D**) 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 10 000 connections.

Appendix D provides the key results from the benchmarking exercise. 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 4.1** and 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 intermediate range. The sample group represents approximately 4% of the total number of water suppliers in the country.

Table 4.1: Grouping for case study participants

Grouping	Criteria	Group Size	% of Total
1. Large	No of connections > 50 000	10	33
2. Medium	10 000 </= No of Connections </= 50 000	11	37
3. Small	No of Connections < 10 000	9	30

4.4 RESULTS FOR PARTICIPATING SOUTH AFRICAN WATER SUPPLIERS

4.4.1 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 D**. Each Water Supplier is given a reference number. Reference is made to the graphs in **Appendix D** throughout the discussions in **Section 4.4**.

4.4.2 System data

Table 4.2 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 4.1**). Of the total sample group consisting of 30 Water Suppliers, 33% have more than 50 000 service connections (Group 1), 37% have less than 50 000 but more than 10 000 connections (Group 2) and

30% 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, 91% of cases in Group 2 have mains less than 1 000 km but more than 300 km, while in Group 3, all have mains of less than 300 km.

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 all 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 Mℓ/yr, while for Group 2 it is typically more than 10 000 Mℓ/yr. Water systems in Group 3 typically reported System Input Volume of more than 700 Mℓ/yr, but less than 10 000 Mℓ/yr.

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 24 344 Mℓ/yr. In Group 2 three water suppliers have values of System Input Volume of 34 739, 39 153 and 26 976 Mℓ/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 Mℓ/yr, between 20 000 Mℓ/yr and 6 000 Mℓ/yr, and between 6 000 Mℓ/yr and 200 Mℓ/yr, respectively.

Table 4.2: 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	2 400	198 951	83	60	83 788	71 948	991
2	2 943	191 518	65	45	139 685	113 369	1 622
3	1 850	145 000	78	45	69 775	56 863	1 074
4	2 390	112 000	47	70	85 020	66 465	1 626
5	1 571	97 592	62	75	46 218	36 048	1 012
6	1 552	94 105	61	50	52 389	40 999	1 194
7	1 315	79 306	60	50	30 284	25 362	876
8	2 082	75 059	36	75	135 687	98 616	3 600
9	1 275	69 000	54	50	36 353	27 159	1 078
10	1 069	60 208	56	40	24 344	9 583	436
Group Ave	**1 845**	**112 274**	**60**	**56**	**70 354**	**54 641**	**1 351**
Group 2 – Medium (10 000 < No of service connections < 50 000)							
11	678	44 550	66	50	34 739	17 323	1065
12	732	36 253	50	35	39 153	37 103	2804
13	718	31 200	43	50	22 039	17 134	1505
14	920	30 786	33	70	18 347	11 814	1051
15	746	29 760	40	50	21 603	8 730	804
16	431	22 700	53	50	11 505	5 997	724
17	467	21 577	46	50	7 257	6 058	769
18	456	21 100	46	50	12 043	8 965	1164
19	386	18 931	49	45	12 254	9 992	1446
20	263	12 555	48	30	12 019	10 083	2200
21	358	10 200	28	40	26 976	24 207	6502
Group Ave	**560**	**25 419**	**46**	**47**	**19 812**	**14 310**	**1 821**
Group 3 – Small (No of service connections < 10 000)							
22	103	5 872	57	50	3 654	3 113	1 452
23	209	4 419	21	45	11 695	10 776	6 681
24	114	4 226	37	57	4 170	2 763	1 791
25	71	2 727	38	28	1 752	1 463	1 470
26	52	1 478	28	35	742	594	1 101
27	35	1 156	33	51	760	566	1 341
28	38	1 142	30	63	1 110	940	2 255
29	28	1 017	36	40	1 419	1 391	3 747
30	27	557	21	35	250	203	998
Group Ave	**75**	**2 510**	**34**	**45**	**2 839**	**2 423**	**2 315**
Sample Ave	**843**	**47 498**	**47**	**49**	**31 568**	**24 188**	**1 813**

4.4.3 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. The average operating pressure for the sample data set varies from about 28 m to about 75 m with an average value of 49 m.

In South Africa, most systems operate on a 24-hour basis and are continually pressurised. While this is often taken for granted by most South African residents is not the case in most 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.

4.4.4 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. For this data set the density varies from 21 service connections/ km to 83 service connections/ km. The average value for the reference set is approximately 47 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. h 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. In such cases the density of connections can exceed 100 per km of mains with a maximum value in the order of 130 to 150.

4.5 SELECTED OPERATIONAL PERFORMANCE INDICATORS

4.5.1 Summary of Results

Table 4.3 provides a summary of the operational performance indicators for the sample group in terms of the sub-groups as explained in **Table 4.1**

Since the total losses and apparent losses are heavily dependant on the system size in most cases, it is not considered useful to provide comment on the total loss or apparent loss values shown in **Table 4.3**.

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 were able to supply reliable information in this regard. The apparent losses were assessed in the manner discussed in **Section 3.4** which is regarded as a more appropriate method than the simple percentage used in previous assessments.

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. In such cases it is unlikely that the apparent losses can be converted to revenue water since any payment for water is likely to be accompanied by a reduction in overall demand.

CARL for Group 1 ranges from about 3 940 Mℓ/yr to about 29 400 Mℓ/yr with an average of about 12 560 Mℓ/yr. For Group 2 it ranges from a minimum of about 960 Mℓ/yr to a maximum of 13 580 Mℓ/yr with an average of 4 370 Mℓ/yr. Group 3 reports CARL of minimum, maximum and average of about 22 Mℓ/yr, 1 125 Mℓ/yr and 336 Mℓ/yr respectively. The median (or 50^{th} percentile) value of CARL for Group 1, 2 and 3 is approximately 9 900 Mℓ/yr, 2 460 Mℓ/yr and 165 Mℓ/yr respectively.

Table 4.3: Selected Operational Performance Indicators

Utility Ref No.	Total Losses (Mℓ/yr)	Ratio of Total Losses to Authorised Consumption	Ratio of Authorised Consumption to System Input Volume	Apparent Losses (Mℓ/yr)	Current Annual Real Losses			CARL per conn per metre of pressure
					(Mℓ/yr)	(ℓ/conn /day)	(ℓ/ km of mains/ day)	(ℓ /conn /day/ m of press)
Group 1 – Large (No of service connections > 50 000)								
1	11 840	0.16	0.86	2 368	9 472	130	10 813	2.17
2	26 316	0.23	0.81	5 299	21 197	303	19 733	6.74
3	12 912	0.23	0.81	2 582	10 330	195	15 298	4.34
4	18 555	0.28	0.78	3 711	14 844	363	17 016	5.19
5	10 170	0.28	0.78	2 034	8 136	228	14 189	3.05
6	11 390	0.28	0.78	2 278	9 112	265	16 085	5.31
7	4 922	0.19	0.84	984	3 938	136	8 205	2.72
8	37 071	0.38	0.73	7 354	29 417	1074	38 710	14.32
9	9 194	0.34	0.75	1 839	7 355	292	15 804	5.84
10	14 761	1.54	0.39	2 952	11 809	537	30 265	13.43
Group Ave	**15713**	**0.39**	**0.75**	**3140**	**12561**	**352**	**18612**	**6.31**
Group 2 – Medium (10 000 < No of service connections < 50 000)								
11	17416	1.01	0.50	3832	13 584	835	54 892	16.71
12	2050	0.06	0.95	410	1 640	124	6 138	3.54
13	4905	0.29	0.78	981	3 924	345	14 973	6.89
14	6533	0.55	0.64	1307	5 226	465	15 563	6.64
15	12873	1.47	0.40	2575	10 298	948	37 820	18.96
16	5508	0.92	0.52	1322	4 186	505	26 609	10.10
17	1199	0.20	0.83	240	959	122	5 626	2.44
18	3078	0.34	0.74	616	2 462	320	14 792	6.39
19	2262	0.23	0.82	339	1 923	278	13 649	6.18
20	1936	0.19	0.84	252	1 684	367	17 543	12.25
21	2769	0.11	0.90	554	2 215	595	16 951	14.87
Group Ave	**5503**	**0.49**	**0.72**	**1130**	**4373**	**446**	**20 414**	**9.54**
Group 3 – Small (No of service connections < 10 000)								
22	541	0.17	0.85	108	433	202	11 517	4.04
23	919	0.09	0.92	184	735	456	9 635	10.13
24	1 407	0.51	0.66	271	1 125	729	27 037	12.80
25	289	0.20	0.84	58	231	232	8 914	8.29
26	148	0.25	0.80	22	126	234	6 639	6.67
27	194	0.34	0.74	29	165	391	12 916	7.67
28	170	0.18	0.85	26	145	348	10 454	5.52
29	28	0.02	0.98	6	22	59	2 153	1.48
30	47	0.23	0.81	7	40	197	4 059	5.62
Group Ave	**416**	**0.22**	**0.83**	**79**	**336**	**316**	**10 369**	**6.91**
Sample Ave	**7380**	**0.38**	**0.76**	**1485**	**5891**	**376**	**16 800**	**7.68**

Expressing Real Losses and/or non-revenue water as a percentage of system input is often used as a benchmarking parameter and is continually criticised for the fact that it can be very misleading. Percentages can be used when considering the real losses as a percentage of the running costs of the system – i.e. a financial indicator and not a technical indicator.

To highlight the problem with percentages, the data shown in **Table 4.4** can be used. In this table, the Current Annual Real Losses (CARL) (or simply Real Losses) are shown in units of ℓ/ connection/ day and as a percentage of the System Input Volume together with the Authorised Consumption (also in units of ℓ/ connection/ day). This is exactly the same data as given in **Table 4.2, Table 4.3** and **Table 4.5**, which has been sorted according to the CARL in ℓ/ connection/ day.

Two examples of how percentages can be misleading can be taken from the data presented in **Table 4.4**:

- Water supplier No. 8 and 9 reported real losses of 21.7% and 20.2% respectively. Although the percentage losses in this case are virtually the same, the real losses per connection for No. 8 and 9 are 1074 and 292 ℓ/ connection/ day respectively, which clearly highlights the fact that the two utilities have different levels of leakage although the percentage leakage values are similar.
- In the case of water supplier No. 7 and 12 the percentage real losses is 13% and 4.2% respectively. However, the real losses per connection are virtually the same (136 and 124 ℓ/ connection/ day 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 352, 446 and 316 ℓ/ connection/ day respectively. The minimum and maximum for the three respective groups are 130 and 1074, 122 and 948, and 59 and 729 ℓ/ connection/ day respectively.

From these figures it is evident that expressing real losses per connection shows no definite trends with regard to grouping, indicating that it is not biased in terms of system size or total system input. As in the case of CARL per connection/ day, expressing real losses per kilometre of mains (recommended only for systems with a density of connections less than 20 per km mains) or per connection per meter of pressure also shows no definite trends or distribution patterns.

Table 4.4: Illustrating the problem with percentages

Ref No.	Current Annual Real Losses (ℓ /conn /day)	Current Annual Real Losses (% of System Input)	Authorised Consumption (ℓ /conn /day)
8	1074	21.7	3600
15	948	47.7	804
11	835	39.1	1065
24	729	27.0	1791
21	595	8.2	6502
10	537	48.5	436
16	505	36.4	724
14	465	28.5	1051
23	456	6.3	6681
27	391	21.7	1341
20	367	14.0	2200
4	363	17.5	1626
28	348	13.1	2255
13	345	17.8	1505
18	320	20.4	1164
2	303	15.2	1622
9	292	20.2	1078
19	278	15.7	1446
6	265	17.4	1194
26	234	17.0	1101
25	232	13.2	1470
5	228	17.6	1012
22	202	11.9	1452
30	197	16.0	998
3	195	14.8	1074
7	136	13.0	876
1	130	11.3	991
12	124	4.2	2804
17	122	13.2	769
29	59	1.6	3747

4.5.2 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 the use of percentages is not recommended as a comparative technical indicator for real losses. It should be noted that percentages can still be used as a financial indicator in which case the losses are expressed as a percentage of the total cost of running the system.

Caution when using percentages is particularly important in South Africa 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, sometimes exceeding 400l/capita/day. Adjoining these affluent areas are areas of extreme poverty where the per capita consumption is very low and often closer to 25 ℓ/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 40%. In reality, however, the losses from the low-income area may be more lower than from the affluent area, although this is not indicated by the percentage losses.

4.5.3 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 indicator is generally used for systems which have a density of connections of less than 20 connections per km of mains – typically rural areas.

From **Table 4.3**, it can be seen the "Current Annual Real Losses per Kilometre of Mains" ranges from approximately 2 150 ℓ/ km of mains/ day to approximately 55 000 ℓ/ km of mains/ day with an average value in the order of 16 800 ℓ/ km of mains/ day.

4.5.4 Current Annual Real Losses per Connection

Expressing the "Current Annual Real Losses" in terms of losses per connection per day is the preferred PI for systems with more than 20 connections per km of mains. This helps to remove the influence of the size of the system, and allows a more direct comparison between different systems.

From **Table 4.3** in **Section 4.6.1** it can be seen the "Current Annual Real Losses per Connection" range from approximately 60 ℓ/ connection/ day to approximately 1 070 ℓ/ connection/ day with an average value in the order of 380 ℓ/ connection/ day.

4.5.5 Current Annual Real Losses per Connection per metre of Pressure

Different systems operate under different average operating pressures and one criticism of the previously mentioned indicators is the fact that they do not take system pressure into account. To overcome this potential problem, the real losses can be expressed in terms of litres per connection per day per me of pressure. .

Table 4.3 also shows the “Current Annual Real Losses per Connection per Metre of Pressure” and it can be seen that the values range from approximately 1.5 l/ connection/ day/ m pressure to almost 19 l/ connection/ day/ m pressure with an average value of approximately 8 l/ connection/ day/ m pressure.

4.6 SELECTED FINANCIAL PERFORMANCE INDICATORS

4.6.1 Summary of Results

Table 4.5 provides a summary of the financial performance indicators for the sample group. The total Non-Revenue water as percentage of System Input Volume ranges from about 2% to about 61%. 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 25%, 28% and 15% for Groups 1, 2 and 3 respectively.

Little confidence should be attached to the data with regard to non-revenue water as a percentage of running cost since 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 difficult for water suppliers to provide a break-up of the components of the Unbilled Authorised portion of non-revenue water. Most of the water suppliers included in the analyses could not provide an estimate of the average annual operating cost of the system. For this reason, the values for the non-revenue water as a percentage of running cost should be treated with caution.

Table 4.5: 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	0.30	3	11	14	0	3	5	8
2	0.45	4	15	19				
3	0.00	4	15	19	0	4	15	19
4	0.58	4	17	22				
5	0.95	4	18	23				
6	0.00	4	17	22				
7	0.00	3	13	16				
8	12.92	5	22	40				
9	0.00	5	20	25				
10	0.00	12	49	61	0	10	24	34
Group Ave	**2.75**	**5**	**20**	**26**	**0**	**6**	**15**	**20**
Group 2 – Medium (10 000 < No of service connections < 50 000)								
11	0.00	11	39	50				
12	0.00	1	4	5	0	17	3	20
13	0.00	4	18	22				
14	2.35	7	28	38				
15	0.00	12	48	60				
16	0.00	11	36	48				
17	0.00	3	13	17				
18	0.00	5	20	26				
19	0.00	3	16	18	0	4	11	15
20	3.87	2	14	20				
21	0.02	2	8	10	0	2	8	10
Group Ave	**0.41**	**6**	**22**	**29**	**0**	**8**	**7**	**15**
Group 3 – Small (No of service connections < 10 000)								
22	0.00	3	12	15				
23	0.00	2	6	8				
24	0.00	6	27	33	0	7	18	25
25	0.00	3	13	16				
26	0.00	3	17	20	0	6	31	37
27	0.00	4	22	26	0	7	28	35
28	0.00	2	13	15	0	5	22	27
29	0.00	0	2	2	0	1	0	1
30	0.00	3	16	19	0	6	17	23
Group Ave	**0.00**	**3**	**14**	**17**	**0**	**5**	**19**	**25**
Sample Ave	**1.05**	**5**	**19**	**24**	**0**	**6**	**15**	**21**

4.6.2 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 **Table 4.6** and range from approximately 0% to 31% with an average value in the order of 15%.

Table 4.6: Distribution of Non-Revenue Water as % of Running Cost

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

4.6.3 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 **Table 4.5** and range from approximately 2% to more than 61% with an average value of almost 24%.

4.6.4 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 **Table 4.5**, and as can be seen, the values range from approximately 1% to more than 37% with an average value of 21%.

4.7 INFRASTRUCTURE LEAKAGE INDEX

Table 4.5 provides details of the Unavoidable Annual Real Losses (UARL) and the Infrastructure Leakage Index (ILI). The Infrastructure Leakage Index (ILI) is rapidly becoming the performance indicator of choice when assessing real losses from potable water distribution systems. It is simply the ratio of the current annual real losses (CARL) divided by the unavoidable annual real losses (UARL) – both of which are discussed earlier in this report.

$$ILI = CARL / UARL$$

The ILI is obviously based on the assessment of the unavoidable annual real losses (UARL) can be easily assessed for any given system as long as the number of connections, length of mains and average operating pressure are known – as discussed previously. Details of all the calculations are provided in the BENCHLEAK User Guide (Mckenzie and Lambert , 2002) which is available from the WRC together with the model**.**

The UARL and ILI parameters represent the key output from the BENCHLEAK Model and effectively allow meaningful comparisons to be made from one system to another.

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 64, 59 and 62 ℓ/ connection/day respectively. For the ILI it is 5.1, 8.0 and 6.4 for Groups 1, 2 and 3 respectively.

Table 4.5: Summary of UARL and ILI

Utility Ref No.	Unavoidable Real Losses		Infrastructure Leakage Index
	(M l/yr)	(l /conn /day)	
Group 1 – Large (No of service connections > 50 000)			
1	4430	61	2.1
2	3355	48	6.3
3	2964	56	4.2
4	3393	83	4.4
5	2921	82	2.8
6	1889	55	4.8
7	1592	55	2.5
8	2657	97	11.0
9	1436	57	5.2
10	989	45	12.1
Group Ave	**2563**	**64**	**5.6**
Group 2 – Medium (10 000 < No of service connections < 50 000)			
11	878	54	15.6
12	543	41	3.0
13	695	61	5.7
14	1056	94	5.0
15	684	63	15.2
16	472	57	8.8
17	559	71	1.7
18	454	59	5.4
19	366	53	5.3
20	160	35	10.4
21	212	57	10.4
Group Ave	**553**	**59**	**7.9**
Group 3 – Small (No of service connections < 10 000)			
22	120	56	3.6
23	119	74	6.1
24	113	73	10.0
25	35	35	6.6
26	27	50	4.6
27	29	69	5.7
28	37	88	3.9
29	19	52	1.2
30	12	59	3.4
Group Ave	**57**	**62**	**5.0**
Sample Ave	**1074**	**61**	**6**

An ILI value of 6 indicates that if 1 litre of water is considered to be the unavoidable leakage from a particular water distribution system, 6 litres is physically being lost. 5 litres could theoretically be saved through some form of leakage intervention, however, experience has shown that it is not economically viable to target leakage levels below a certain level. The economic level of leakage is a topical issue and , to date, there is no internationally accepted approach to calculate the economic level of leakage. In the case of South Africa, an ILI value of 2 to 3 would generally be considered acceptable while in some other countries a value of 3 would be considered unacceptably high. In many other countries with exceptionally high leakage, a value of 10 would be considered as acceptable.

The ILI values for the South African data sets used in this project are provided in **Figure 4.1** for 27 of the 30 water utilities considered in the analyses. A further three data sets were excluded from the analyses since they were based on systems which can be regarded as too small to be used for international comparisons. It is generally accepted that systems must have at least 2 000 connections (and preferably 5 000 connections) to provide consistent and reliable results. The UARL and ILI calculations are likely to be inconsistent at best and unreliable at worst when used on small systems with less than 2000 connections. It has also been found in recent studies undertaken in several Asian countries that average operating pressures are sometimes less than 10 m in which cases the ILI values tend to become unrealistically high. Mr Lambert (personal communication) has suggested that the ILI should only be used for systems with average operating pressures above 20 m to overcome the problems experienced when analysing low pressure systems. In South Africa, this issue is not a problem since most systems tend to operate around 50 m of pressure.

While it is recommended by the international experts that the ILI is only used for relatively large systems (more than 5 000 connections) with relatively high pressures (more than 20 m), several leakage management specialists have found the indicator to be very useful even in smaller systems for highlighting areas with unusually high leakage. While the ILI values may sometimes become so high that they are considered to be unreliable (i.e. a value of 200 quoted by Mr Liemberger for an Asian system – personal communication), they can still be very useful in identify problem areas. In such cases, the authors of this report support the use of the ILI as an aid in identifying areas of unusually high leakage relative to the surrounding areas. Although the ILI values may be so high as to be unrealistic when compared to the international data sets, they do provide a leakage indicator which can be used to prioritise the various areas within a given system or country.

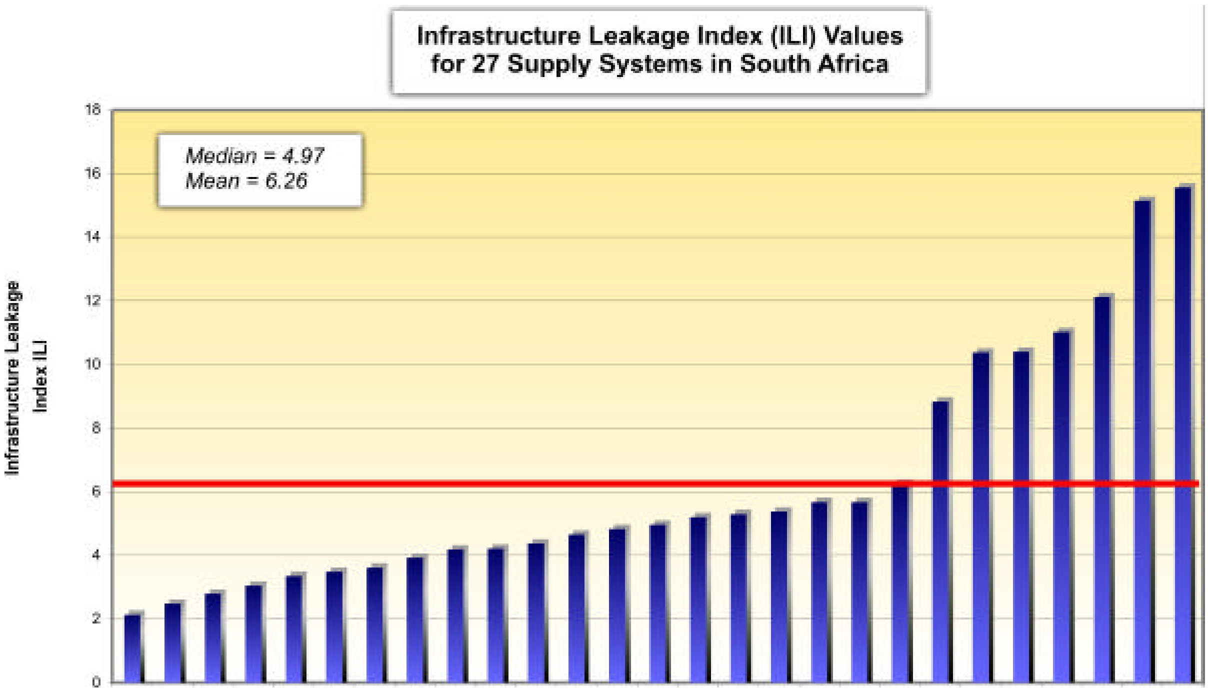


Figure 4.1: ILI results for 27 systems in South Africa

From **Figure 4.1** it can be seen that the ILI values range from 2.0 to approximately 15.5 with an average value in the order of 6.0. This data set can now be compared to several other international data sets compiled by various WDM specialists from around the world and the corresponding results for the UK, North America and Australia are provided in **Figures 4.2, 4.3 and 4.4**. It should be noted that these international results were provided by various specialists to whom the authors of this report are most grateful.

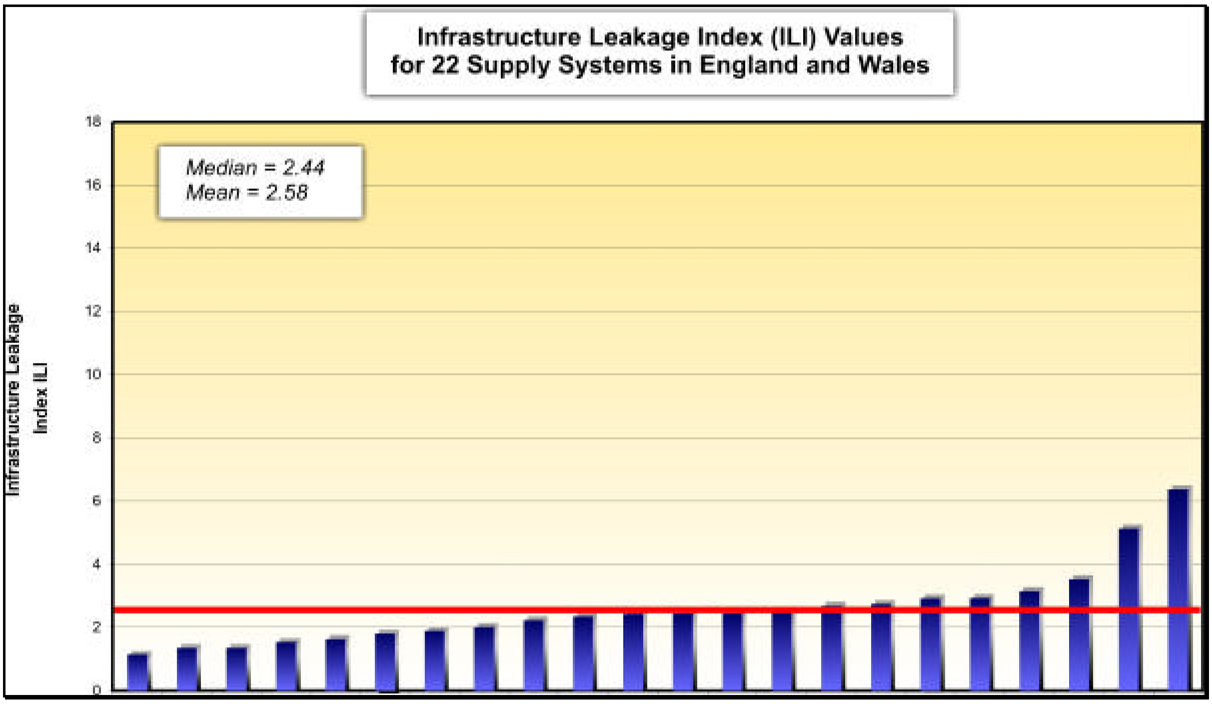


Figure 4.2: ILI results for 20 systems from England and Wales

(Source: February 2004 paper by David Howarth, Environment Agency)

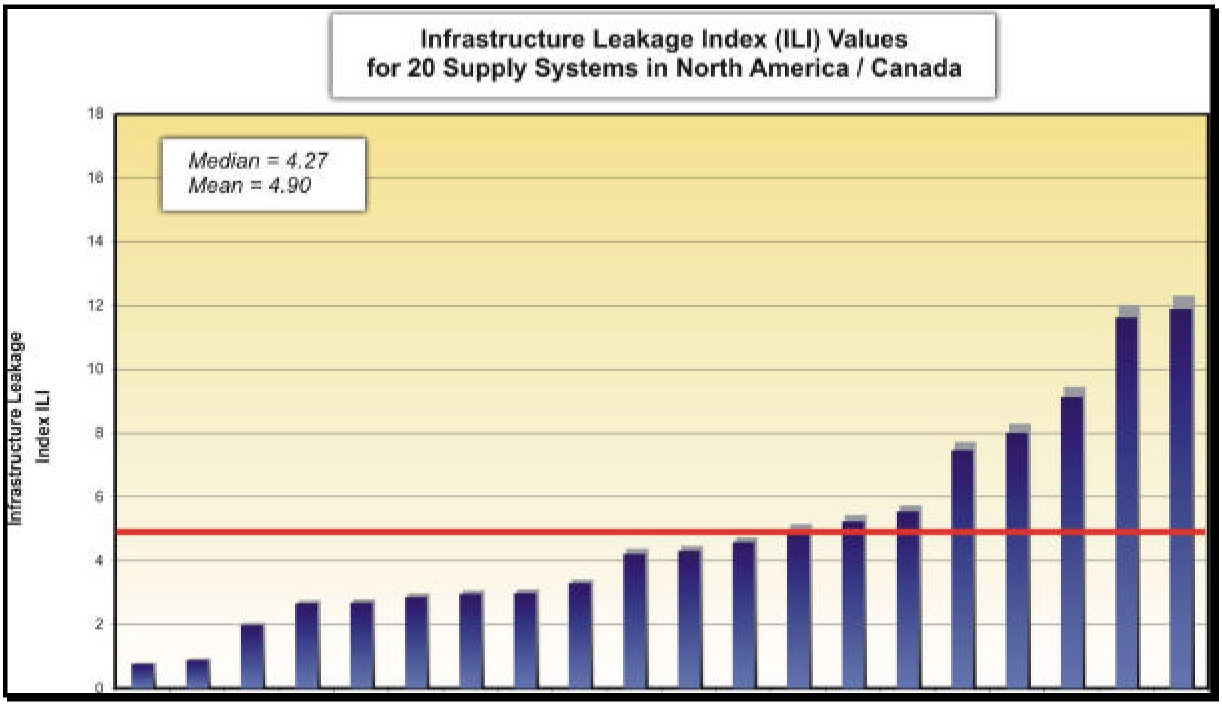


Figure 4.3: ILI results for 20 systems from the USA and Canada

(Source: Russell Titus, Allan Lambert and Ken Brothers based on various data sources)

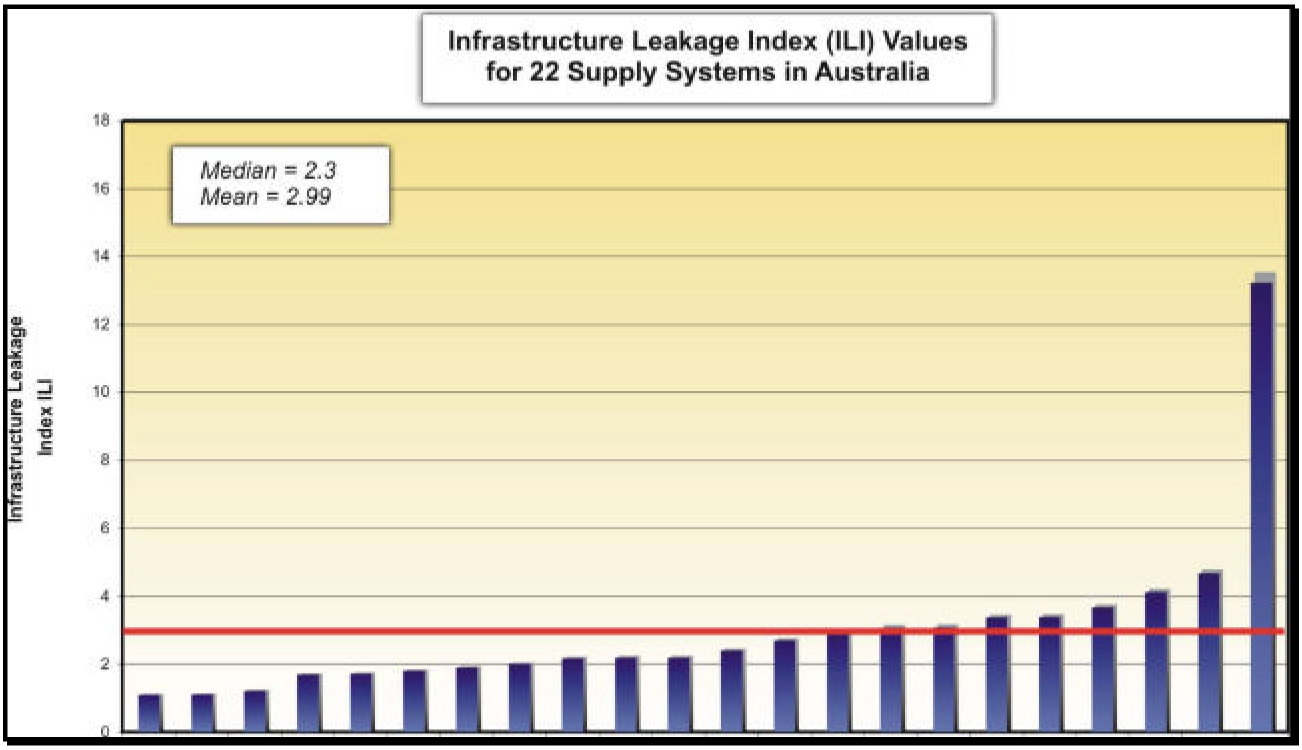


Figure 4.4: ILI results for 20 systems from Australia

(Source: March 2004, Tim Waldron, Wide Bay Water)

4.8 COMPARISONS WITH PREVIOUS SOUTH AFRICAN RESULTS

It was interesting to note the similarities between the average results obtained from the 30 selected Water Suppliers and the previous results obtained from a similar exercise carried out on 34 Water Suppliers. **Table 4.6** presents these comparisons in the three different groups.

Table 4.6: Comparison with previous South African results

Parameter	Group 1 previous	Group 1 New	Group 2 previous	Group 2 New	Group 3 Previous	Group 3 New
Mains Length	2 349	1 845	542	560	140	75
No. service connections	127 620	112 274	27 788	25 419	4 206	2 510
Density service connections	57	60	52	46	38	34
Operating pressure	53	56	47	47	42	45
System input volume	84 729	70 354	19 403	19 812	3 745	2 839
Authorised consumption	66 642	54 641	15 287	14 310	3 237	2 423
Total losses	18 087	15 713	4 117	5 503	509	416
Apparent losses	3 568	3 140	827	1 130	102	79
Current annual real losses	14 519	12 561	3 290	4 373	407	336
Unavoidable annual real losses	2 679	2 563	541	553	83	57
Infrastructure leakage index	5.1	5.55	8.0	7.86	6.4	5.02

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 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 are unable to provide basic information on their systems such as the total length of mains and number of service connections etc.
- 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 if there are more than 2 000 connections and the zone is relatively homogeneous. 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. Internationally the
- 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 15.5 with an average value in the order of 6.0. The average values are 5.5, 7.8 and 5.0 for Groups 1, 2 and 3 respectively. This can be compared to average ILI values from North America / Canada of 4.9, Australia of 2.9 and England / Wales of 2.6.
- 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.

5.2 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.

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APPENDIX A

Glossary of Terms

APPENDIX A : GLOSSARY OF TERMS

Descriptions of the components 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 ℓ/conn/d or m^3/year etc. Same as Real Losses.

Infrastructure Leakage Index (ILI)

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

ILI = CARL / UARL

Length of Mains (Lm)

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

Non Revenue Water

The non-revenue water is becoming the standard term replacing unaccounted-for water in

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

- Unbilled Authorised Consumption
- Apparent Losses and
- Real Losses

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

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

Number of Service Connections (Ns)

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

Real Losses

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

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

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

System Input

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

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

Total Consumption

Total consumption is the sum of the following three components:

- Billed authorised consumption
- Unbilled authorised consumption
- Apparent losses

Target Annual Real Loss (TARL)

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

Total Losses

Total losses are the sum of the real and apparent losses.

Unavoidable Annual Real Losses (UARL)

The minimum level of real losses for a specific system that can be achieved under the most efficient operating conditions. It is an indication of the level of leakage that can theoretically be achieved if everything possible is done to minimise the leakage. It 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

Derivation of the Unavoidable Annual Real Losses

CALCULATION OF UNAVOIDABLE ANNUAL REAL LOSSES (UARL)

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

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

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

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

Table B1: Parameters required for the calculation of UARL

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

Table B2: Parameter values used to calculate UARL

Component of Infrastructure	Background losses	Reported bursts	Unreported bursts
Mains	20* ℓ/km/hr	• 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* ℓ/conn/hr	• 2.25/1 000 connections/year at • 1.6 m^3/h per burst* • average duration of 8 d	• 0.75/1 000 conn/yr at • 1.6 m^3/h per burst* • average duration of 100 d
Unmetered Service connections after street/property line	0.50* ℓ/conn/hr per 15m length	• 1.5/1 000 connections/year at • 1.6 m^3/h per burst* • average duration of 9 d	• 0.50/1 000 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 50 m pressure. The average duration assumed for reported bursts is based on best practice world-wide. The average duration for unreported bursts is based on intensive active leakage control, approximating to night-flow measurements once per month on highly sectorised water distribution systems.

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

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

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

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

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

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

Where:

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

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

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

APPENDIX C

Methods Of Calculating Average Pressure In Distribution Systems

APPENDIX C: METHODS OF CALCULATING AVERAGE PRESSURE IN DISTRIBUTION SYSTEMS

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

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

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

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

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

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

If network analysis models are not available, the approach used in **Section C2** of this appendix should be followed. If network analysis models are available, the approach suggested in **Section C3** should be followed.

C2. AVERAGE ZONE PRESSURES WHERE NO NETWORK MODELS EXIST

C2.1 Calculate Weighted Average Ground Level for Each Sector

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

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

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

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

Table C1: Example calculation of weighted ground level

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

Weighted Average Ground Level = 3907 / 357 = 10.9 m

C2.2 Measure or Calculate Average Zone Pressure

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

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

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

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

C2.3 Calculate Weighted Average Pressure for Aggregation of Zones

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

Table C2: Example calculation of weighted ground level

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

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

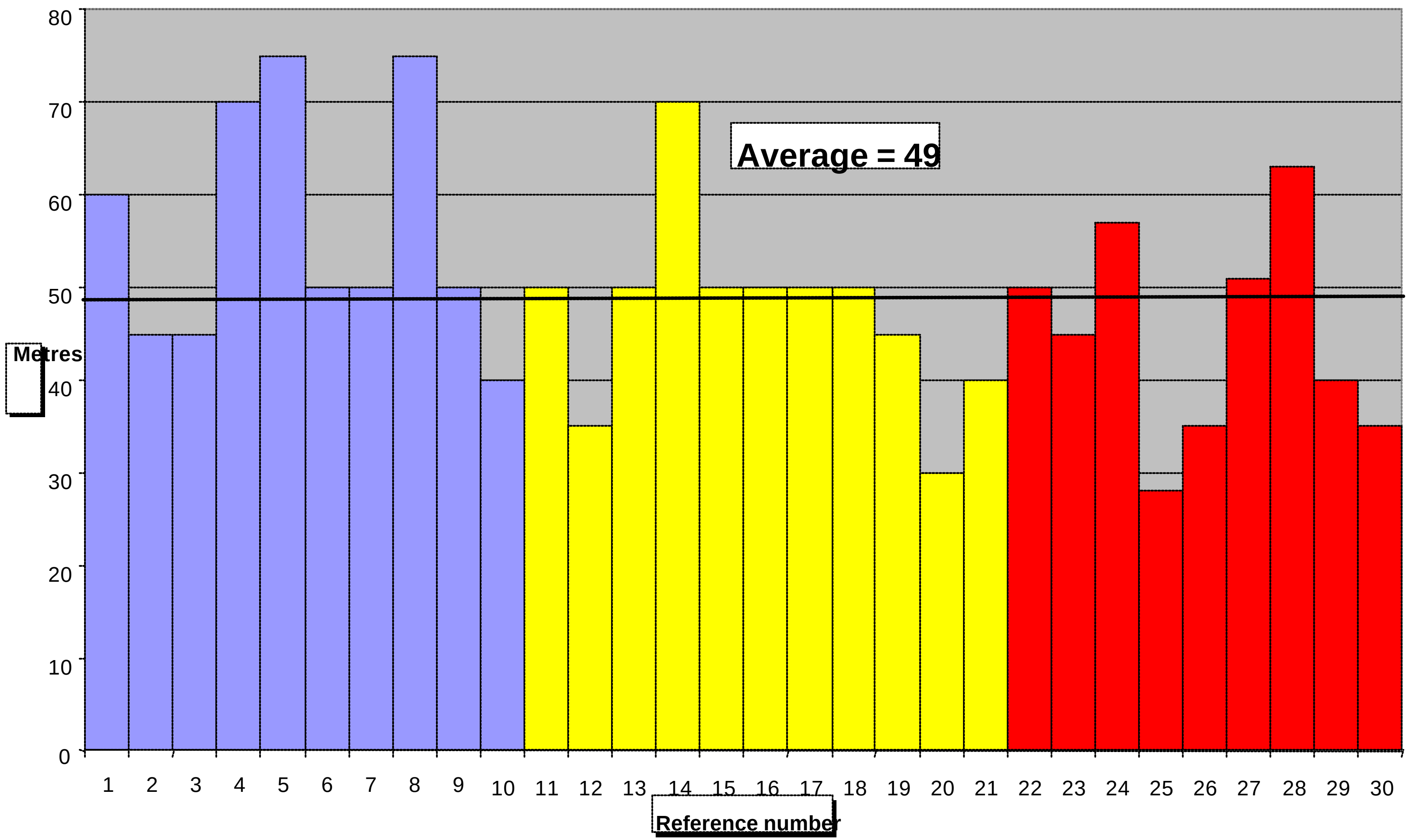
C3. AVERAGE ZONE PRESSURES USING NETWORK MODELS

C3.1 Calculate Weighted Average Ground Level for Each Sector

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

APPENDIX D

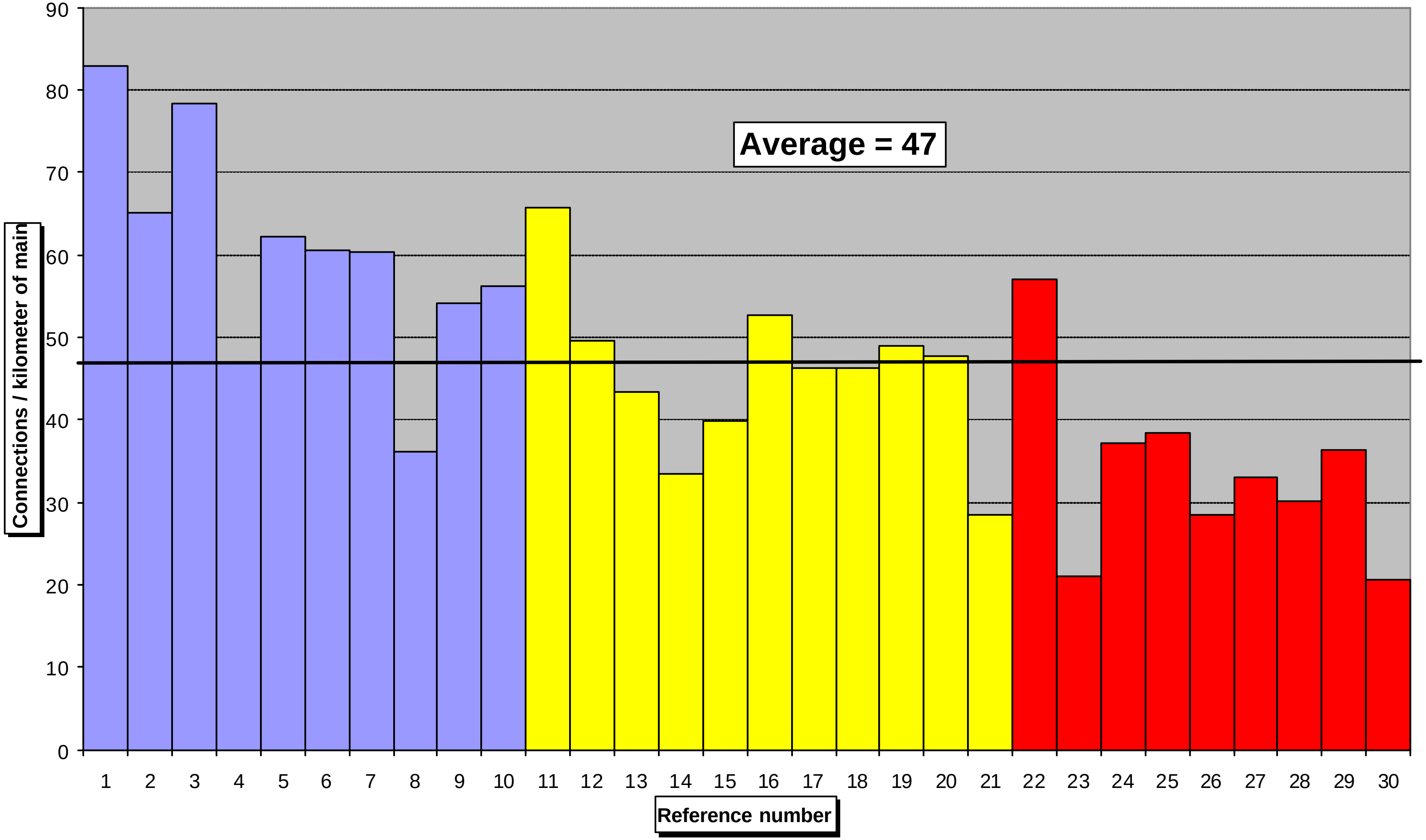
Graphic Results from Participating Water Suppliers



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

Average operating pressure

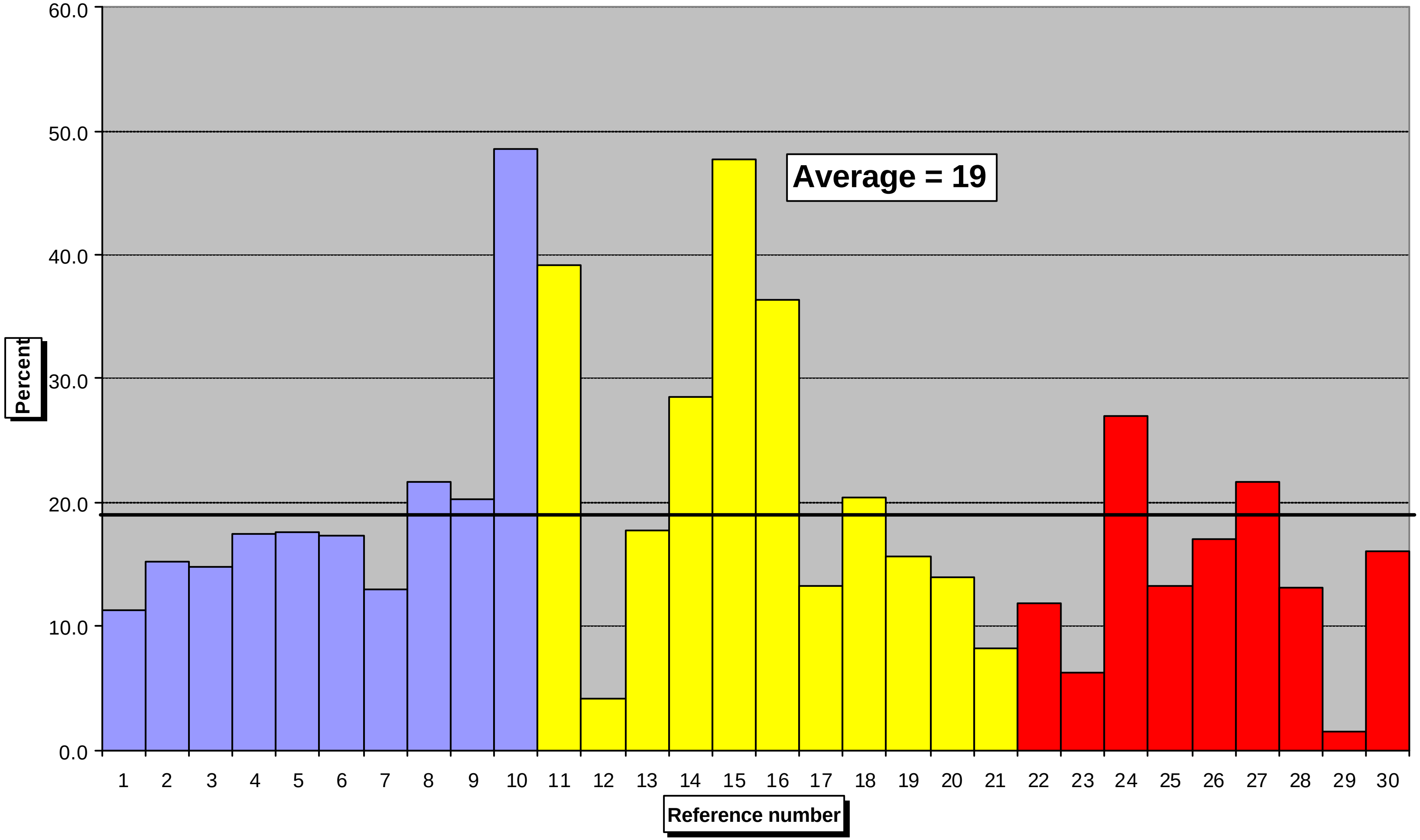
Fig D.1



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

Density of Connections

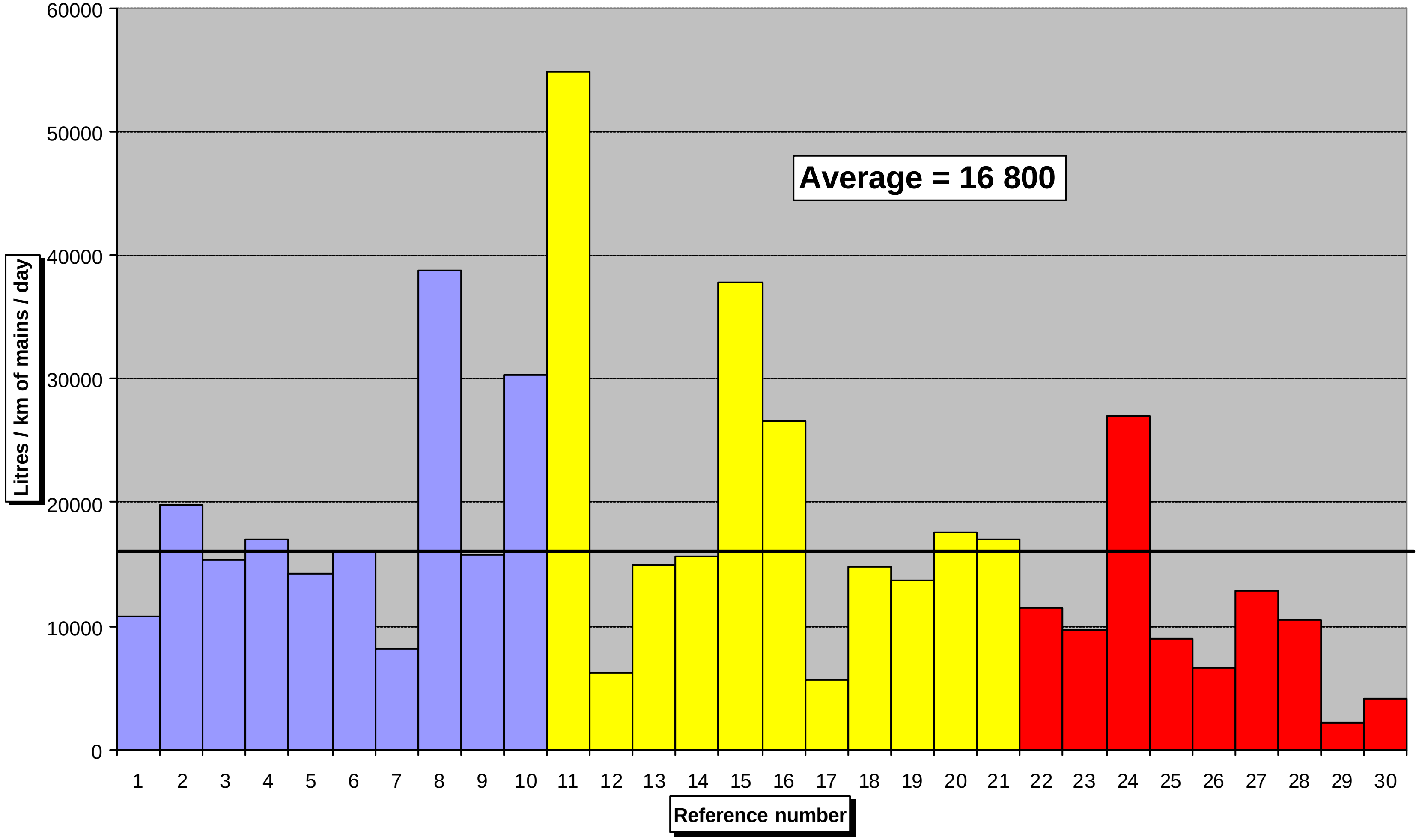
Fig D.2



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 Input Volume

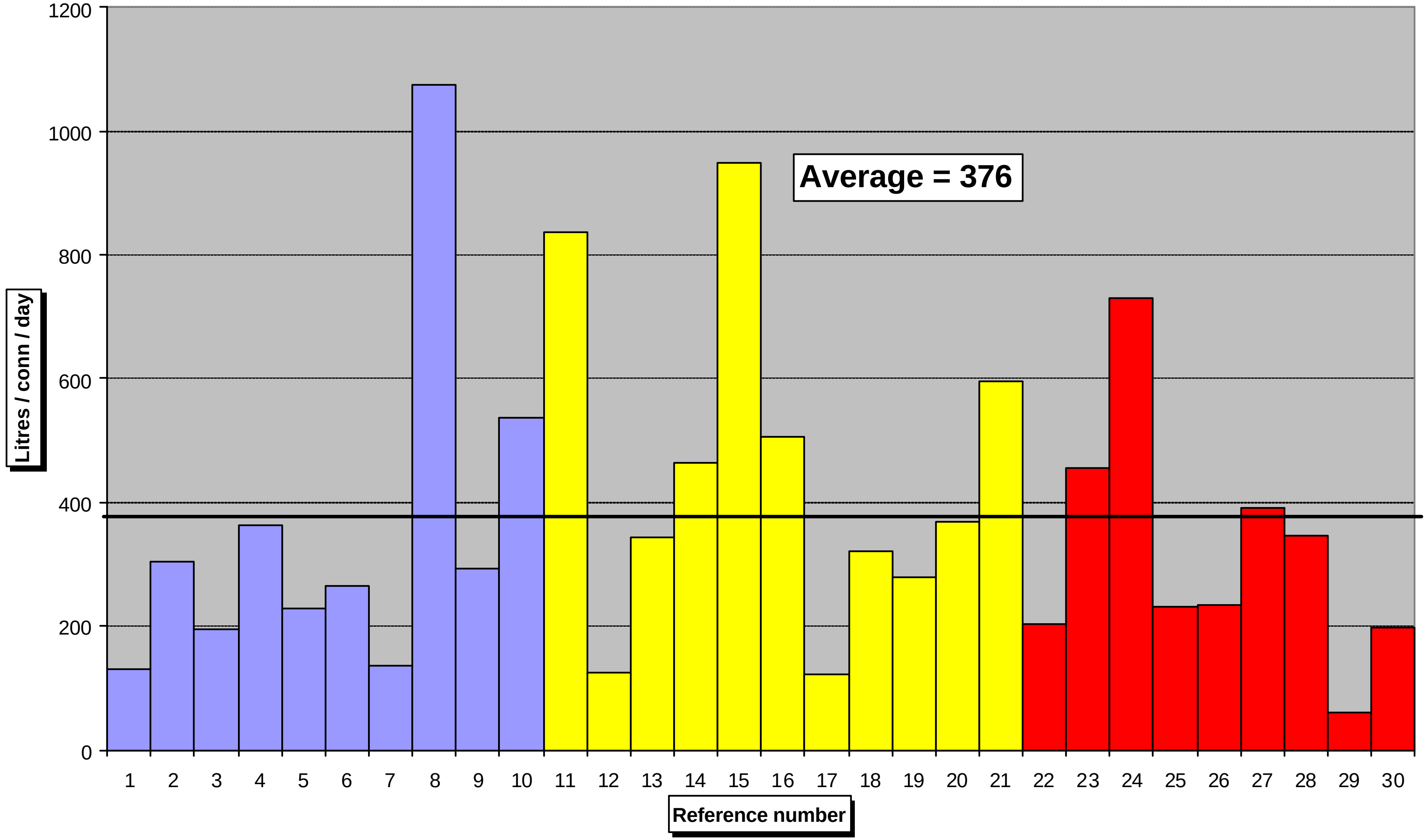
Fig D.3



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

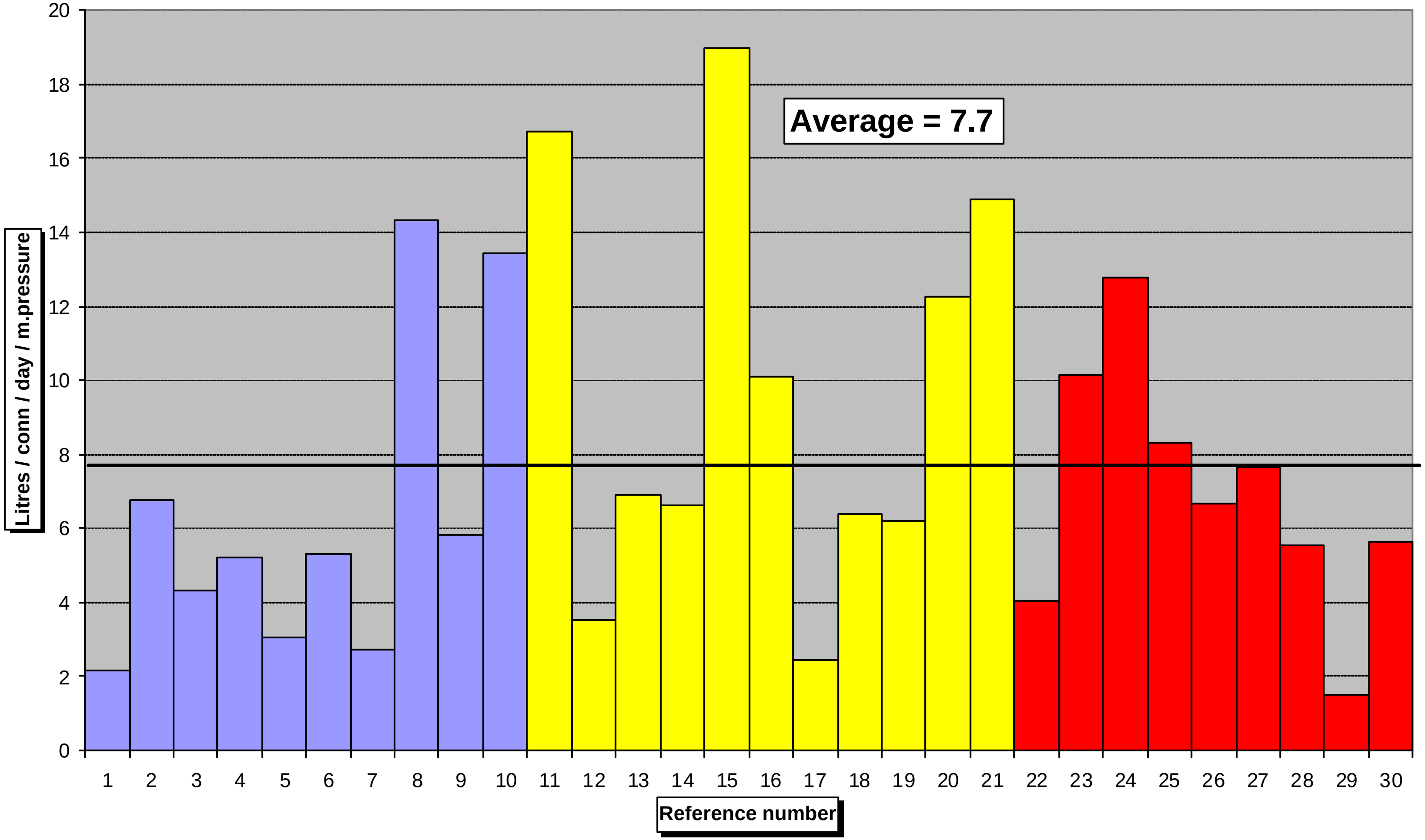
Fig D.4



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

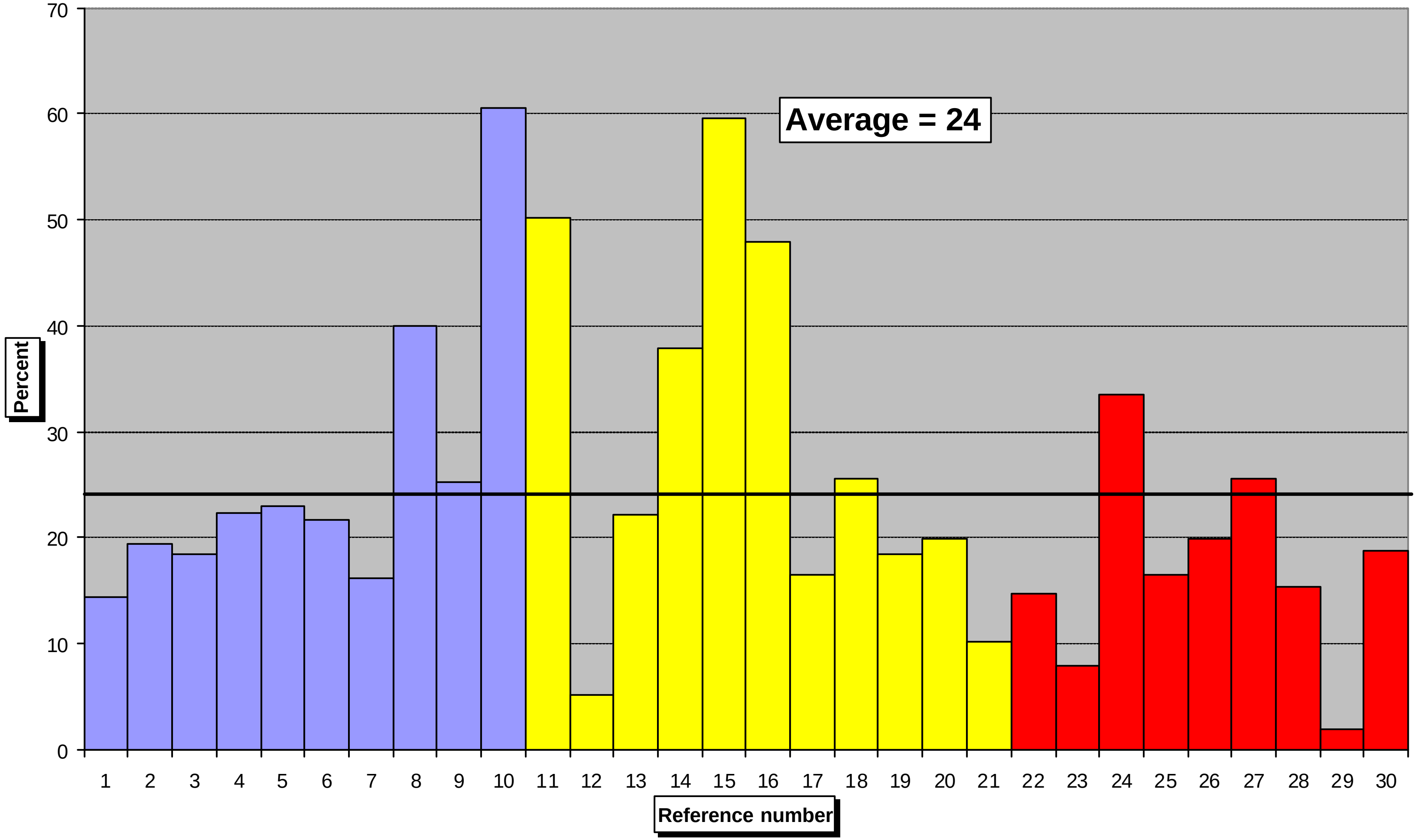
Fig D.5



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 per metre pf pressure

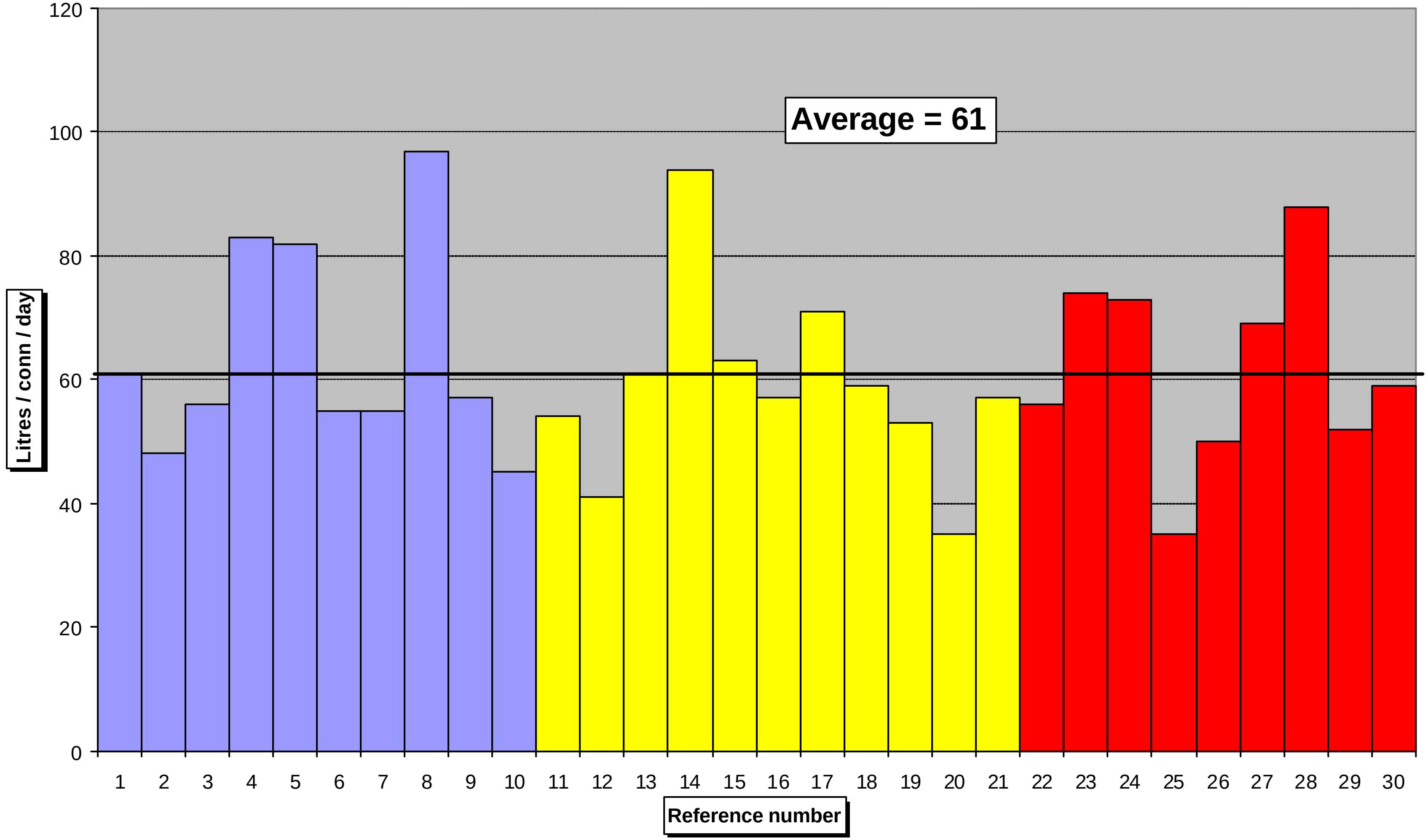
Fig D.6



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

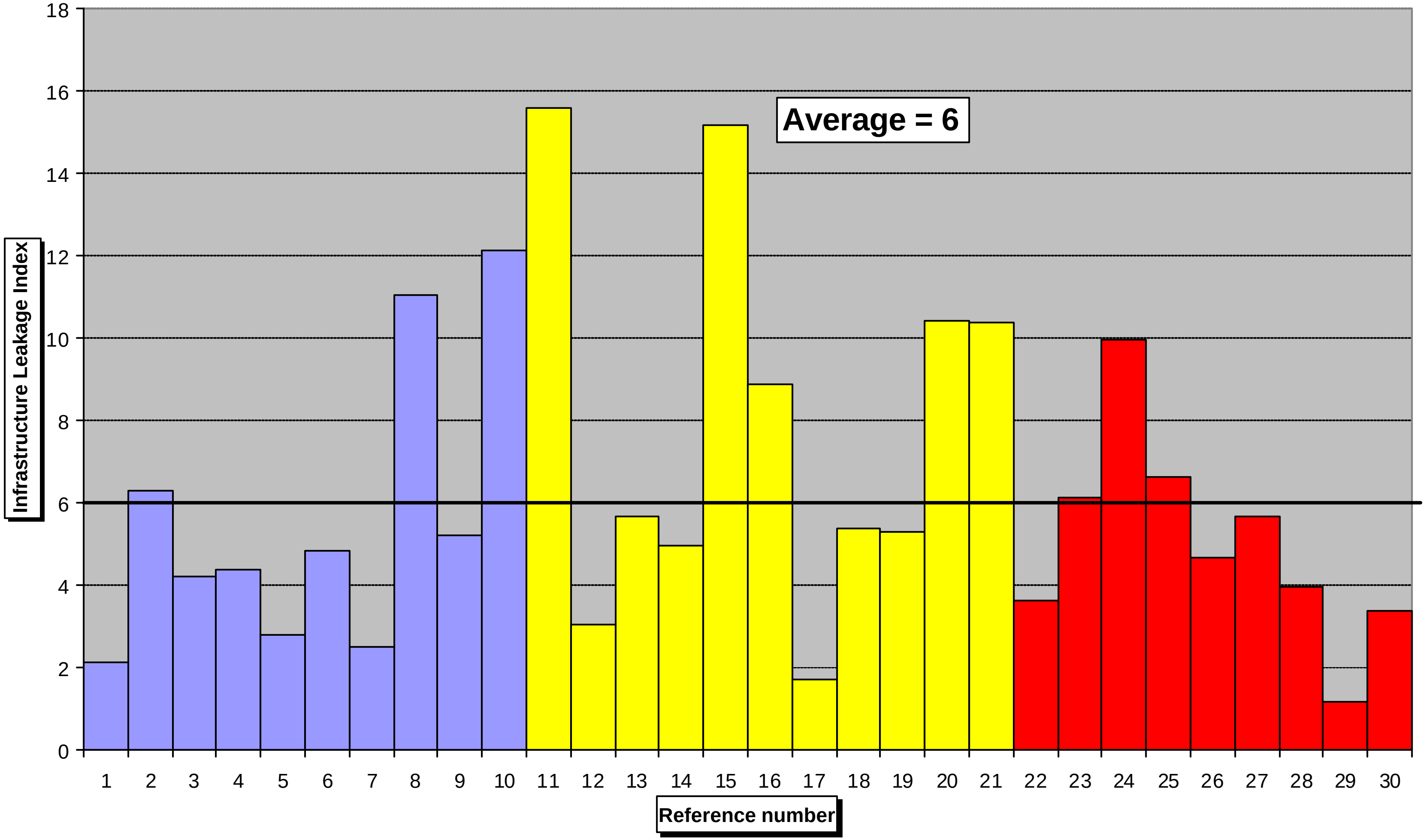
Fig D.7



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

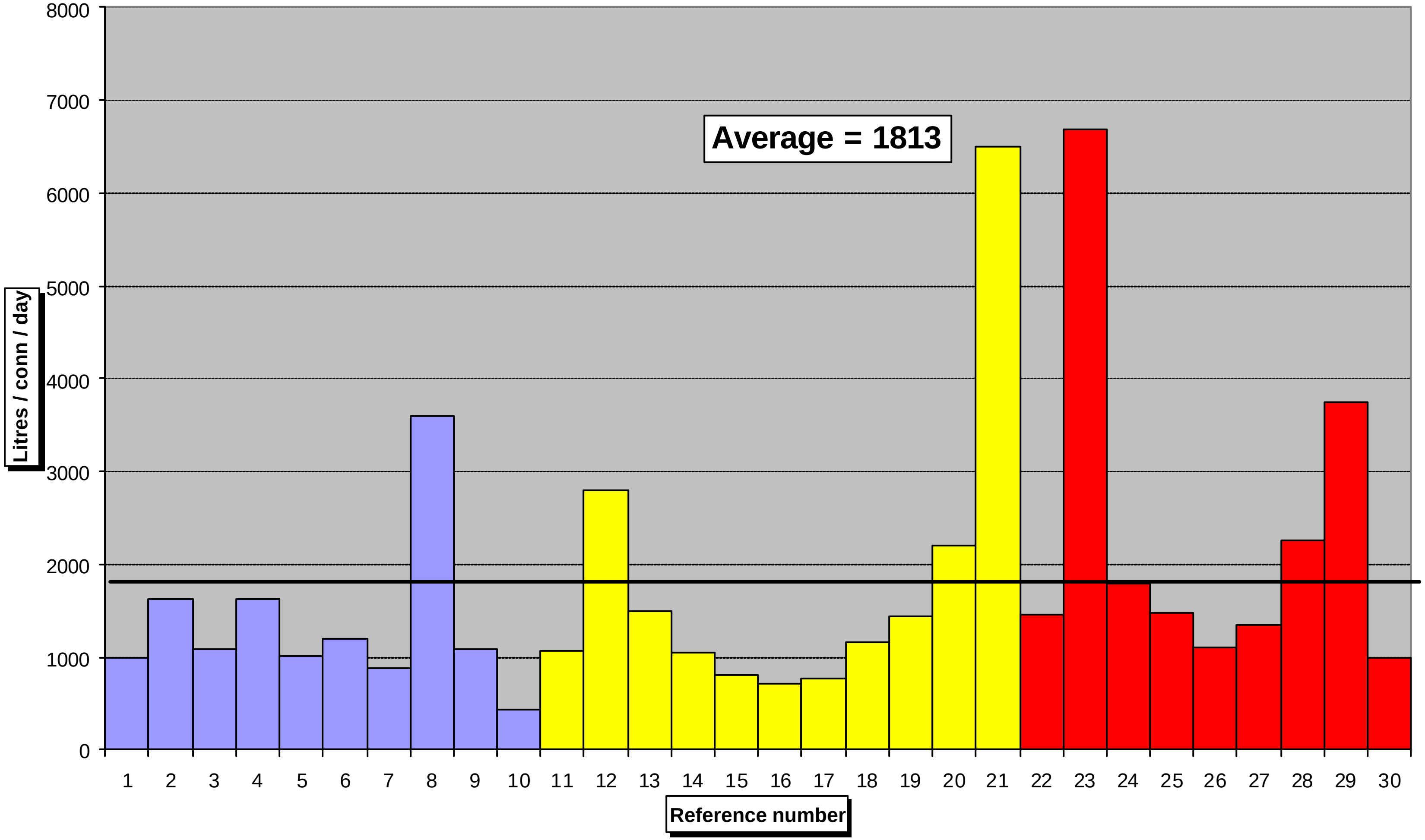
Fig D.8



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

Infrastructure Leakage Index

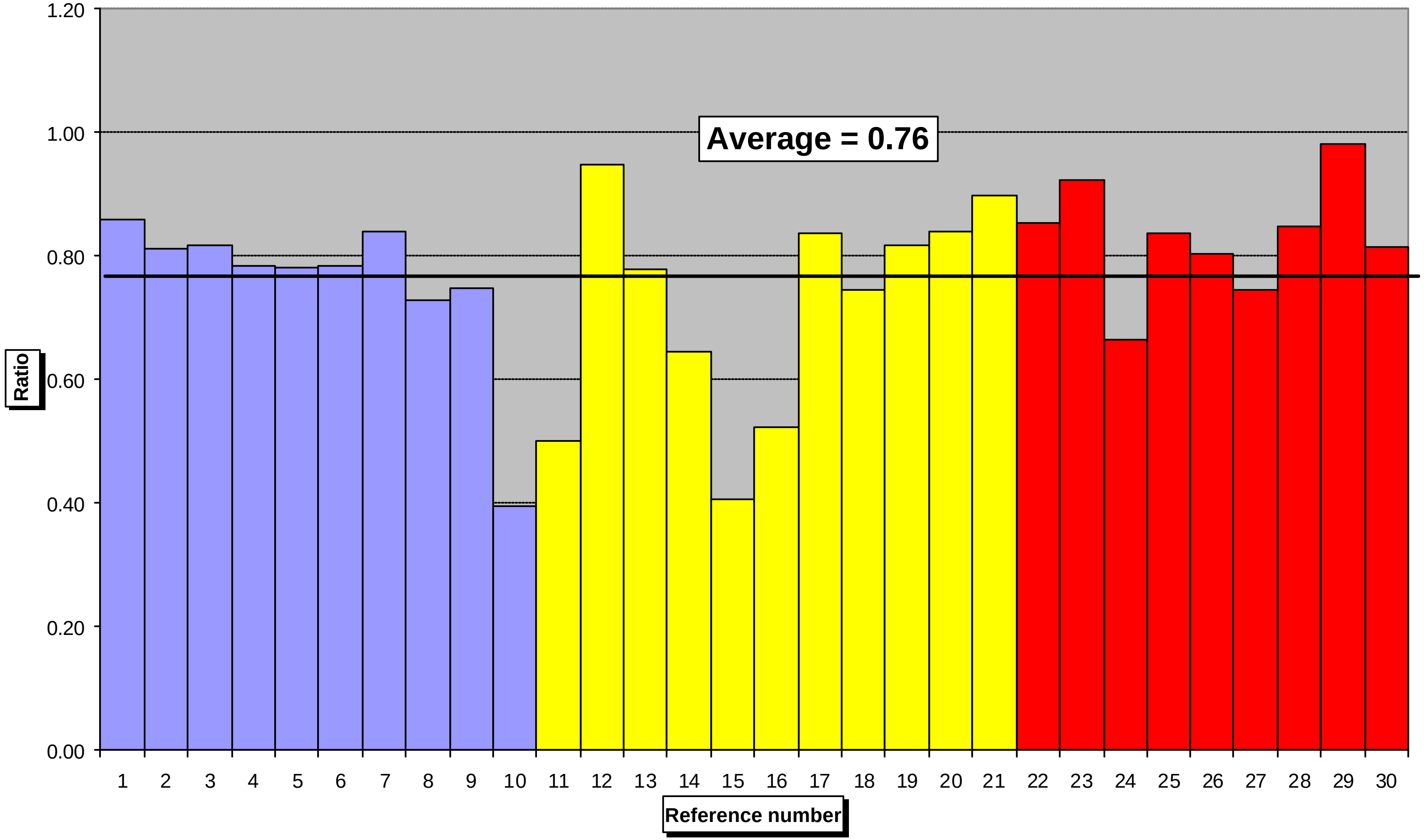
Fig D.9



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

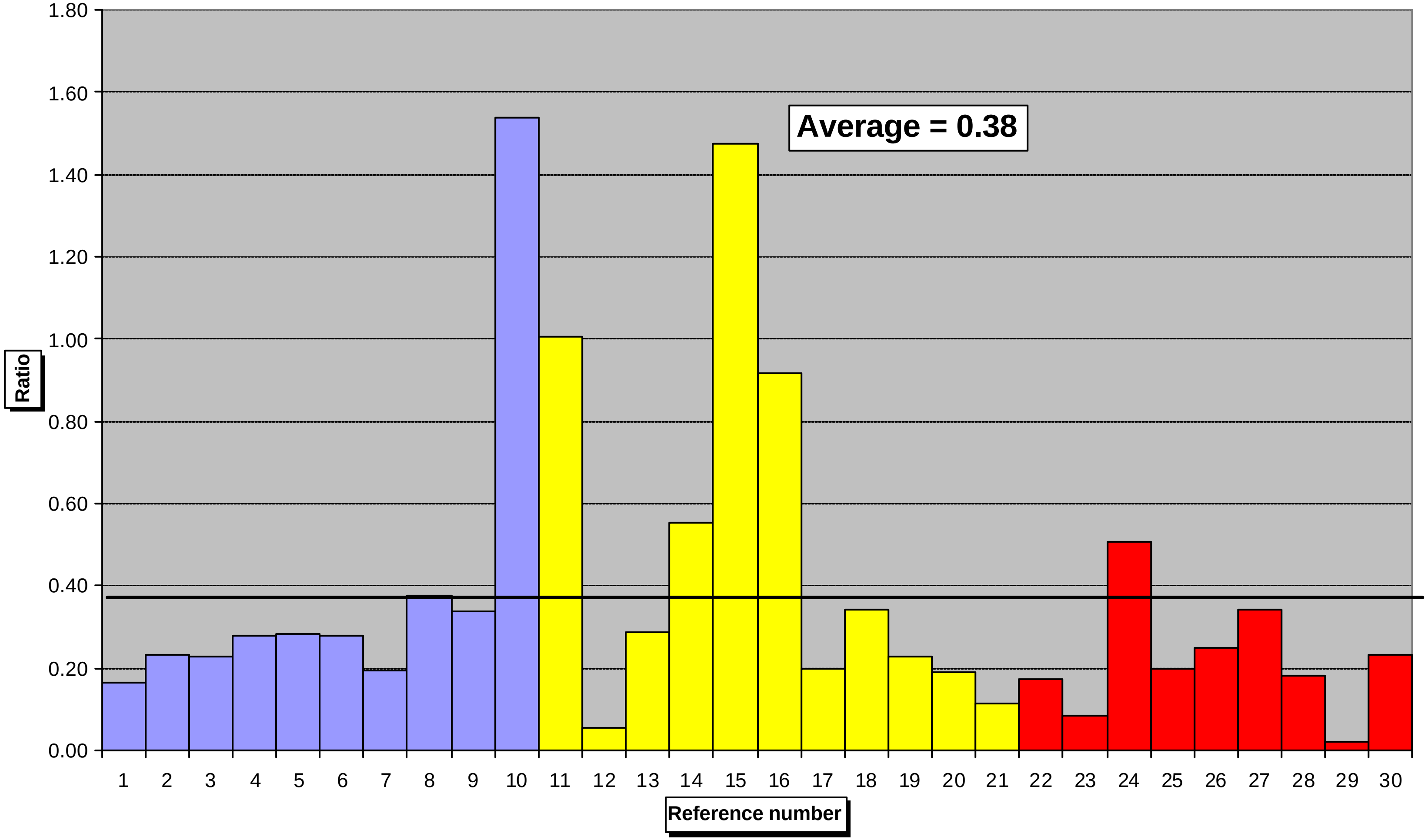
Fig D.10



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 D.11



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 D.12

APPENDIX E

Sample Printout of BENCHLEAK Worksheets

SUMMARY SHEET FOR LEAKAGE BENCHMARKING IN SOUTH AFRICA

Any Town

S1. SYSTEM NAME AND CONTACT DETAILS

Name of Water Undertaking	Anywater	
Name of Water Supply System		
Contact Details:	Name	A N other
	Address	123 Main Road
		Civic Centre
		Anytown
	Telephone	012 345 6789
	Fax	012 345 6879
	E-mail	name@org.co.za

S2. Performance Indicators of Water Loss

Viewpoint	Level	Parameter	Typical Range			Actual PI	Units
			Excellent	Good	Poor		
Operations management of distribution system at current pressure	Basic	% of year system is pressurised	100	100	<100	100	%
		Current Annual Real Losses (CARL) (when system is pressurised - see note 2)	30 to 100	100 to 200	>200	168	Litres/connection/day
		Unavoidable Annual Real Losses (UARL) (see note 3)	n/a	n/a	n/a	57	Litres/connection/day
	Detailed	Consumption	n/a	n/a	n/a	1502	Litres/connection/day
		Infrastructure Leakage Index (ILI) (= CARL/UARL : see note 4)	1	2	>3.0	3.0	non dimensional
Financial management aspects of water losses	Basic	Volume of non-revenue water as a% of system input volume (see note 5)	<10%	20%	30%	17	%
	Detailed	Value of non-revenue water as a % of annual cost of running the system (see note 6)	<5%	10%	15%	12	%

Notes:

Note1: taken from data in "AQUA" article, December 1999 or estimated by WRP

Note 2: takes account of % of time system is pressurised, but not system pressure, density of connections or customet meter location

Note 3: takes account of density of connections and customer meter location at current pressure

Note 4: measures overall efficiency of management of distribution system at current operating pressure

Note 5: strongly influenced by average consumption per service connection

Note 6: Allows different values of Rand/m3 for different components of non-revenue water

S3. Key Operating Parameters which influence Unavoidable Annual Real Losses (UARL)

Variable	Typical Range			Actual PI	Units
	Low	Medium	High		
Average Operating Pressure	30	45	100	50	Metres
Density of connections	20	45	120	53	per km of mains

4. Key Components of Annual System Input Volume

Component	m3/year	m3/connection/day	% of System Input Volume
Water Exported	6500	not applicable	0.0
Authorised Consumption excluding exports	81200000	1.39	81.2
Apparent Losses	2460000	0.04	2.5
Actual Consumption excluding exports	83660000	1.43	83.7
Real Losses	9840000	0.17 (see note 7)	9.8 (see note 8)
System Input Volume	100000000	1.71	100.0

Please return the completed form to R Mckenzie or C Seago at WRP Pretoria, tel: (012) 346 3496
Fax: (012) 346 9956
e-mail: wrp@wrp.co.za

DATA ENTRY SHEET FOR LEAKAGE BENCHMARKING IN SOUTH AFRICA

Note: Note: An example has been included to assist you in completing this data sheet. The example input data can be seen in the pale blue shaded areas. Your input data should appear in the pale yellow shaded areas. The light green shaded areas are protected calculation fields and nothing can be entered in these fields.
Use the units as shown. If you have to use other units; you have to change the appropriate cells.

D1. GENERAL

Name of Water Undertaking		Sample
Name of Water Supply System		
Contact Details:	**Name**	A N Other
	Address	123 Main Road
		Civic Centre
		Anytown
	Telephone	012 345 6789
	Fax	012 345 6879
	E-mail	name@org.co.za

D2. SYSTEM DATA

Input Description	Variable	Example Data	Actual Data	Units	
Length of Mains (Transmission + Distribution)	Lm	1500	3000	km	
Number of Service Connections	Ns	60000	160000	Number	See Notes 1 & 2
Density of Service Connections (per km of mains)	Ns/Lm	40	53	Per km	
Percentage of time system is pressurised during year	T	100	100	%	See Note 3
Average operating pressure when system pressurised	P	45	50	metres	See Note 4
Population served by the supply system	Pop	100000	950000	Number	

Note 1: The number of service connections is not always the same as the number of meters or billed accounts. For South African conditions, however, you can use the total of the number of metered accounts plus the estimated number of unmetered connections

Note 2: In South Africa customer meters are usually located close to the street/stand boundary. If this is not the case for your system, then add a note here.

Insert your comments in this space.

Note 3: Use T in % eg. If T = 80%, use 80 and not 0.8

Note 4: If you do not have an accurate figure, please make a best estimate and provide brief details of how you derived it.

CCT consumers on the Cape Flats (approx 80% of the consumers in the CCT area) are supplied from reservoirs at 110m above MSL

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	986	10^3 m^3/yr
On Service Connections	0.8 x Ns x P x 365 x T/10^8	788	2336	10^3 m^3/yr
Total Volume of UARL		**1232**	**3322**	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**	**57**	Litres/ conn./day

D4. ANNUAL WATER BALANCE DATA

D4a. Data Period

12-MONTH PERIOD FOR WHICH DATA APPLIES		Example Data	Actual Data
	Start Date	April 1, 1998	July 1, 2003
	End Date	March 31, 1999	June 30, 2004

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					
From Other Suppliers:	1000			280	1280	100000				100000
Total:	37000		720	280	38000	**100000**				**100000**

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	6500				6500
Households:	24500	500			25000	30500	4500		5000	40000
Non-households:	6900	100			7000	40000				40000
Standpipes:		500	10		510	1200				1200
Firefighting:				100	100					
Mains Flushing:				100	100					
Building water:	1040				1040					
Other (specify):										
Other (specify):										
TOTALS:	33940	1100	10	200	35250	**78200**	**4500**		**5000**	**87700**

D4d. Components of Water Losses

Details	Example Result	Actual Result	Units
Water Losses = System Input – Authorised Consumption	2750	12300	10^3 m^3/yr
Percentage of Total Losses estimated to represent the Apparent Losses	20	20	%
Apparent Losses	550	2460	10^3 m^3/yr

Annual Real Losses (ARL) = Water Losses – Apparent Losses	**2200**	**9840**	10^3 m^3/yr

D5. SELECTED OPERATIONAL PERFORMANCE INDICATORS

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	168	Litres /conn./day
Consumption in litres/conn/day		1610	1502	Litres /conn./day

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	2.96

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	5000	100000	5.00
Apparent Losses:	550	38000	1.45	2460	100000	2.46
Real Losses:	2200	38000	5.79	9840	100000	9.84
Total Unbilled:	**2960**	**38000**	**7.79**	**17300**	**100000**	**17.30**

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	1.14	R /m^3
Unit Value of Apparent Losses (eg selling price)	2.70	2.34	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	240000	10^3 R/year

D6c. Non-Revenue Water as % by Value of Cost of Running System

Description of Unbilled Items	Example Result				Actual Result			
	Volume 10^3 m^3/yr	Unit Value R /m^3	Value 10^3 R/year	% of Annual Running Costs Costs	Volume 10^3 m^3/yr	Unit Value (R /m^3)	Value 10^3 R/year	% of Annual Running Costs Costs
Unbilled Consumption	210	2.70	567	1.26	5000	2.34	11700	4.88
Apparent Losses:	550	2.70	1485	3.30	2460	2.34	5756	2.40
Real Losses:	2200	0.15	330	0.73	9840	1.14	11218	4.67
Total Unbilled:	2960		**2382.00**	**5.29**	17300		28674	**11.95**

APPENDIX F

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BENCHMARKING LEAKAGE FROM WATER RETICULATION SYSTEMS IN SOUTH AFRICA

Caryn Seago*, **Jay Bhagwan**** and **Ronnie Mckenzie***

WRP Consulting Engineers; PO Box 1522, Brooklyn Square, Pretoria, 0075
caryns@wrp.co.za, ronniem@wrp.co.za
Water Research Commission, PO Box 824, Pretoria, 0001
jbhagwan@wrc.org.za

ABSTRACT

A project to assess the levels of leakage in 30 water utilities throughout South Africa was initiated by the Water Research Commission. The BENCHLEAK software was used to evaluate the water utilities and performance indicators calculated by the model were used to compare levels of non-revenue water. Results showed that utilities ranked differently according to the different indicators, and that the South African results are similar to world norms.

Feed back from the water utilities showed that some of the data requested were confusing and required clarity. The number of service connections, apparent losses and length of pipe between the street edge and the meter were looked at in more detail. Standard drawings were developed to assist water utilities in determining their number of service connections. A table is presented to assess the apparent losses of each water utility in a more pragmatic way.

INTRODUCTION

There is an increasing awareness in South Africa that water is limited and that careful management should be applied when dealing with this scarce resource. Water lost from potable water distribution systems remains a major issue when examining the overall water wasted throughout the country. The BENCKLEAK software was developed through the Water Research Commission to provide a simple yet pragmatic approach to the evaluation of leakage from potable water distribution systems. The model is used to assist water utilities to evaluate the levels of leakage and non-revenue water in their water distribution systems.

A project was previously initiated by the Water Research Commission in order to develop a standardised software package (BENCHLEAK) and undertake some initial evaluations on selected water utilities in South Africa. This first project did not allow for analysis and checking of the data and results that came from the water suppliers due to budget and time constraints and there were many anomalies which were identified but never corrected. As the software has now been available for sometime in South Africa, it was considered worthwhile to build on the previous work and to carry out a detailed analysis of leakage in selected water utilities.

The project was then initiated to compare the levels of leakage of 30 water utilities in South Africa. The results will become part of a larger International Water Association (IWA) initiative to gather leakage information from around the world by creating an international data set which will allow comparisons to be made of leakage levels between various countries. A number of water utilities in South Africa were requested to provide data on their respective systems including length of mains, number of service connections, average operating pressure, systems input volume and the components of authorised consumption. The data were processed through the BENCHLEAK model and the results carefully screened for errors.

While the main aim of the project was to gather a data set of water suppliers in South Africa and to determine the levels of leakage being experienced, it was also necessary to investigate certain issues in depth to ensure that a standard format was being used. Some confusion had been experienced by the water utilities in the previous project with regard to certain of the input parameters for the model, namely, the number of service connections and the estimation of apparent losses. It is of little value comparing water utilities if they have made their own assumptions with regard to key elements of the benchmarking calculation.

For this reason, standard drawings were developed to assist users in assessing the number of service connections in their systems as well as the levels of apparent losses. The apparent loss figure was previously very subjective and open to interpretation. In this project the apparent losses have been evaluated in a more detailed and pragmatic approach. The age of the meters and the number of illegal connections are the main factors influencing the apparent losses in South Africa. The apparent losses for each individual water utility have been assessed according to these factors.

This paper presents the main findings of the project. Results from the various water utilities included in the data set are presented and discussed. Standard approaches for dealing with various inputs required for the model have been developed and are presented.

THE BENCHLEAK MODEL

The BENCHLEAK model was developed through the Water Research Commission in order to facilitate the evaluation of leakage levels and, in particular, non-revenue water, in potable water distribution systems (Mckenzie and Lambert, 2002). It is a simple, user friendly model that is based on an excel spreadsheet and provides various performance indicators for non-revenue water and real losses. The model was used in the evaluation of 30 water utilities throughout South Africa, which were then compared to international water utilities. The input for the model was provided by the water utilities and a brief description of each follows.

BENCHLEAK Input

Length of mains: The length of mains is the total length of the bulk and distribution mains in a particular system. All pipes excluding the connection pipes are considered to be mains. This value can sometimes cause confusion in that water utilities are unsure as to what it includes. It is in fact the total length of transmission and distribution mains.

Number of service connections: This value has been a topic of debate amongst many water demand management specialists, and is discussed in more detail later in this paper. It is defined as the number of connections to the mains.

Operating pressure: The average operating pressure for the whole system over the period in question.

Population: The population that is served by the water utility in question. This parameter plays no real role in the model and is simply used to calculate the per capita consumption.

System input volume: The total volume input into the water supply system, allowing for known errors. It is broken up into water supplied by own sources as well as water supplied by other suppliers.

Components of authorised consumption: Also divided into various sections namely, billed metered, billed unmetered, unbilled metered and unbilled unmetered. Examples of each of these can be seen in **Table 1**.

Table 1. Examples of the various components on authorised consumption

Billed metered	Domestic consumers Industrial / commercial consumers
Billed unmetered	Consumers charged on a flat rate tariff basis
Unbilled metered	Schools Recreational parks Some government buildings Police stations Municipal swimming pools
Unbilled unmetered	Fire fighting Mains flushing

Valuation of real and apparent losses: For this section unit values are derived from the costs of water purchased and the average price of water sold by the water utility. An annual cost of running the system is also input required by the model.

BENCHLEAK output

The BENCHLEAK model carries out a number of calculations providing the user with useful output that can be used to compare various water utilities. The main comparison values are as follows:

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 well below the economic level of leakage.

Apparent Losses (AL): Unauthorsied consumption (theft or illegal use) as well as all technical and administrative inaccuracies associated with customer metering and billing. It is given as a percentage of the total water lost in the system ie. system input less the authorised consumption. 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.

Apparent losses are discussed in more detail later.

Current Annual Real Losses (CARL): The physical water losses from the pressurised system, up to the point of measurement of customer use. Calculated as the total water lost less the 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.

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. It is a ratio of the Current Annual Real Losses to Unavoidable Annual Real Losses (Lambert *et. al,* 1999).

RESULTS FROM 30 WATER SUPPLIERS

The main objective of the project was to gather data from as many water suppliers throughout South Africa as possible, and to enter the data into the BENCHLEAK model. The output was then closely screened for errors, and a representative short list of 30 suppliers was developed. Missing data was the main reason for leaving out suppliers which had volunteered information. **Table 2** provides data from the short listed suppliers. Each supplier has been allocated a number to which it will be referred.

The ILI values for the 30 suppliers range from 0.08 to 15.96. No. 4's 0.08 is a result of the very similar system input value (19 179 10^3m^3/year) and authorised consumption value (19 089 10^3m^3/year) and is very likely incorrect. The ILI value often highlights problems with the suppliers base data due to either meter error or simple fudging of information. Anything under 2.0 in South Africa should be reviewed critically as it is likely to be erroneous due to some form of data error. Utilities 12 and 21 require closer examination and no. 4 will be left out of the final data set. No. 8 has a very high ILI value due to the high difference in input (34 739 10^3m^3/year) and consumption (17 323 10^3m^3/year). The average ILI value for all 30 utilities is 5.69. 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.

Table 2. A summary of the data and results of the 30 South African water utilities

No.	Mains Length	Service cons.	Density	Pressure	UARL	System Input	Authorised Consumption	AL	ARL
	Km	no.	no. / km	m	lit / con / day	10^3 m^3/year	10^3 m^3/year	10^3 m^3/year	10^3 m^3/year
1	718	31 200	43	50	61	22 039	17 134	981	3 924
2	1 069	60 208	56	40	45	24 344	9 583	2 952	11 809
3	1 315	79 306	60	50	55	30 284	25 362	984	3 938
4	762	52 928	69	45	48	19 179	19 089	18	72
5	2 400	198 951	83	60	61	83 788	71 948	2 368	9 472
6	35	1 156	33	51	69	760	566	29	165
7	38	1 142	30	63	88	1 110	940	26	145
8	678	44 550	66	50	54	34 739	17 323	3 832	13 584
9	456	21 100	46	50	59	12 043	8 965	616	2 462
10	27	557	21	35	59	250	203	7	40
11	2 082	75 059	36	75	97	135 687	98 616	7 354	29 417
12	28	1 017	36	40	52	1 419	1 391	6	22
13	103	5 872	57	50	56	3 654	3 113	108	433
14	1 552	94 105	61	50	55	52 389	40 999	2 278	9 112
15	1 275	69 000	54	50	57	36 353	27 159	1 839	7 355
16	431	22 700	53	50	57	11 505	5 997	1 322	4 186
17	52	1 478	28	35	50	742	594	22	126
18	746	29 760	40	50	63	21 603	8 730	2 575	10 298
19	920	30 786	33	70	94	18 347	11 814	1 307	5 226
20	358	10 200	28	40	57	26 976	24 207	554	2 215
21	467	21 577	46	50	71	7 257	6 058	240	959
22	2 390	112 000	47	70	83	85 020	66 465	3 711	14 844
23	386	18 931	49	45	53	12 254	9 992	339	1 923
24	2 943	191 518	65	45	48	139 685	113 369	5 299	21 197
25	732	36 253	50	35	41	39 153	37 103	410	1 640
26	166	7 817	47	40	47	2 966	2 377	118	471
27	1 850	145 000	78	45	56	69 775	56 863	2 582	10 330
28	263	12 555	48	30	35	12 019	10 083	252	1 684
29	353	11 283	32	33	45	4 427	3 477	190	760
30	1 571	97 592	62	75	82	46 218	36 048	2 034	8 136

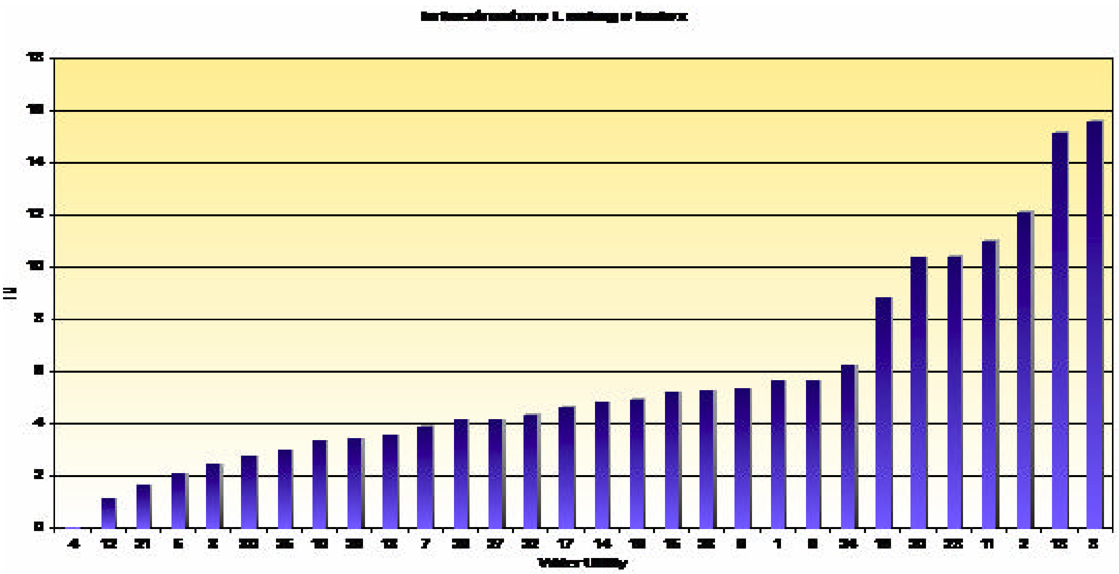

Figure 1. Chart showing results of the Infrastructure Leakage Indices.

The norm for UARL is approximately 50 litres per connection per day at standard pressure. Most of the suppliers fall within this range except for 30, 22, 7, 19 and 11 which are all greater than 80 litres per connection per day. The average UARL for the utilities is 59.93 litres per connection per day.

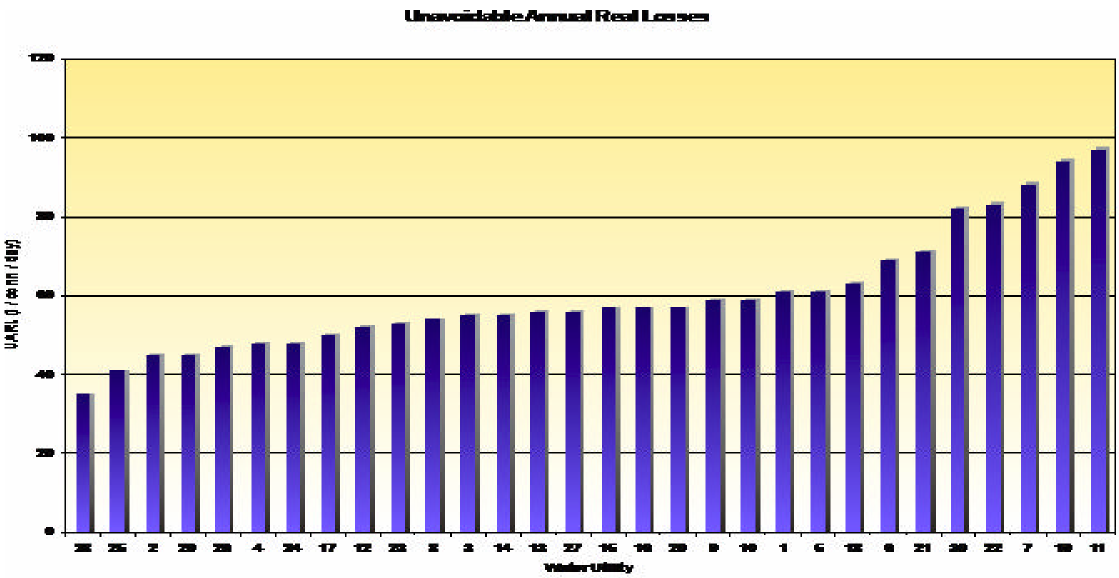

Figure 2. Chart showing results of the Unavoidable Annual Real Losses.

The apparent losses have been presented in units of litres per connection per day rather than m^3/year in order to best compare them. The average is 82.83 litres per connection per day. Utility 11 has the highest apparent losses of 268 litres per connection per day.

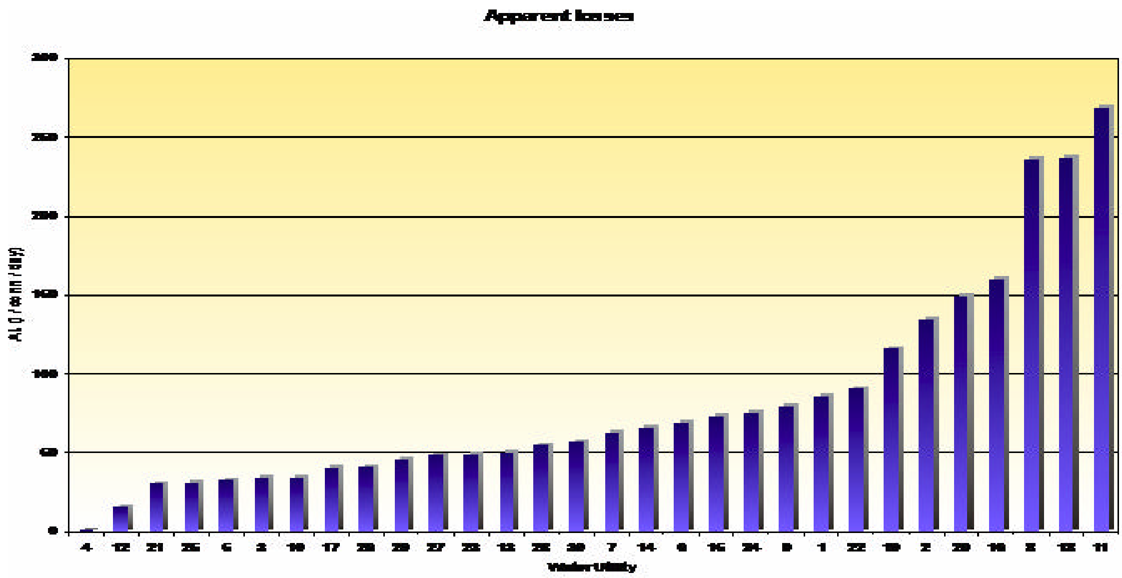

Figure 3. Chart showing results of the Apparent Losses.

The average annual real loss is 340 litres per connection per day. This compares to the International data set average of 276 litres per connection per day. An average of 15 740 litres per km mains per day was obtained for the 30 utilities. The international data set's average was 12 550 litres per km mains per day.

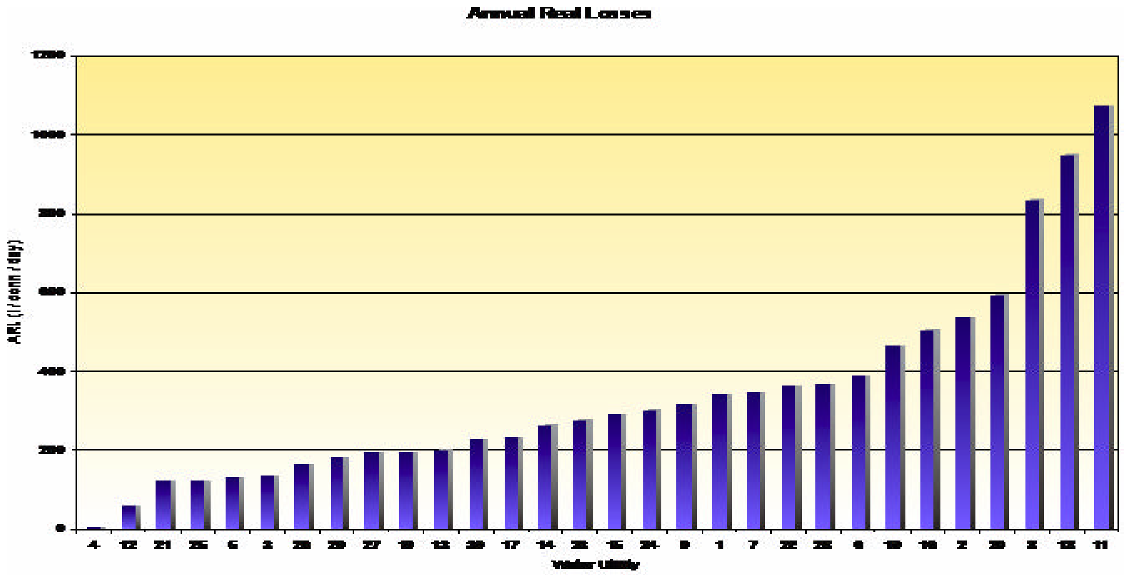

Figure 4. Chart showing results of the Annual Real Losses.

One can see from the four graphs presented here that various performance indicators can be used to compare water utilities. Utility 8 has the highest ILI value, but its ARL is not the highest. Utility 11 has the highest ARL value of 1073.7 litres per connection per day which is unacceptably high.

PROBLEM AREAS

At the outset of the project, a few problem areas existed that caused confusion for the water suppliers providing information. An objective of the project was to highlight these “grey areas” and to propose standard solutions to be used in the future. The first issue is that of the number of service connections. It was unclear precisely what this number meant and which was the best way to represent the number of service connections. Another unclear area that required clarification was that of apparent losses. Previously, a value of 20 % was suggested as a lump sum of the total losses and this was assumed to be apparent losses. However, this is not entirely correct due to the many factors that contribute to apparent losses. Apparent losses could be well above 20% in some areas, and might not necessarily be 20% in others. Lastly the length of underground pipe was looked at. This value is included in the calculation of UARL, and it was not clear exactly what length was required. These three problem areas are discussed in more detail in the following section.

Number of Service Connections

The IWA Manual of Best Practice ‘Performance Indicators for Water Supply Services’ (Alegre *et. al.*, 2000) clearly defines a service connection as “*the authorised pipe connecting the main to the measurement point or the customer stop-valve, as applicable. Where several registered customers or individually occupied premises share a physical connection or tapping off the main, eg. apartment buildings, this will still be regarded as the one connection for the purposes of the applicable Performance Indicator, irrespective of the configuration and number of customers or premises*“. The “number of service connections” Ns variable is used to calculate the UARL in a system, by taking into consideration the unavoidable leakage expected to occur on service connections between the main and the stop-valve or property line. It is then added to the other components of UARL (on mains, and on pipes between the stop-valve / property line and the customer meter) to calculate the total UARL as follows:

UARL = [(18 x Lm) + (0.8 x Ns) + (25 x Lp)] x P

1

where UARL = Unavoidable Annual Real Losses (l/conn/day)

Lm = length of mains (km)

Ns = number of service connections

Lp = length of unmetered underground pipe from street edge to meter (km)

P = Average operating pressure at average zone point (m)

Experience shows that most water suppliers do not know how many saddle connections they have and what proportion support one, two, four or eight properties. However, they do usually have information on the numbers of billed accounts, customer meters, or stands (the South African term for defined plots of land). It is also usually possible to count the number of stop-valves sited outside the stands, typically in the pavement. By considering a representative sample of service connection layouts for a particular system, it is usually possible to produce a correlation between one of these parameters (billed accounts, customer meters or stop-valves) and the number of service connections Ns (physical connections to the mains) for that particular system.

If all service connection layouts were as simple as Figures 5 and 6 that follow, there would be no uncertainty in calculating Ns from one of the other parameters, the ratio would be one to one. However, there is a wide variety of different layouts in South Africa and an even wider range internationally. In practice the situation in most reticulation systems is not clear-cut and defining the number of service connections can sometimes be confusing.

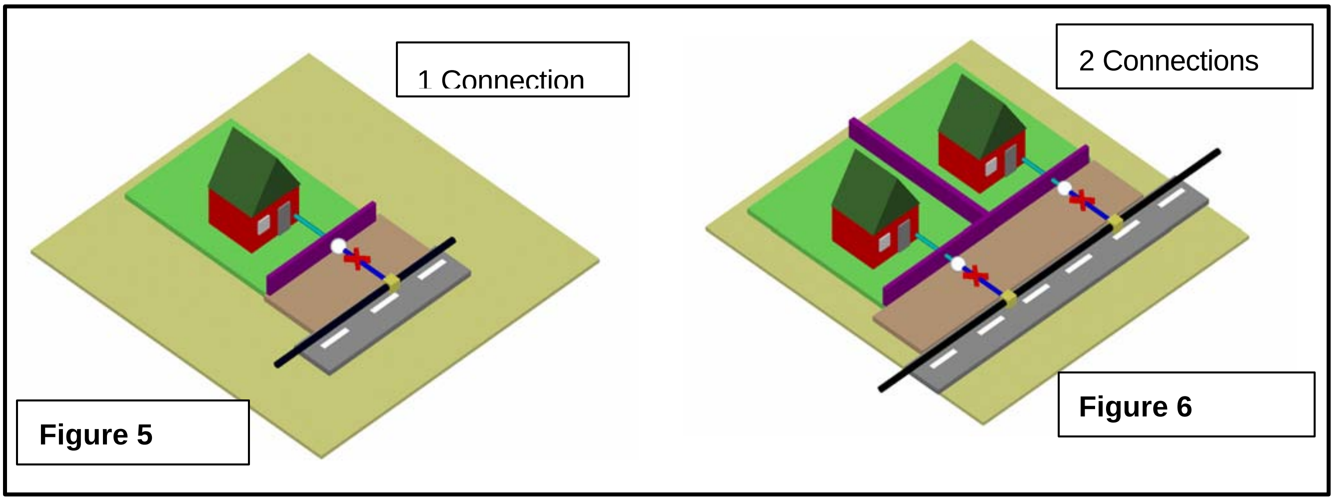

Figure 5: *A single billed metered property on a street, situated on a single stand. There is one physical connection from the main that goes to the stop-valve, on to the external meter in the pavement and then on to the stand/property.* ***Figure 6:*** *Two single billed metered properties on a street, each situated on their own separate stands. There are two physical connections onto the main, one for each property, and therefore also two stop-valves and two meters.*

According to the current IWA definition of a service connection, **Figure 6** would count as two service connections. In contrast, the layout for two separate properties in **Figure 7** below would only count as one service connection, as there is only one physical connection to the main. However, the argument arises:- does the system layout in **Figure 6** necessarily produce double the unavoidable leakage than that of the **Figure 7** layout? The number of "fittings" (here defined as points breaking the pipe's continuity, excluding the meter) where background leakage and detectable leaks are most likely to occur, is four for **Figure 6** and also four for **Figure 7** (Figure 6 being at the two physical connections to the main and the two stop-valves; **Figure 7** being the one physical connection onto the main, the T-piece and the two stop-valves). Therefore, theoretically the unavoidable leakage resulting from **Figure 7** should be approximately the same as the unavoidable leakage from **Figure 6**. For this reason it was proposed that the configuration shown in **Figure 7** be considered as 2 connections. Similarly, **Figure 8** would represent 4 connections, even though there is only one mains tapping.

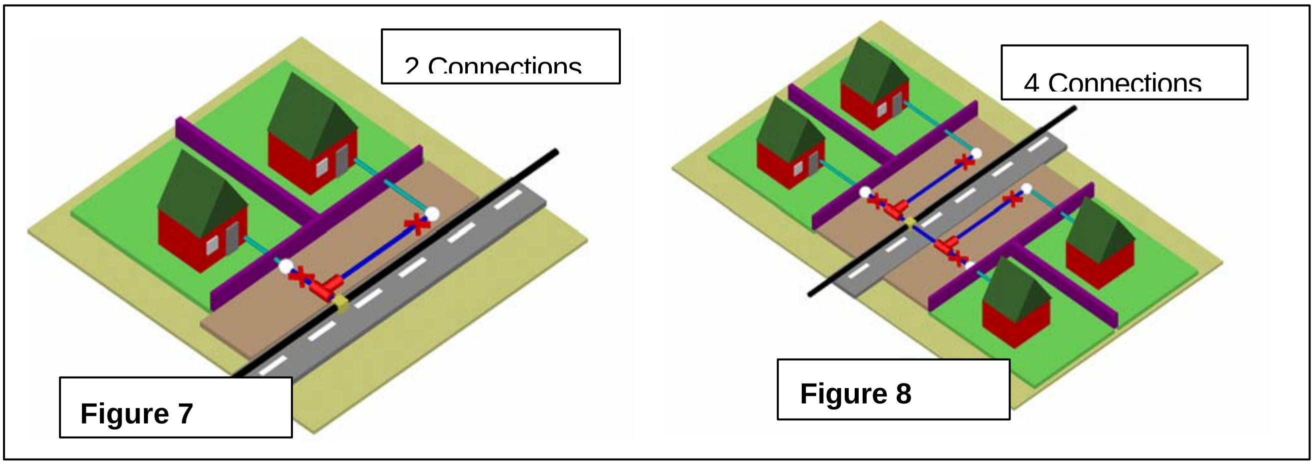

Figure 7*: Two billed metered properties on a street, each situated on their own stand. There is only one physical connection onto the main, with a T-piece on the connection pipe to the second house. There are two meters.* ***Figure 8****: Two properties on one side and two on the other side of a street. There is only one physical connection onto the main, with two connection pipes, one to each side of the street. Each connection pipe then branches at a T-piece to two stop-valves, each with its own meter.*

A trend become evident having looked at the diagrams closer and the proposal was therefore made to make Ns equal to the number of properties, or stop valves, which is in most cases the same as the number of customer meters. This is in contradiction to the IWA definition in that when more than one premises share a particular connection or tapping off the main, the proposal was to choose the number of connections equal to the number of premises rather than the number of connections. The main purpose for the change was to reduce the complexity of gathering data with a method of approaching the Ns value on a more practical basis.

This proposal was accepted by the IWA with a few notable exceptions. A valid point put forward was the topic of confidence limits. New leakage assessment models currently available (Aqualibre and Fastcalc) have the option to include 95% confidence limits for all parameters, including the Ns. A moderate uncertainty in Ns will have comparatively little effect upon the 95% confidence limits for the Performance Indicator.

A main concern when using the number of properties or meters was in situations where a block of flats is served by one tapping off the main. Some apartment blocks in parts of Europe contain only one service connection serving numerous customer meters each adjacent to its own stop-valve. As these meters tend to be read frequently, any leaks at the stop-valve or meter should be quickly detected as part of the meter reading process, and it would be over-generous to use the number of stop-valves as a surrogate for Ns when calculating the UARL. It was this which lead to considering the merits of standardising on counting the number of stop-valves, but reducing the '0.80' coefficient for Ns in situations where the ratio of "number of stop-valves to number of physical connections to mains" is large (Lambert, 2004).

For the UARL calculation, the coefficient of 0.8 l/service conn/day/metre of pressure used in the equation was based on one service connection to one customer. Rather than changing the way Ns is calculated for different situations, it was decided that it would be more practical to change the coefficient applied to Ns for some situations. The equation was proposed, relating the coefficient (0.8) to the ratio of number of stop-valves to number of physical connections to the main (Nm).

$$\text{Ns Coefficient} = 0.8\,(1.0 - A \times \log\,(Ns/Nm) \qquad 2$$

The value of 'A' could be adjusted to give coefficients which tied in with theoretical calculations based on number of joints.

Perhaps one of the most significant sources of error or confusion occurs when the 'number of billed accounts' is used as a surrogate for Ns when calculating UARL. If the 'number of billed accounts' is the only data readily available, then it was suggested that the number of billed accounts be multiplied by an assessed factor (less than 1) which takes into account the numbers of billed accounts served by a single service connection, with 95% confidence limits.

For example, consider a utility with 500 000 billed accounts, of which 400 000 have their own separate service connection; the remaining 100000 billed accounts are in multi-residential blocks. If the average number of multi-residential accounts per multi-residential block is 10, and each multi-residential block has one service connection, then the number of service connections is:

400 000 + 1 x (100 000/10) = 410,000 and the ratio of service connections to billed accounts is: 410,000 / 500,000 = 0.82 with 95% confidence limits of (say) +/- 5%.

Apparent losses

Apparent losses, often referred to as non-physical or paper losses, are in many cases the most expensive water losses to occur from a system since they represent a direct loss of revenue to the water supplier. In cases where the water bills are based on the metered consumption, any losses occurring due to meter error or data handling and/or processing, will result in reduced sales revenue (Thornton and Rizzo, 2002).

Meter error is often thought to be the main cause of apparent losses in a water system and can be due to wear and tear, incorrect meter installation, lack of maintenance, incorrect meter type or incorrect sizing. Data transfer errors can also contribute to the apparent losses. These can include merely recording an incorrect reading, incorrect interpretation of a decimal point or incorrect calibration of the meter. Estimated readings are often used to generate water accounts when a meter is situated in such a manner that it is difficult to read, and such assumed figures are often inaccurate.

Another contribution to apparent losses in South Africa and other developing countries is theft or illegal connections. Water may be stolen from a number of points in the system, but most commonly it is stolen from the customer supply point or fire hydrants. Customers have been known to tamper with water meters, by placing a magnet close to the register magnets to interfere with the correct rotation of the register and therefore causing lower readings. Hydrants are often abused by construction workers, street cleaners, taxi drivers who wash their vehicles and others who merely use the water for drinking or bathing. In addition to blatant theft, many accounts go unnoticed in the system. An example may be a temporary construction feed, which eventually becomes a permanent supply point but is never metered, billed or included on the billing database.

In the past a simple lump sum was used to express apparent losses in terms of the total losses and a default value of 20% was suggested but could be changed by the user. This is a very simple approach, however, and is not scientific. In South Africa for example, an area such as Sandton in Johannesburg is unlikely to experience the same level of water theft as say Soweto, and might in fact have a policy of replacing or servicing their meters every 5 years or so. To then assume that both Sandton and Soweto be given an estimate of 20% for apparent losses would be unrealistic. To overcome this problem a simple yet effective approach was adopted.

Water utilities were asked to classify their expected illegal connections as very high, high, average, low and very low. They were also asked to provide information on their water meters in terms of accuracy and age. Lastly they were asked to provide an estimate on the accuracy of their billing data in terms of good, average and poor. The following table presents a more pragmatic and realistic approach to the estimate of apparent losses for a typical system (ie. non flat rate tariff) based on the information received.

Table 3. Suggested apparent loss percentages for a typical system

Illegal connections		**Meter age and accuracy**			**Data transfer**	
			Good water	Poor water		
Very high		Poor > 10 years	8 %	10 %	Poor	8 %
High						
Average		Average 5- 10 years	4 %	8 %	Average	5 %
Low						
Very low		Good < 5 years	2 %	4 %	Good	2 %

For example, in a non flat rate tariff area, if a water utility has a high occurrence of illegal connections (8 %), the meters in place are more than 10 years old but the water quality of the area is fairly good (8 %) and the data transfer side is average (5 %), the apparent loss estimate would be 21 %.

The information on the meters was estimated from the fact that Europe has a compulsory replacement programme on all meters every five years. Most of the domestic meters in place in South Africa are similar to the European meters. Many factors play a role in the accuracy of a meter, but were excluded in order to minimise complexity, with the exception of the water quality factor which has a major influence on the lifespan of a water meter.

The flat rate tariff ratio is to include areas, such as townships, where the flat rate charged is less than the amount actually being used, which can have a major impact on apparent losses. The following example can be used to illustrate the problem. If an area with 43 000 connections is charged on a flat rate of 10 kl / month. This value may not necessarily be recovered by the users, however, it is billed and is therefore considered to be part of the billed authorised component of the water balance. This amounts to 5.16 mill m^3 / year. However, the water utility measures the water supplied to be 25 mill m^3 / year. The sewerage return flow measured to be 18 mill m^3 / year and garden irrigation is estimated to be 2 mill m^3 / year. The quantity of water flowing through the 43 000 properties is in fact 20 mill m^3 / year (18 mill m^3 / year + 2 mill m^3 / year), however, they are only billing 5.16 mill m^3 / year. The apparent losses becomes 14.84 mill m^3 / year (20 mill m^3 / year – 5.16 mill m^3 / year) and the real losses are then 5 mill m^3 / year (25 mill m^3 / year – 5.16 mill m^3 / year – 14.84 mill m^3 / year). **Figure 9** shows a pie cart of the example area.

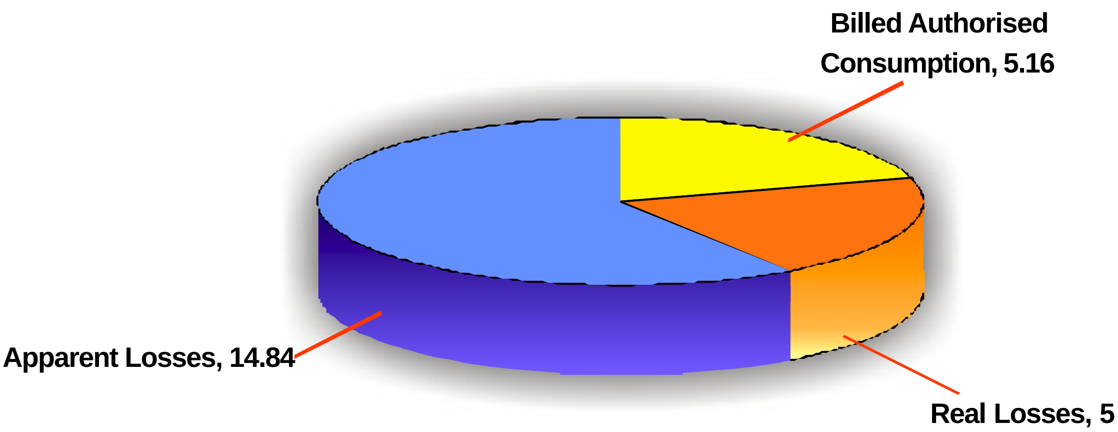

Figure 9. Components of the example area

It should be noted, however, that it is unlikely that the apparent losses can all be converted to revenue water by proper metering and billing since when payment is enforced, the level of consumption is likely to reduce dramatically. This is contrary to the normal assumption that reduction of apparent losses will result in greater revenue water. The normal practice of multiplying the apparent losses by the selling price of water is not appropriate in some cases and a more realistic value of the losses can be estimated using the purchase price (or product price) of water.

Length of underground pipe

The last issue that requires clarity is the length of underground pipe which is the third term in the UARL calculation. There was some confusion over what should be included and what is already taken into account in the Ns component of the calculation. If the meters are located at a street edge then it is assumed a particular length of pipe has already been included in the connection component of the UARL. In such cases, no additional allowance is made for the length of underground pipe. It is only included when it is located beyond the property boundary in which case the average length of underground pipe is used.

The section after the street /property line can be ignored in the South African context, as most meters are located close to the street / property line, and this length has already been included in the Ns part of the UARL calculation.

SUMMARY

The BENCHLEAK software is a powerful tool for assessing and comparing leakage amongst water utilities, both local and international. From the results of the 30 South African water utilities to be included in the international data set, it appears that South Africa is in accordance with world norms in terms of their performance indicators. There is room for improvement for some water utilities and suggestions have been made on how to achieve better levels of leakage.

In summary, the solution proposed to solve the number of service connections debate is to base the calculation of Ns on the number of stop-valves and to include hydrants with separate mains connections. For systems where the ratio of stop-valves to physical connections is high, reduce the coefficient for Ns in the UARL equation in accordance with a published table.

The apparent losses have been looked at in more detail in this project and a more pragmatic approach is proposed. This is to break the apparent loss components down into various factors that contribute, and to assess each water utility differently according to these factors rather than merely using a lump sum estimate of apparent losses.

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