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IMPORTANT

This document was produced through a joint initiative of the United Nations Human Settlement Programme UN-Habitat in association with Rand Water. It is a relatively simple and straightforward document aimed at providing water suppliers with some guidance on how to manage their water losses in their potable water distribution systems. Unlike many other publications aimed at Water Conservation and WDM procedures, this manual does not attempt to cover the entire field but concentrates on certain key issues that are of particular relevance and importance in most African situations. The manual also concentrates on the technical aspects of WDM and does not address the social or environmental issues in detail. Such issues are extremely important but vary significantly from area to area, especially in Africa, which has tremendous cultural and social diversity. The key objectives of this manual are therefore:

- To introduce a standard terminology for component-based leakage management and to encourage African water suppliers to calculate components of Non-Revenue Water and Water Losses using the standard annual water balance;
- To highlight the importance of adopting standard terminology and a standard approach to the complex issue of leakage in a water distribution system;
- To highlight and explain certain key issues which water suppliers throughout Africa should be addressing even in situations where the available financial resources are insufficient to implement normally accepted international practices;
- To identify and explain various issues and items of equipment that can be of use in the African situation.

The methodologies discussed in this manual draw strongly on recent 'best practice' recommendations of Task Forces of the International Water Association (IWA) and make reference to certain free software and associated documentation available from the South African Water Research Commission (WRC – see www.wrc.org.za).

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• Mr Tim Waldron	WDM specialist from Wide Bay Water, Queensland Australia

Water Demand Management Cookbook

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THE WATER FOR AFRICAN CITIES PROGRAMME – A BACKGROUND

Almost all of the world's major cities will enter the 21st century facing a water crisis. The explosive growth of urban centres over the past 25 years or so, which continues unabated, is rapidly depleting previously bountiful fresh water resources. The urban water challenge is taking an ominous dimension in vast tracts of Africa, the Middle East and Central Asia, where the situation is most precarious. Rapid urbanisation, growing populations and development are overwhelming traditional water management practices.

Water scarcity is also a potential source of social and political conflict. Rapid population growth in urban areas has led to degraded environments and increasing competition for resources. The world's cities not only face the challenge of supplying safe water and adequate sanitation facilities to their residents, but must also ensure that the available water is not wasted or contaminated. An integrated approach to urban water management is essential for the social, economic and environmental sustainability of cities.

The Water for African Cities Programme was launched by UN-HABITAT in 1999 as a direct response to the Cape Town Resolution (1997), adopted by African Ministers, addressing the urban water challenge facing the continent. This was the first comprehensive initiative to support African countries to effectively manage the growing urban water crisis and protect the continent's threatened water resources from the increasing volume of land-based pollution from the cities.

The programme was started with core funding support from the United Nations Foundation for International Partnerships (UNFIP/UNF). A growing number of multi-lateral and bilateral external support agencies including UNDP/UNV, The World Bank, governments of Sweden, the Netherlands, Finland and Germany have since extended their support, increasing the scope and outreach of the Programme.

The Programme focuses on three inter-linked priorities:

- Introducing effective urban water management strategies in African cities (Water Demand Management (WDM) and other related measures are being implemented in seven participating cities through pilot demonstrations);
- Protecting freshwater resources from the growing volume of urban waste (the Programme is assisting the participating cities to strengthen capacity for monitoring of freshwater pollution from urban waste and to take mitigating measures); and
- Enhancing regional capacity for urban water management through information sharing, enhancing public awareness, training and education.

The Programme was implemented in a phased manner, as follows:

- A Start-up phase which was completed in June 1999, devoted to in-country consultations and discussions with external partners to firm up implementation arrangements.
- An implementation phase (October 1999 to December 2002) which included:
    - execution of demonstration activities in seven participating cities; and

- region-wide activities including information exchange, awareness-raising, training and education.

- A dissemination phase for sharing of Programme results and implementation experience with other African countries towards the end of the Programme.

The regional activities of the Programme are primarily aimed at extending its outreach and benefits to other cities on the continent which are not participating directly in demonstration Programmes. Such cities could gain from sharing of information and experience of good practices. Regional activities also promote synergy among the seven demonstration cities and the optimal use of Programme resources.

The Programme governance structure follows a three-tiered pattern:

- A UN-HABITAT core professional team, supported by UNEP expertise, directs and supervises Programme implementation from the Headquarters on a continuing basis;
- City managers from the seven participating cities meet on a biannual basis to review progress of Programme activities and agree on future Programme priorities over the next six months;
- A High-level Advisory Group, comprising responsible Ministers from the seven participating countries, meet periodically to provide oversight and policy guidance in Programme implementation.

ACHIEVEMENTS TO DATE

Acceptance of WDM Principles and Practices

The most notable success of the Programme has been the wide acceptance of WDM as the most cost-effective form of augmenting supply at both utility and national policy-making levels. At national policy level, the willingness to invest in WDM measures was increasingly evident (for example, World Bank funds were allocated in Dakar Long Term Programme and in Addis Ababa and Lusaka internal resources were mobilised for leakage control Programmes). Water restructuring secretariats and water regulators in several countries have started to incorporate the WDM principles and practices in their regulatory frameworks (e.g. in Zambia, the national regulators will use the Lusaka WDM strategy as a model for developing a national WDM strategy; in Ghana, the Water restructuring secretariat is currently introducing WDM in the regulatory framework and in the national water policy).

Application of Integrated Water Resource Management (IWRM) Principles at Local Level

The introduction of catchment management strategies at local level has been one of the most impressive achievements of the Programme so far. Specific catchment management strategies have been developed for the Densu River Basin in the Accra-Tema region, Klip River Basin in Johannesburg and the Nairobi River Basin in Kenya. The strategy relies on active community involvement and participation in catchment management. This strategy also provides a unique platform for bringing together diverse stakeholders from the urban, water and environment sectors as well as community groups to plan the monitoring and implementation of local water resource and environment management initiatives. These community groups are also becoming effective lobbies for bargaining with local authorities on a diversity of issues such as local environmental management, protection of sources of livelihoods, promotion of investment etc.

Promoting New Investments for Water in African Cities

From the very beginning, the programme has leveraged its limited resources to attract new investments in the water sector in African cities. Partnership with the World Bank has encouraged new investment in WDM in Dakar, Senegal, which is being further expanded through a second phase. Similar investments have been stimulated in Ghana in partnership with DANIDA, and in Ethiopia with a consortium of international donors. The Ministerial Advisory Group overseeing the programme implementation has actively supported the various efforts.

Raising Public Awareness on Urban Water Issues

To achieve this, the Programme had to direct its effort initially to promote a customer responsive culture in the utilities and then to establish capacity within the utilities to organise and sustain public awareness campaigns. The initial sensitisation process proved time-consuming but yielded excellent results. In many utilities, new public relations units had to be established and the human resources capacity developed. In Addis Ababa, for example, the Addis Ababa Water and Sewerage Authority has conducted a very successful, city-wide, public awareness campaign following Programme support over a period of one year to establish and build capacity for conducting public awareness campaigns. The impact of the public awareness campaign has since been evaluated with positive results.

Introducing Water Education in African Cities

Early on, the Programme developed a comprehensive strategy for raising public awareness which focused not only on achieving short term results, through public awareness campaigns, but also longer term approaches through water education, targeting school children and youth. The Programme fund was successfully leveraged to raise additional funds for schools educational activities. The Value-based Water Education Programme, which is now fully established in the participating countries, is complementing public awareness campaigns with the objective of creating a new water-use ethic in African cities.

Training and Capacity-Building for Utility Managers

Another notable achievement of the Programme has been the sensitisation of city and utility managers on the need for institutionalising development of skills in Integrated Water Resource Management (IWRM) in the urban context. Following intensive consultations with city managers and external experts, a comprehensive training and capacity building proposal was developed by the Programme, which has been fully funded by the Dutch Government. The Programme is institutionalising staff training in the utilities and helping to develop regional and city level capacity for training in IWRM with the help of the IHE, Delft.

Developing a Global Consensus on Urban Water Issues

The Programme's experience with urban water management issues and its continuing efforts in advocacy have successfully raised the profile of urban water issues on the international agenda. The Programme experience was widely disseminated at the Stockholm Water Symposium (August 2001) and at the Bonn International Conference on Freshwater (December 2001). The Programme experience in African cities and the lessons learnt were also widely disseminated in a Seminar in Johannesburg during the World Summit for Sustainable Development in late August 2002.

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1 INTRODUCTION

1.1 GENERAL

In recent years, throughout most parts of the world, there has been a clear move away from the traditional approach of resource development, for meeting the ever growing water demands, to one of water conservation. The rapidly increasing water demands in many parts of the world cannot be sustained indefinitely and many countries are already in a situation of severe and permanent water stress. Other countries face the prospect of prolonged and more frequent periods of water shortage as the demand for water outstrips the available resources. Water conservation is therefore becoming a major issue in many countries and is being promoted by both local governments and many of the international funding agencies.

Recent studies have shown that proposed augmentation schemes can often be postponed for many years, if not delayed permanently, if the growth in demand can be trimmed by only a few percent – a target that is certainly achievable in most cases. The savings associated with delaying new water transfer schemes are generally so large that the measures needed to achieve the delays are not only environmentally attractive but also very cost effective.

The rapid rate of urbanisation in Africa is resulting in many African cities facing major challenges of providing their increasing populations with adequate and sustainable water services. To compound the problem, extensive parts of the continent are currently water stressed, and the available water resources for these cities are dwindling rapidly. Not only are these cities now unable to reconcile the water requirements and the water resources, but also current utilisation is often both inefficient and ineffective. As a result, the role of water conservation and demand management measures for reduction of water loss and water utilisation in all spheres of the water sector is becoming increasingly important.

The United Nations has recognised that many African cities urgently need to develop and implement effective water conservation and demand management strategies that will utilise the limited water resources equitably and efficiently without wastage, and widen the service coverage, particularly in the burgeoning urban low-income settlements. To this end, a collaborative project was initiated by the United Nations Centre for Human Settlements (Habitat) and the United Nations Environment Programme within the framework of the United Nations Special Initiative on Africa. Their co-clients in this project are the United Nations Foundation for International Partnerships, the World Bank, as well as numerous local stakeholders from the separate cities including Rand Water, which is based in Johannesburg, South Africa.

The project promotes policies and a programme for integrated urban water resource management for seven African cities (Abidjan, Accra, Addis Ababa, Nairobi, Lusaka, Johannesburg and Dakar) addressing the two inter-linked and complementary priorities of:

- Water conservation and demand management; and
- Mitigating the environmental impact of urbanisation on freshwater resources and aquatic ecosystems.

In order to support the Water Conservation and Demand Management initiatives, the UN-habitat, in association with Rand Water (the largest supplier of potable water in Africa and one of the top 3 in the world), commissioned a project to develop two short manuals. The manuals are designed to assist water suppliers in understanding the broad concepts of WDM and to see how various WDM initiatives have performed through a series of documented Pilot Projects. The Pilot Projects are documented in the first of the two manuals titled "***Leakage Reduction Projects Undertaken by Rand Water***" while the broad concepts of WDM are presented in this, the second of the two manuals.

1.2 PURPOSE OF THIS MANUAL

The purpose of this manual is to provide a WDM Toolkit which can be used by water suppliers to assist them in understanding and managing their systems in order to improve the efficiency of water use within their areas of supply.

There are already numerous publications devoted to the concepts and practical implementation of WDM. This document will not attempt to address all of the issues covered by the other publications but will rather concentrate on providing a simple and straightforward approach to WDM, specifically for use in developing countries. Where appropriate, computer models will be discussed and referenced in this document to assist water suppliers. While the objective of the manual is to provide information that can be of assistance to water suppliers throughout Africa, some of the material used in the manual is based on some recent work undertaken through the South African Water Research Commission (WRC) and their support in allowing certain material to be reproduced is gratefully acknowledged.

1.3 LAYOUT OF THE MANUAL

This "Cookbook" has been split into seven sections, which in turn are supported by key information provided in six appendices. The details for each section and appendix are as follows:

Section 1: Introduction – This section provides the general overview of the purpose of the cookbook and provides some general background to the methodology used in the document.

Section 2: Concepts of Leakage – This section covers the various key concepts of leakage that all water distribution managers should understand if they are to manage their systems effectively. It also provides the principles on which the concepts of Component Based Leakage Management are based.

Section 3: Important Considerations – This section addresses various important issues that should be considered when managing leakage in a distribution system or when developing a WDM Strategy.

Section 4: Losses from the Reticulation Network – This section covers various issues influencing the losses from the reticulation network including pressure management, mains replacement, sectorising, low level audits, etc.

Section 5: Losses from Properties after the Water Meter – This section deals with losses after the property boundary which therefore includes internal plumbing losses and also discusses issues such as retrofitting and water re-use etc.

Section 6: Public Awareness and Education – This section deals with the very important but complex and often overlooked aspects of public awareness and education with regard to water use efficiency. It does not explore the issues in detail since many of the issues are dependant on the country in question and they vary significantly, due to the great cultural diversity, throughout Africa.

Section 7: Documentation – This section provides some useful references and web-site addresses which may be of interest to the water manager if more detailed information is required on various aspects of WDM.

Appendix A: Glossary of Water Balance Terms – This appendix provides a list of terms used to describe the various components of the standard IWA Water Balance.

Appendix B: Introduction to BABE, FAVAD and UARL – This appendix provides a general overview of the Burst and Background Estimate methodology as well as details of the Fixed Area Variable Area Discharges theory. It concludes with a breakdown of the calculation used to assess the Unavoidable Annual Real Losses associated with an area.

Appendix C: Methods of Calculating AZP Pressure – This appendix provides a simple description to assist water users in calculating the Average Zone Point pressure which is one of the key parameters used in the BABE calculations.

Appendix D: **Example of a High Level Water Audit:** This appendix includes a completed Water Audit for a large water supply system for reference purposes.

Appendix E: Summary of the Various WDM Models developed through the WRC. This appendix provides a short description of the four main models developed by the WRC which are available through the internet.

Appendix F: Details of the Khayelitsha Pressure Management Project. This appendix includes a short description of one of the most successful examples of pressure management in the world where the results exceeded all expectations.

1.4 FLOWCHART FOR DEVELOPING WDM STRATEGY

Figure 1.1 (courtesy Tim Waldron, Wide Bay Water, Australia, 2002) provides a schematic overview of the various components of WDM. As can be seen from the figure there are numerous components which tend to be linked in some manner and it is clear that they cannot be considered in isolation. A proper WDM strategy will typically involve many different measures, which are selected to suit a particular water supply system. Each water supply system is unique to some degree and the measures selected for one system will not necessarily be appropriate for another. For example, in many township areas with very high levels of leakage, the WDM strategy may involve leak detection, pressure management, retrofitting, education/awareness and new household water metering. At an adjacent area, the appropriate strategy may involve only leak detection and repair without any of the other measures.

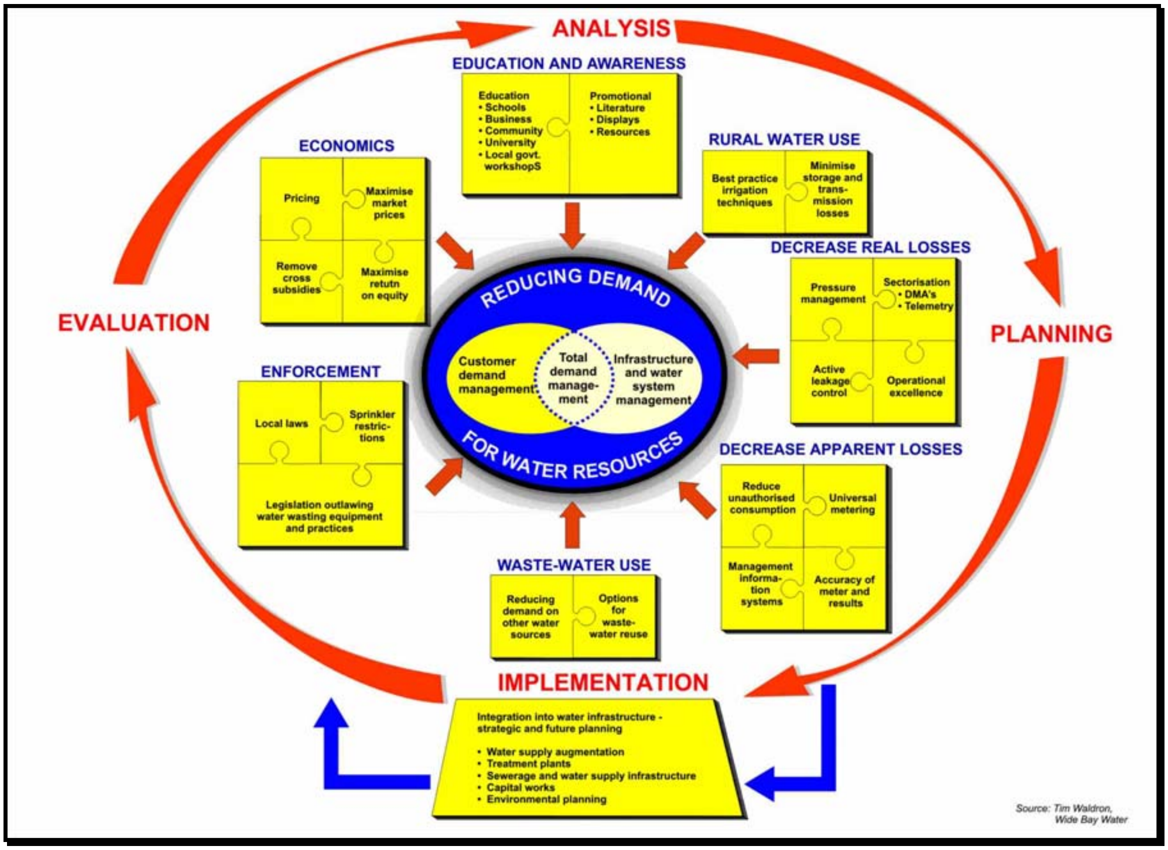


Figure 1.1: Flowchart for Developing WDM Strategy

(figure courtesy of Tim Waldron, Wide Bay Water, Queensland, Australia)

To summarise this section of the manual, each water supply system has its own unique characteristics and deficiencies. In order to address these, it is necessary to understand not only the deficiencies, but also the various contributing factors and to develop a strategy that is clear, concise and applicable to each specific situation.

2 CONCEPTS OF LEAKAGE

2.1 GENERAL

All water supply systems leak to some extent and system leakage can never be eliminated. It can, however, be managed and in many instances reduced through various WDM and/or Leakage Management interventions.

The traditional approach to leakage reduction in a water supply system is to send in a team of leak detection experts to identify any leaks in the system. The leaks are then repaired, with the result that the leakage is reduced. While this approach may be justified in some cases, it is often neither cost effective nor appropriate.

Before deciding to carry out a leak location and repair exercise, the water supplier should first answer the following questions:

What is the extent of the leakage in a specific area?

What is the main source of the leakage?

Only after these two questions have been answered satisfactorily, can the water supplier develop an appropriate strategy to address the real problem issues. For example, a specific system may experience high levels of background leakage (small leaks) without any serious burst leaks (large leaks). In such a case, the leakage levels will be high but the leak detection teams will find few, if any, leaks since background leaks are too small to identify using normal leak locators. Even if the small leaks can be detected, they are so small that it is rarely (if ever) cost effective to repair them.

Another typical example, which is common in many parts of Africa, concerns areas with high leakage within the properties. It is often found that leakage within the property boundaries or even inside the properties themselves is the dominant source of leakage. Again in such cases, leak location and repair teams will have

little impact on the problem and the only solution is to address the leakage on a property-by-property basis in association with general pressure management.
These examples serve to illustrate the importance of identifying the problem before trying to solve it. Before undertaking any form of leakage reduction activity, it is essential to carry out a basic assessment of the water supplied to an area and the water used in the area – often referred to as a Basic Water Audit.

Many water suppliers already undertake some form of water audit and the result is often an indication of the Unaccounted-For-Water as well as the losses from the system expressed as a percentage. For reasons, which will become clear later in this document, the term "Unaccounted-For-Water" should not be used and percentages should be avoided if possible. Instead, the term "Non-Revenue Water" should be used together with losses expressed as a quantity (e.g. m^3 per year) or preferably in terms of litres/connection/day. This issue is discussed in more detail at various sections in this manual.

Before proceeding to discuss the various WDM initiatives that can be considered for a system, it is important to understand certain key concepts of leakage which, if understood correctly, will assist the water supply manager in selecting the appropriate intervention for his/her system.

2.2 INTRODUCTION TO COMPONENT BASED LEAKAGE MANAGEMENT

The Component Based Leakage Management methodology and concepts have been widely accepted throughout the world and are generally regarded as the most comprehensive and pragmatic approach to leakage management in potable water distribution systems. The methodology provides a simple approach to the very complex and often confusing problem of leakage from water distribution systems. Although it was originally intended for developed world conditions, the methodology is in no way limited to these conditions and is also appropriate for use in the developing world. The techniques have been promoted and presented in many African countries including, Ethiopia, Ghana, Zambia, Lesotho, South Africa, Botswana, Namibia, Malawi and Kenya. Many African countries are already using

Component Based Leakage Management techniques to analyse and address their leakage problems – sometimes under the name of the Burst and Background Estimate (BABE) techniques and sometimes simply through proper and well structured management principles.

The Component Based Leakage Management techniques can be considered as addressing the following four principal issues (see **Figure 2.1**):

- Benchmarking of leakage and auditing of non-revenue water;
- Logging and analysis of minimum night flows;
- Economics of leakage and leakage control;
- Pressure management.

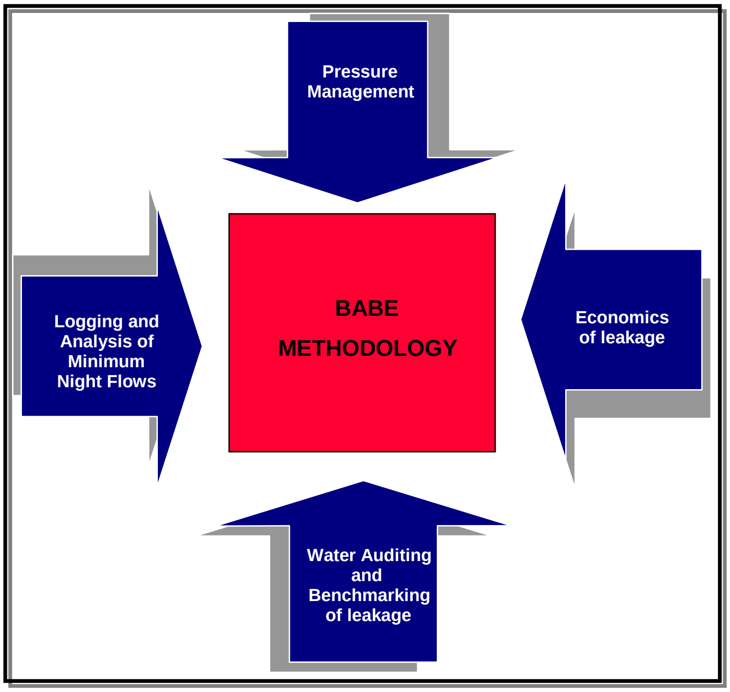


Figure 2.1: Four Main Elements of the Component Based Methodology

In order to address the four key components of the Component Based Leakage Management methodology, four models were developed over a period of approximately four years, as shown in **Figure 2.2**. Each model is a small self-contained program, which addresses one specific issue. It was decided to adopt this simple and straightforward approach in order to avoid confusion and allow water suppliers to use one or all of the models as appropriate.

The models are available in the public domain and can be obtained from the WRC, or downloaded from their website together with the appropriate documentation. Although the models are relatively simple and straightforward, they do provide a very useful toolkit for water distribution system managers who wish to control and reduce leakage and wastage from their systems.

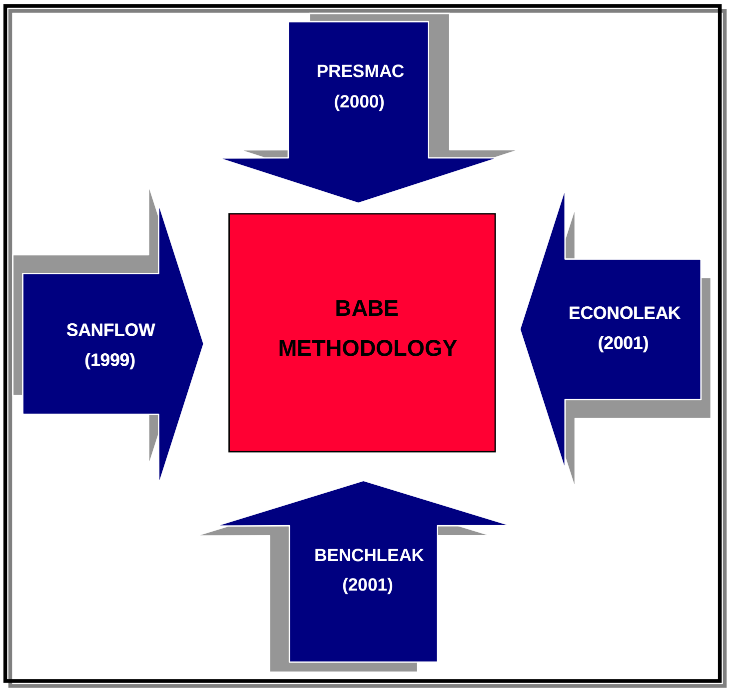


Figure 2.2: Models Developed through the WRC

All four models are available through the Water Research Commission and details of the models are provided in **Table 2.1 and Appendix E** for reference purposes. The various manuals accompanying the software can be obtained directly from the internet at the following address: ***www.wrc.org.za***.

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. Due to time and budget constraints, this manual concentrates on the technical aspects of WDM and does not attempt to address the often complex social issues which vary significantly from area to area.

Table 2.1: Details of the various WRC models available to Water Suppliers

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

2.3 WHAT ARE BURST AND BACKGROUND LEAKS?

In the course of the UK research into leakage management the leaks found in any water supply system were split into two categories – those large enough to warrant serious attention with regard to location and repair and those that were too small to warrant such attention. The larger more serious leaks that warrant direct attention are referred to as bursts (see **Figures 2.3 and 2.4**) while those that are too small to deserve such attention are referred to as background leaks. The threshold between bursts and background leaks is not fixed and can vary from country to country. In the UK, a threshold limit of 0.5 m^3/h is used, while in South Africa a lower limit of 0.25 m^3/h is considered more appropriate. In other words:

Leaks	>	$0.25\ m^3/h$	=	Bursts

and

Leaks	<	$0.25\ m^3/h$	=	Background Leaks

Figure 2.3: Typical Mains Burst

Figure 2.4: Typical Connection Pipe Burst

2.4 MAINS AND CONNECTION LEAKAGE

In order to address leakage in a system, it is often useful to break the leakage down into the different types, each of which has its own characteristics. System leakage is normally addressed under the following headings:

- Transmission Mains and Reservoir Leakage;
- Reticulation Mains Leakage;
- Connection Leakage;
- Service Pipe Leakage.

A typical water distribution system is shown in **Figure 2.5**. The transmission mains tend to be the high pressure large diameter mains (e.g. 600 mm and 300 mm) which convey water from the major reservoir or treatment works to the smaller bulk water reservoirs which in turn tend to act as pressure break tanks in many cases. The water pipes leading from the smaller bulk water reservoirs tend to be smaller diameter (e.g. 150 mm) water mains or Reticulation Mains, which distribute the water to the various consumers. Pipes from the Reticulation mains to the consumer are called the Connections and these tend to be of a small diameter (e.g. 25 mm). The portion of pipe from the water main to the customer meter is termed the connection while the portion of pipe from the meter to the property is called the service pipe (see **Figure 2.6**).

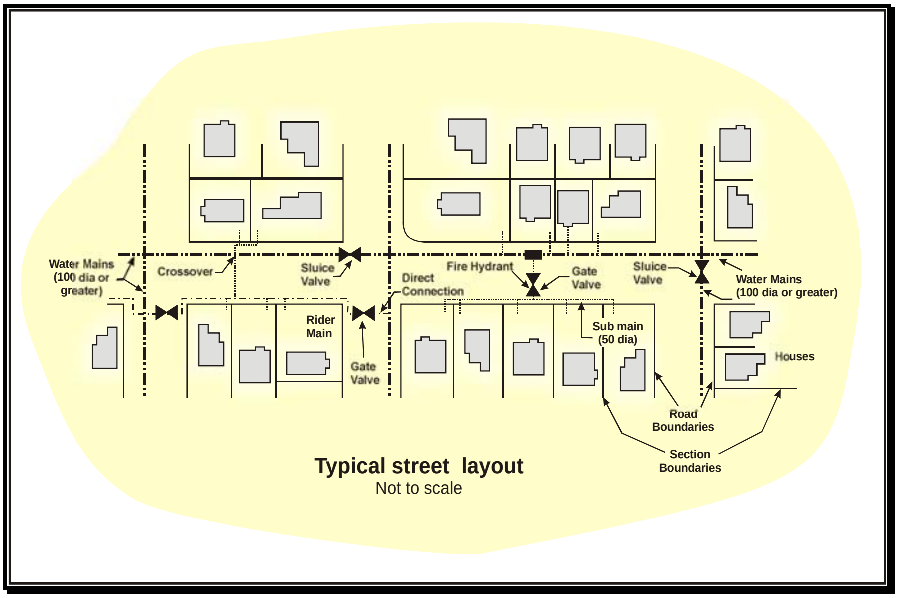


Figure 2.5: Typical Water Distribution System

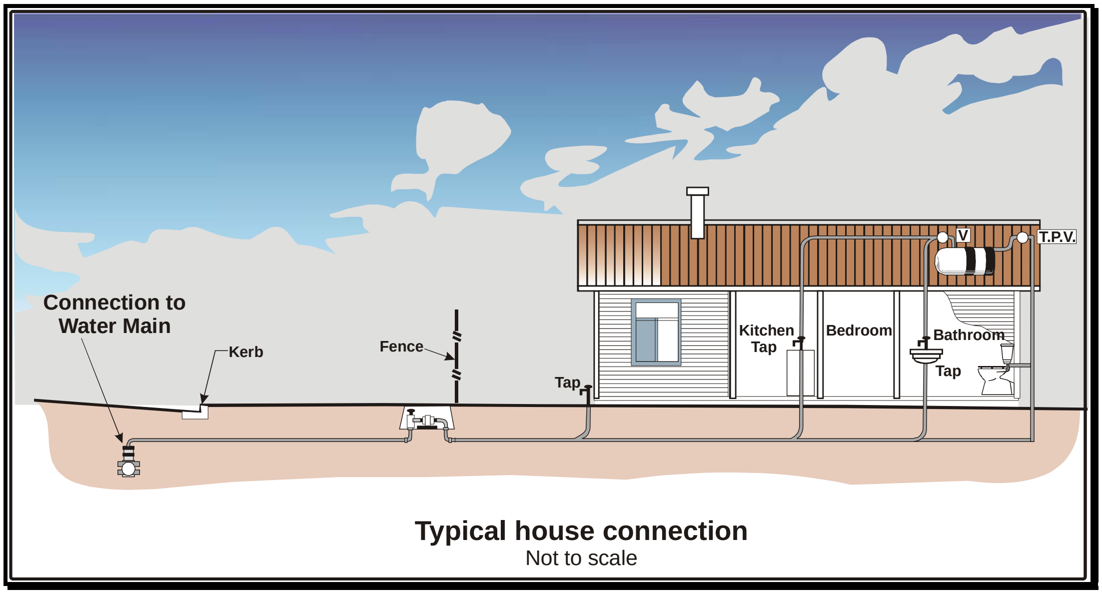


Figure 2.6: Example of a House Connection to a Fully Serviced Property

Transmission Mains and Reservoir Leakage

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

Reservoir leakage is often difficult to assess since it normally occurs from cracks in the water retaining structure or overflows which tend to occur at night, both of which can run undetected for months if not years. **Figure 2.7** shows a typical reservoir overflow which had been running unchecked for many years.

Figure 2.7: Example of a Reservoir Overflow

Reticulation Mains Leakage

Reticulation mains tend to be medium-sized pipes operating at high to medium pressures with regular branches and off-takes. Such pipes can experience regular leaks and when a leak does occur it is generally quite obvious (as shown previously in **Figure 2.3**) and relatively serious with the result that it is repaired within a day. The frequency of leaks from reticulation mains would be expected to be in the order of 0.150 per km mains per year with an average leakage rate in the order of 12 m^3/hr at a standard pressure of 50 m. While it is uncommon for reticulation mains leaks to remain undetected for any length of time, some unreported mains leaks will occur. The frequency of such unreported leaks will normally be relatively low and in the order of 0.008 per km of mains per year with an average leakage rate of 6 m^3/hr – i.e. half the rate of the reported reticulation mains bursts.

Connection Leakage

Leakage from connection pipes (see **Figure 2.4**) is normally the main source of leakage in any water distribution system and tends to exceed all other leakage combined. The leaks usually occur at the joint between the water main and the connection pipes, which represent points of weakness in any water distribution system. The connection pipe leaks often occur at or near the road-side and are often caused by the traffic loading, which results in some movement and differential settlement. The frequency of leaks from connections in a normal system is in the order of 2.5 per 1 000 connections or 0.0025 per connection, with an average leakage rate in the order of 1.6 m^3/hr at a standard pressure of 50 m. Connection leaks are often unreported and such leaks can represent a sizeable portion of leakage in any system. The frequency of such unreported connection bursts is usually in the order of 0.825 per 1 000 connections per year with an average leakage rate of 1.6 m^3/hr – i.e. the same rate as for the reported connection bursts but with a lower frequency.

Service Pipe Leakage

Service pipe leaks are relatively common and tend to run undetected for longer periods than other forms of leakage. In cases where service pipe leakage is considered important, the same figures can be used as suggested for the connection leakage. In cases where such leakage occurs after the customer meter and all water is being paid for by the consumer, the service pipe leakage is often disregarded from the water balance calculation since it is already included under the "metered consumption" component in the water balance.

Summary of Leakage Rates and Burst Frequencies

The leakage rates and frequencies for the different forms of leakage are summarised in **Table 2.2** for reference purposes. It should be noted that while the figures provided are based on considerable international research, they should be used as first estimates, which may be altered if more realistic figures can be obtained from the relevant water supplier. Unfortunately in most parts of Africa, it appears that few water suppliers record and analyse their burst pipes to the level of detail required to provide the figures given in the table. It should also be noted that the leakage rates given in the table are based on normal pressure of 50m. If the average pressure in a system is higher or lower than 50m, the leakage rates should be adjusted accordingly – see **Section 2.10** for details.

Table 2.2: Basic Information on Reported and Unreported Bursts

Details	Reported Bursts		Unreported Bursts	
	Frequency	Leakage Rate (m^3/hr)	Frequency	Leakage Rate (m^3/hr)
Transmission Mains	0.030 /km/yr	30.0	0.00 /km/yr	12.0
Reticulation Mains	0.150 /km/yr	12.0	0.008 /km/yr	6.0
Connections	2.5 /1 000 conn/yr	1.6	0.825 /1 000 conn/yr	1.6
Service Pipes	2.5 /1 000 conn/yr	1.6	0.825 /1 000 conn/yr	1.6

The other important aspect of reported and unreported leakage concerns the actual running time. In the case of unreported leaks, the running time can be considered to be half of the interval between active leakage control interventions. An active leakage control intervention involves sending out a leak detection team to identify leaks that have not been reported. If an Active Leakage Control intervention is undertaken each year then the average running time for the unreported leaks is estimated to be 6 months. In the case of reported bursts, the running time will depend upon the level of efficiency in the awareness, location and repair process. The average running times of the different leaks are often of interest to the water supply manager but such information is rarely available, particularly in most African water supply systems. In cases where reliable information is not available, the values recommended in **Table 2.3** can be used.

Table 2.3: Information on Duration of Reported Bursts

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

It should be noted that the figures given in **Table 2.3** are average values for an average water utility and should only be used as a first estimate in cases where reliable information is not available. They can also be used to test the sensitivity of the leakage to various possible scenarios where the water supplier wishes to improve some aspect of its service. For example, if the water supplier wishes to improve its repair time for reported connection pipe bursts on all connections from 6 days to 3 days.

2.5 ACTIVE AND PASSIVE LEAKAGE CONTROL

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

- Administration and set up costs;
- Human resources inspection costs;
- Supervision costs;
- Mains repair costs;
- Connection repair costs;
- Various other small costs.

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

While passive leakage control is clearly not ideal from the viewpoint of reducing leakage, the key issue is to determine whether it is more cost effective to use teams of plumbers to detect and repair leaks or simply to react to customer complaints when the leaks become so large that they are reported. In some instances, it is cost effective to investigate a system every six months, while in other instances it may not be cost effective to carry out such investigations more frequently than every two years or even longer. Every system is different and should be judged on its own merits. In cases, where active leakage control has not been implemented for many years (if ever), it is likely that such effort will be very cost effective since there will be a substantial backlog of unreported leaks to be found.

It should be noted that Active Leakage control does not necessarily require teams with sophisticated and expensive equipment. While such equipment is readily available in many developed countries, it is often too expensive for many water suppliers in Africa. In such cases, the water supplier can adopt a low-cost and basic form of Active Leakage control which involves personnel simply driving past or walking along the route of all water mains on a regular basis and recording any “visible” leaks that are evident. The water utility can make up some very basic and inexpensive sounding rods from a piece of steel reinforcing bar and a block of wood at the ear piece. While such listening rods are not ideal, they are very cheap to make up and are relatively effective. **Figure 2.8** shows the normal sounding rods together with the “home-made” low budget rods which may be appropriate in some areas of Africa. In most cases, such efforts will pick up many of the “unreported” leaks, although some will remain undetected if they are below ground with no visible signs of leakage evident. A small budget devoted to this simple form of Active Leakage Control will often reap large benefits in water savings.

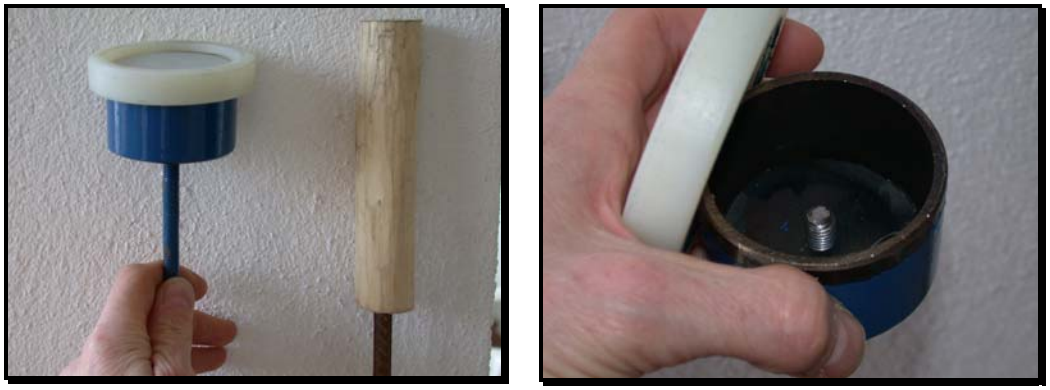


Figure 2.8: Examples of commercial and "home made" sounding rods

In cases where a water utility does not have sufficient funds to support even a low-level form of Active Leakage Control, a well managed and effective system for dealing with reported leaks will often provide a cost-effective and reasonably efficient form of leakage management. It should be noted that it is extremely important for water suppliers to act quickly and efficiently to repair reported leaks, since the consumers will tend to waste water and ignore leaks if the water supplier is perceived to do likewise. No amount of awareness and education is going to rectify the perceptions of consumers towards non-service delivery by the supplier. Consumers are also not going to assist in any efforts of WDM if the water supplier does not react to their complaints in this regard.

2.6 DURATION OF REPORTED AND UNREPORTED BURSTS

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

- Awareness in the community;

- Location of the leak by the water utility leakage team;
- Repair of the leak.

The awareness time for response to a leak by the water supplier will depend on the size of the leak, its visibility to the public/consumer and its impact on water users in the system. A serious leak that is highly visible and causes low water pressures to certain consumers will be brought to the attention of the water supplier within hours. A smaller leak, however, that causes no real problems and perhaps runs directly into a stream or storm-water drain may run undetected for several days, months or even years. If no form of Active Leakage Control is practiced by the water supplier, such leaks can run indefinitely or until they become sufficiently large to draw some attention. The awareness time for a leak can vary considerably from system to system and will depend upon how diligent the consumers are with regard to reporting leaks and whether or not the water supplier has created a system whereby the consumers are able to report leaks easily. A proper customer awareness and service centre is required to ensure effective leakage control for reported bursts.

It is important to understand the issue of awareness, location and repair of leaks as it is generally assumed that large leaks will result in greater wastage than small leaks and for this reason the repair of small leaks is often given a low priority. In many cases, however, this is not the case and the overall leakage from a small leak can exceed the water lost from a large leak. Consider a typical mains leak, which will normally run at approximately 3 m^3/hr or 75 m^3/day as shown in **Figure 2.9**. This type of leak is normally highly visible and often causes low-pressure problems to some consumers. Because of the inconvenience caused, the leak is reported within a few hours and repaired as a priority in less than a day. This type of leak will typically run for approximately 1.1 days and result in leakage of 80 m^3.

Figure 2.9: Typical Duration and Losses from a Mains Burst

If, however, a relatively small leak develops on a connection pipe, which is by far the most common type of leak in all water reticulation systems, it will run at approximately 25 m^3/day, which is considerably less than the mains leak. In view of the fact that the leak may not cause such widespread disruption as the mains leak, it is not considered a high priority. It may also take a few days for the customer to notice the problem, after which it may take several more days before the water supplier has sent out a team to find the leak and assess the situation. Furthermore, it may then take a few more days to dig up the water pipe and repair the leak. In total, it takes an average of 16 days from the time a connection leak occurs until it is repaired. This type of leak will typically result in losses of 400 m^3 as shown in **Figure 2.10**.

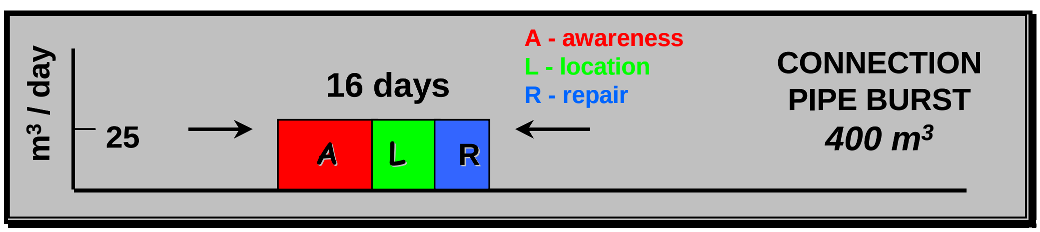


Figure 2.10: Typical Duration and Losses from a Connection Burst

If the leak occurs on the consumer's property after the meter, the situation can be even worse from a leakage viewpoint. In such cases, the consumer may not pick up the leak for several weeks or even months. After identifying the leak, the location and repair may also take many days or weeks to complete, with the result that such leaks normally run for approximately 46 days. The water lost through such a leak will average out to approximately 1 050 m^3 as shown in **Figure 2.11**.

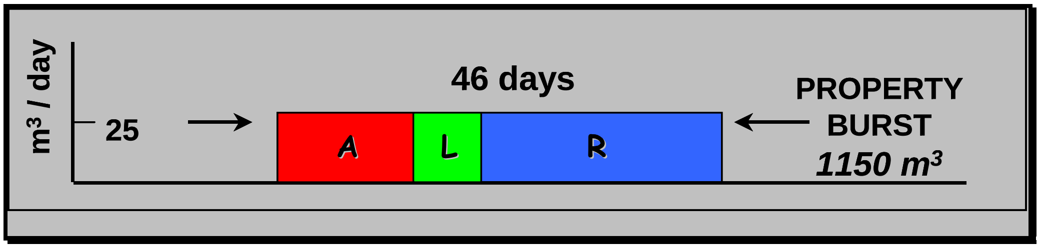


Figure 2.11: Typical Duration and Losses from a Property Burst

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

In some countries where the water bills are based on a monthly flat-rate (i.e. the consumer pays a set rate each month no matter how much water is used) the water companies offer to repair leaks on customers' properties free-of-charge rather than leave such leakage to the customer. While this may initially seem to be very generous of the water company, it has been shown that the savings to the company far outweigh the costs of repairing the leak. In cases where the customer is charged for the water used, the water supplier may decide that such leakage is not a priority issue since the water is being paid for and the water company is not losing any revenue because of the leak. In most African cities, the situation is probably somewhere between the two extremes since many water suppliers supply water to customers who either have no meters, or pay a flat rate each month. In such cases, the water supplier may decide that it is in its best interests to locate and repair all leaks on the customer's property. In other cases, the customer leakage may be metered and paid for by the customer in which case the supplier will usually ignore such leaks and decide that such repairs are the customer's problem.

2.7 REAL AND APPARENT LOSSES

When assessing losses from a water distribution system it is standard practice to split the losses into two components namely Real and Apparent Losses.

Real Losses

Real losses represent the physical water losses (i.e. leakage) from the pressurised system up to the point of measurement of customer use. These real losses represent actual water supplied to the system that is lost into the ground. In many cases, the lost water may return to the natural river system through the storm-water network or through the sewer network. Losses inside the properties, such as a leaking toilet, would not be considered as part of the real losses, since they take place after the property boundary. Such losses are termed internal plumbing losses and are considered part of the metered consumption in cases where household meters are present and un-metered consumption in cases where household meters are not present.

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

Apparent Losses

Apparent losses represent the unauthorised consumption (theft or illegal use), plus all technical and administrative inaccuracies associated with customer metering and billing. It should be noted that the Apparent Losses tend to be low (20% or less of the Total Losses) in well-managed systems but can be high (in excess of 50% of the Total Losses) in poorly managed systems. In areas of low payment or where a flat rate is used, the Apparent Losses tend to be relatively high since there is little incentive for consumers to curb their water use and the actual use is often significantly higher than the assumed unit use used to calculate the tariff.

The assessment of the Apparent Losses is always a difficult and often subjective exercise. Considerable effort is currently being devoted to the quantification of apparent losses through the International Water Association (IWA), however, the results were not available for inclusion in this report. An estimate should therefore be made from local knowledge of the system and an analysis of technical and administrative aspects of the customer metering system.

While in a normal well-managed system, the Apparent Losses normally constitute between 10% and 20% of the total losses, in some large cities such as

Johannesburg the figure can rise to 50% or more. This is due to the large areas where consumers are billed using a flat rate and in many cases the levels of payment for water are very low. In some areas such as Khayelitsha in Cape Town, where most of the water is lost through poor plumbing fixtures after the domestic meter, the Apparent Losses can be as high as 80%. In summary, the Apparent Losses generally range from less than 10% for a well-managed system to more than 80% for a system experiencing major problems with household leakage and high levels of non-payment for services.

It should be noted that reducing Apparent Losses will often result in higher income to the water supplier while reducing Real losses will reduce the volume of water required by the water supplier.

2.8 UNAVOIDABLE ANNUAL REAL LOSSES (UARL)

An interesting and important concept that was recently developed (Lambert et. al., 1999) concerns the level of leakage in a system that cannot be avoided. No system can ever be completely free from leakage no matter how new or well managed. This concept of Unavoidable Annual Real Losses (UARL) is now one of the most useful and important concepts used in Component Based Leakage Management. Effectively, it is a simple concept based on the fact that no system can be entirely free from leakage and that every system will have some level of leakage which cannot be reduced any further. Even a new reticulation system with no use will have some level of leakage, although it may be relatively small. The minimum level of leakage for a system is the lowest level of leakage that can be achieved for the given system based on the following assumptions:

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

Considerable work was undertaken to assess the minimum level of leakage for water distribution systems (Lambert et. al., 1999) and after careful analyses of many systems throughout the world, a relatively simple and straightforward equation was developed. Full details of the equation are provided in **Appendix B**, but the standard form of the equation is as follows:

$$\mathbf{UARL = (18 * Lm + 0.80 * Nc + 25\ Lp) * P}$$

Where:

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

The basic equation is based on an average length of pipe from the water main to the customer meter of 10 m. The third term (the Lp term) is therefore only used in cases where the customer meter is located in excess of 10 m from the water main. In some countries where the customer meter is located at the street edge, the equation can therefore be simplified to the following:

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

To show how easily the UARL can be calculated for a system a simple example can be used. If 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 metres, the UARL can be calculated in the following manner:

UARL = (18 * 114 + 0.80 * 3920 + 25 * 0) * 50 Litres/day

= 102 600 + 156 800 litres/day

= 259 400 litres/day

= 259.4 m^3/day

= 94 681 m^3/year

= 66 litres/connection/day

2.9 NATURAL RATE OF RISE OF LEAKAGE

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

In order to address leakage, it is important to understand the key elements that influence it. This is particularly important when considering the economics of leakage in order to identify the appropriate budget to allocate to leakage reduction.
If the leakage in a particular system is conceptualised, as shown in **Figure 2.12,** it can be seen that there are three basic elements namely:

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

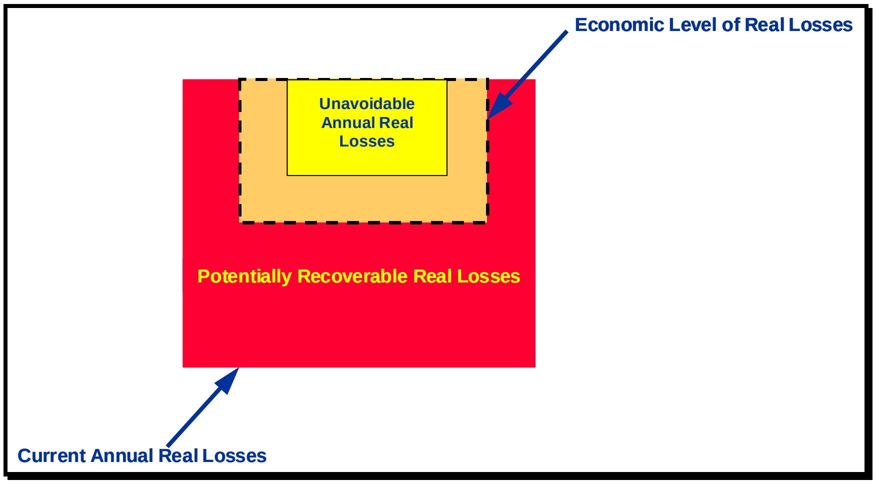


Figure 2.12: Conceptual Representation of System Leakage

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

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

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

These four components can be considered as constraints, which prevent the Annual Real Losses from increasing as shown in **Figure 2.13**.

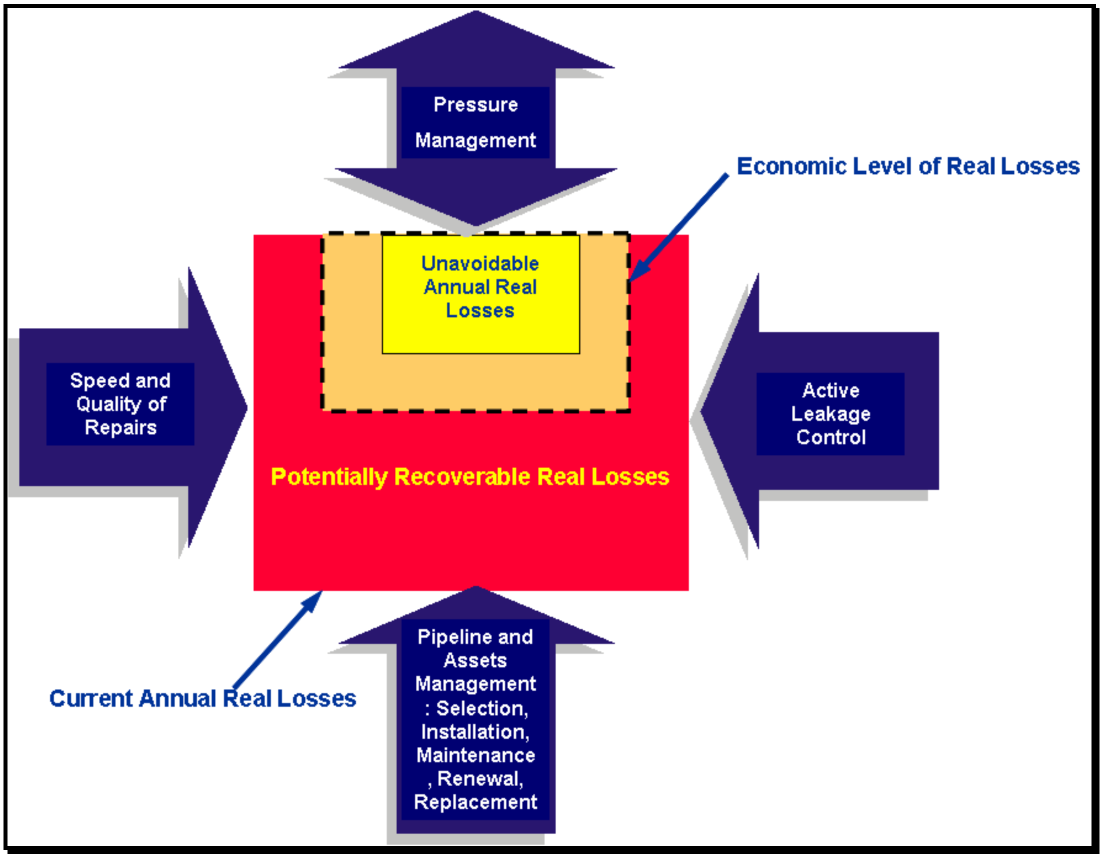


Figure 2.13: Factors Influencing Levels of Real Losses

The purpose of **Figure 2.13** is to highlight the fact that system leakage is highly dependent on several key factors. If the water utility disregards or ignores one or other of these factors, the leakage will tend to increase. It is clearly necessary to address all four issues simultaneously if leakage is to be properly controlled and eventually reduced. For example, if a water utility can improve the speed and quality of repairs through the use of better repair procedures and additional repair teams, then the leakage will improve to some degree, as shown in **Figure 2.14.**

Similarly, if the water utility can also improve their pipeline and asset management and implement an effective maintenance and replacement programme, the system losses can be reduced further as shown in **Figure 2.15.** The same applies to active leakage control as shown in **Figure 2.16**. Finally, if Pressure Management is implemented to reduce leakage, the situation will be improved further as shown in **Figure 2.17**. In the case of pressure management, the reduction of pressure will also lower the UARL as shown in the figure and discussed in **Section 2.8**.

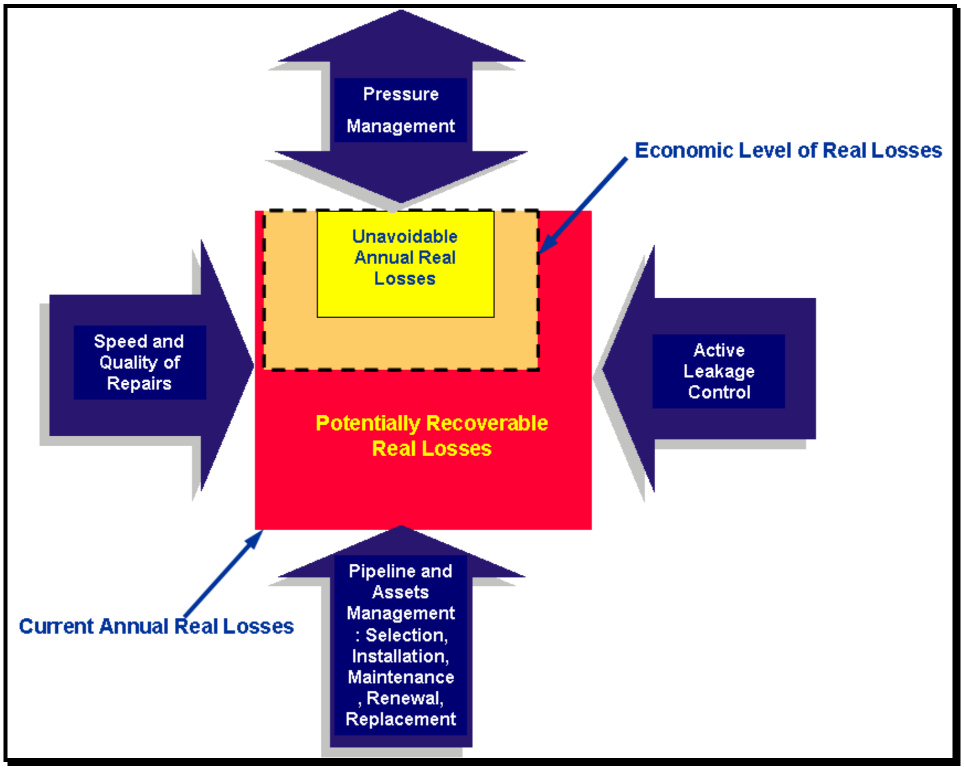


Figure 2.14: Influence on Leakage of Improving Speed and Quality of Repairs

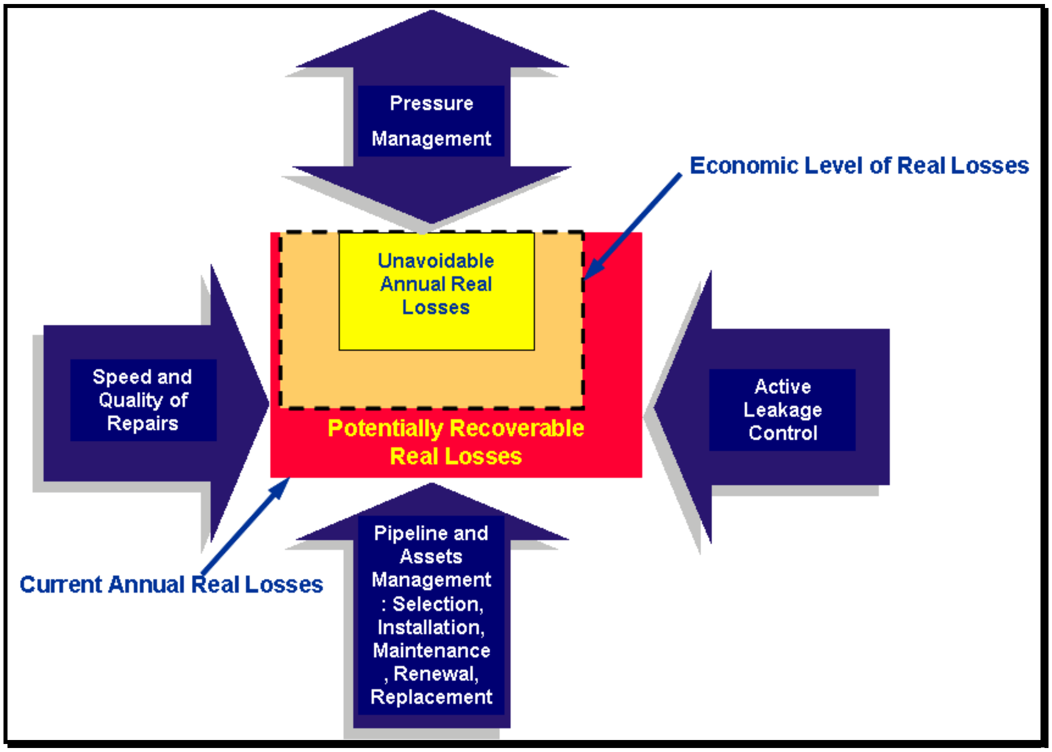


Figure 2.15: Influence on Leakage of Improving Asset Management etc.

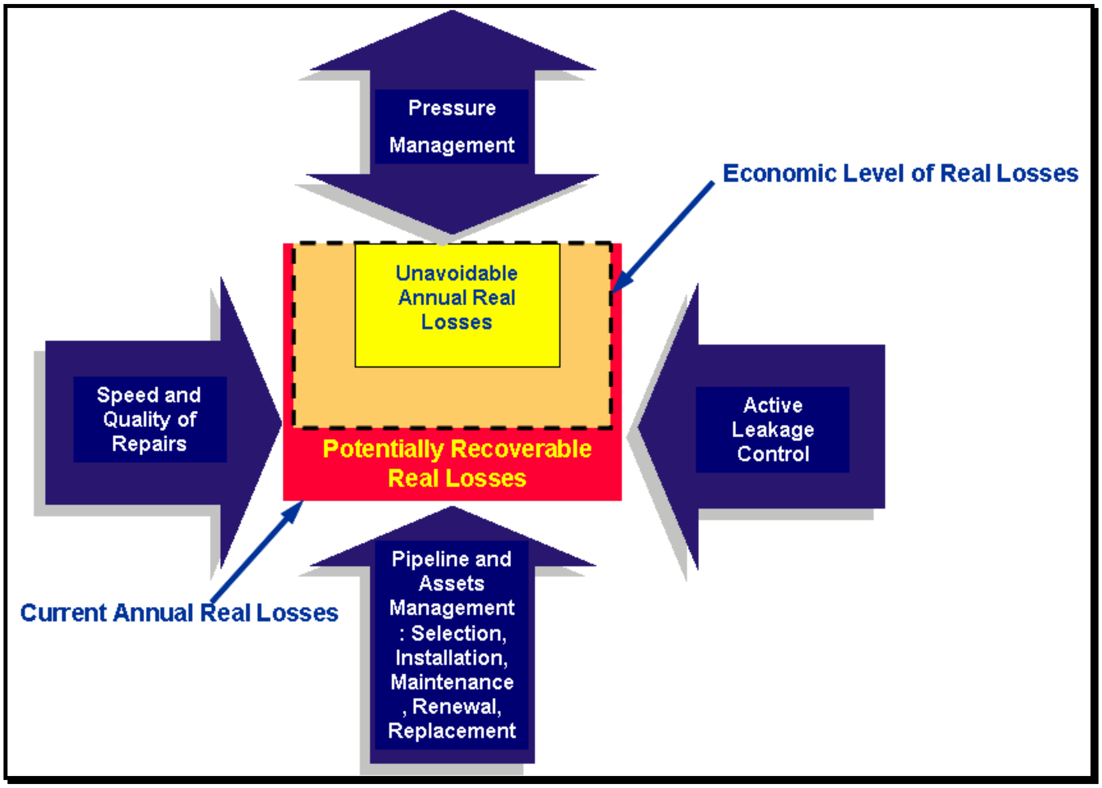


Figure 2.16: Influence on leakage of improving Active Leakage Control

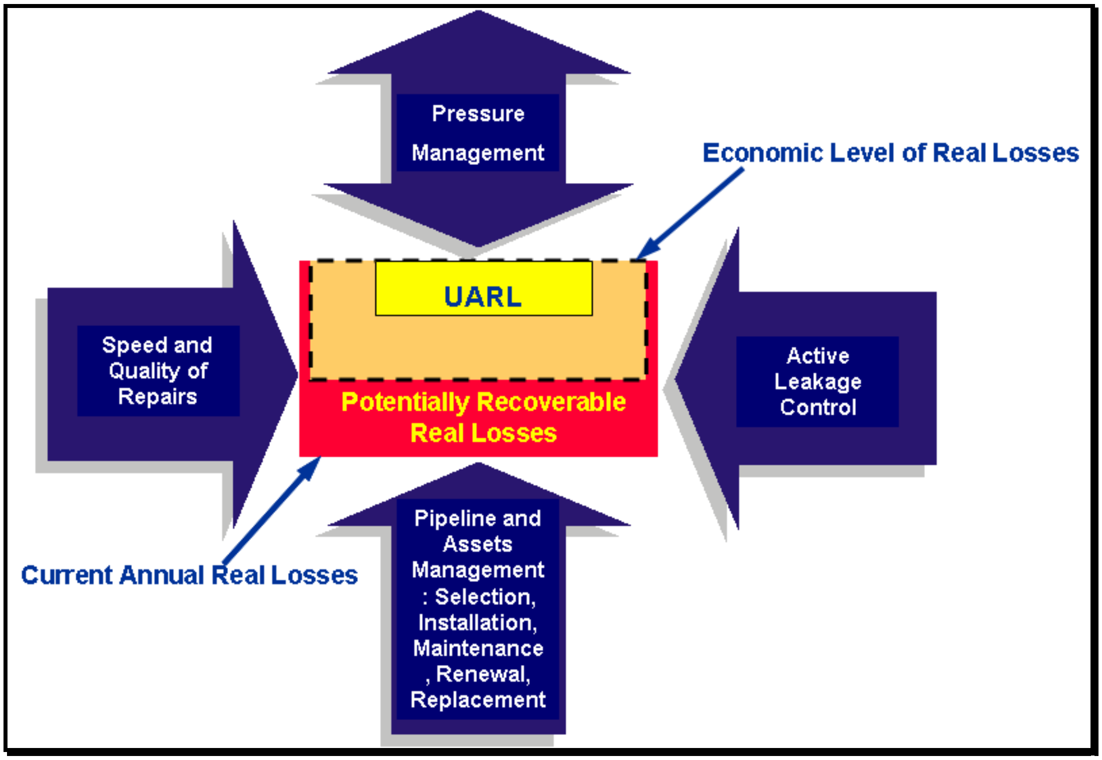


Figure 2.17: Influence on Leakage of Implementing Pressure Management

2.10 INFLUENCE OF PRESSURE ON LEAKAGE

One of the most important factors influencing leakage is pressure. Considerable work has been undertaken over the past 10 years in many parts of the world to establish how leakage from a water distribution system reacts to pressure. It is generally accepted that flow from a hole in a pipe will react to pressure, in accordance with normal hydraulic theory as shown in **Figure 2.18**.

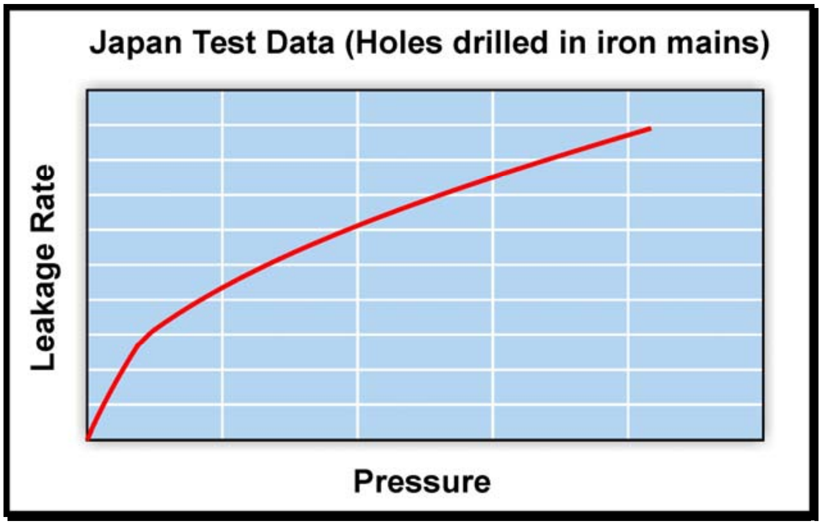


Figure 2.18: Theoretical Pressure / Leakage Relationship

Figure 2.18 shows a square root power relationship between flow and pressure (i.e. the power exponent = 0.5) and is the normally accepted relationship for flow through an orifice such as a hole in a pipe. The general equation used to estimate the influence of pressure on the leakage from a hole in a pipe is given below.

$$Flow_{P2} = Flow_{P1} \times PCF$$

Where:

P1	=	Pressure 1 (m)
P2	=	Pressure 2 (m)
$Flow_{P1}$	=	Flow at pressure P1 (m^3/h)
$Flow_{P2}$	=	Flow at pressure P2 (m^3/h)
PCF	=	Pressure correction factor = $(P2/P1)^{pow}$
pow	=	power exponent

This implies that if pressure doubles, the flow will increase by a factor of 1.4 (i.e. PCF = $2^{0.5}$). This has been tested and found to be realistic, irrespective of whether the pipe is above ground or buried.

In reality, however, it has been found that the leakage tends to be more sensitive to pressure than would be expected from **Figure 2.18**. In most cases the leakage tends to increase almost linearly with pressure (i.e. doubling pressure doubles leakage as shown in **Figure 2.19**) and in certain cases it increases exponentially up to a power of almost three. This has caused considerable debate and confusion, especially when trying to establish the likely savings through pressure reduction measures.

Although there are still various opinions concerning the explanation for the larger-than-expected influences of pressure on leakage in many systems, at least one plausible theory has been suggested. In 1994, John May in the UK (May, 1994) first suggested the possibility of fixed-area and variable-area discharges (FAVAD). He has carried out considerable research on this topic and has found that systems will react differently to pressure, depending on the dominant leakage in the system.

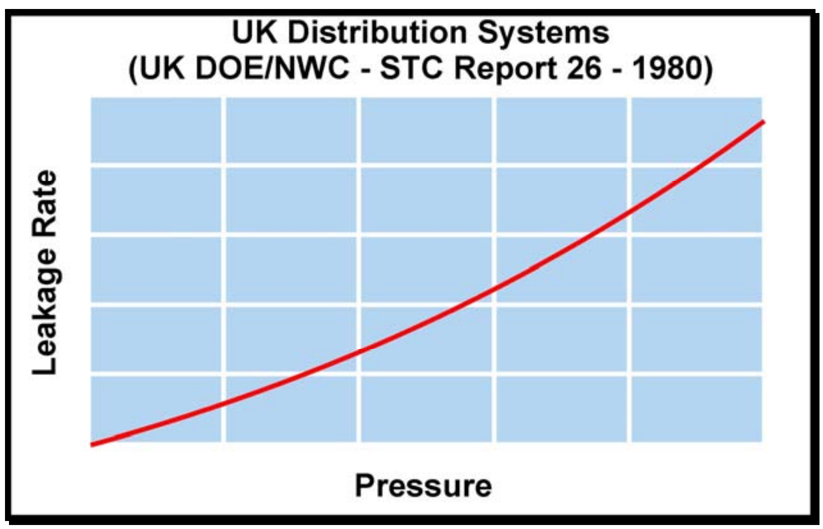


Figure 2.19: Leakage/Pressure Relationship in a Typical Water Supply System

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

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

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

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

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

Table 2.4: Pressure Correction Factors for Various Pressure Exponents

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

Influence of Pressure on Number of Bursts

The previous discussion on the influence of pressure on leakage, concentrates on the leakage occurring from existing bursts and background leakage. There is also another important consideration when assessing the impact of pressure on leakage and that is the burst frequency. It has been shown through considerable research that burst frequency is very sensitive to maximum system pressure, as can be seen in **Figure 2.20**.

This figure indicates that if the maximum pressure in a system is doubled, the frequency of burst pipes will increase by a factor of 8. Similarly, if the maximum pressure can be halved, the number of burst pipes will decrease by a factor of 8. This is a very important consideration since most systems experience their maximum pressure at night when the demand for water by the consumers is very low. If the night-time pressures can be reduced, the leakage from the existing burst and background leaks will reduce and so too will the frequency of burst pipes. In many cases the savings from the reduced bursts will be significant and, at the same time, the pressure reduction measures will prolong the life of the system – a consideration which is usually ignored and excluded from any financial calculations.

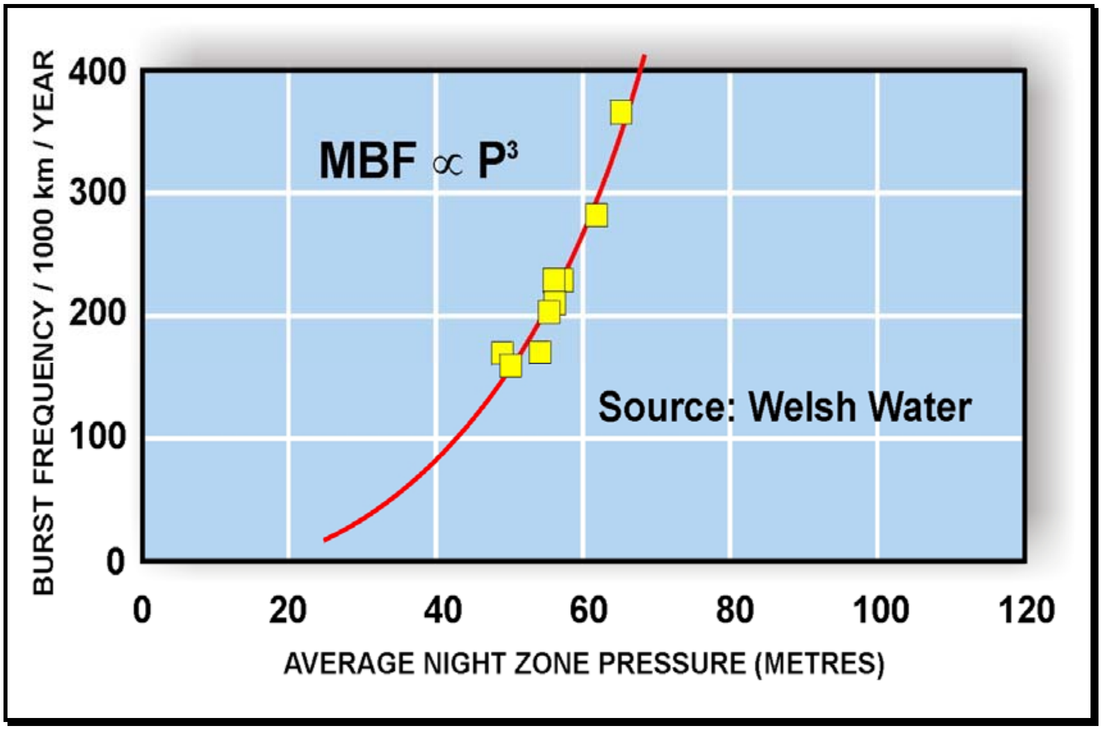


Figure 2.20: Influence of Pressure on Burst Frequency

2.11 USE AND MIS-USE OF PERCENTAGES

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

A simple example can be used to highlight this problem. In this example a distribution system with 100 000 service connections experiences real losses of 15 000 m^3/day (150 litres/service connection/day). The percentage real losses can easily be calculated for a range of different unit consumption as shown in **Table 2.5**.

From **Table 2.5** it can be seen that, although the real losses in litres/connection/day are identical in all cases, the percentage losses vary between 2% and 38%. It is clearly not meaningful to compare the percentage losses of a water distribution system in South Africa with the percentage losses for systems in other countries with different levels of average consumption. This is not only true for comparisons between one country and another but it is also true for comparisons between different systems in the same country.

Table 2.5: Problems with using % Real Losses as a Performance Indicator

Consumption per Service Connection (ℓ/conn/d)	Real Losses (ℓ/conn/d)	System Input (ℓ/conn/d)	Real Losses as % of System Input
250 (e.g. Malta)	150	400	38
500 (e.g. UK)	150	650	23
1 000 (e.g. Australia)	150	1150	13
2 000 (e.g. Japan)	150	2150	7
3 000 (e.g. California)	150	3150	5
8 000 (e.g. Singapore)	150	8150	2

In addition, if WDM activities or seasonal factors influence consumption, the percentage real losses will increase or decrease despite the fact that the volume of real losses remains unchanged. In many parts of Africa, these considerations are particularly relevant and it is for this reason that a model is required that provides details of the various water balance components expressed in terms of both percentage and litres/connection/day.

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

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

A key objective of the BENCHLEAK software was to ensure that the information requested is relatively simple to provide. At the same time, the results and details provided from the software should be of interest and use to the water suppliers by detailing their water balances in a simple and pragmatic manner.

This software is equally applicable in other African countries as it is generic in nature and based on the general methodology developed through the International Water Association (IWA). A typical example using the software to assess the water balance in a water utility is provided in **Appendix D**.

2.12 HIGH LEVEL WATER AUDIT

2.12.1 General

As mentioned in the previous section, one of the first actions to be taken by a water supplier who wishes to address a leakage problem, is to undertake a basic water audit in order to assess the magnitude and source of the leakage problem. This relatively simple concept was, until recently, very difficult if not impossible to carry out in a standard and internationally accepted manner. Every water supplier worldwide had its own way of processing its water balance and used different definitions of the various terms used in the balance. In the past few years, however, a new and systematic approach was developed in close liaison with the International Water Association (IWA) and Mr Allan Lambert, who is recognised as the originator of the BABE concepts.

The authors of this manual in association with Mr Lambert, developed a simple and pragmatic water balance model called BENCHLEAK, which is freely available to all water suppliers wishing to undertake a basic water audit for a particular water supply system. The approach is well documented in the BENCHLEAK User Guide (Mckenzie et. al., 2002) and has been accepted and customised for use in many parts of the world since it was first released in 1999.

Details of the basic water audit are presented in the remainder of **Section 2,** which have been summarised from the Water Research Commission work referenced above. The WRC is acknowledged for its permission to use and reproduce certain figures and text from the BENCHLEAK User Guide.

2.12.2 Basic Water Audit

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

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

The model 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 (**1999**) together with the required system data (i.e., length of mains, number of connections etc);
- Estimate an appropriate **Target Annual Real Leakage (TARL)** for the system based on the theoretical minimum level factored up by a suitable multiplier. For example, it may be considered to be appropriate to set the acceptable leakage at three times the theoretical minimum level of leakage in a particular region, in which case a multiplier of three would be used. Some water suppliers prefer not to set leakage targets, in which case this component of the model can be ignored;
- 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 2.21.**

2.12.3 Basic Terminology

In order to carry out a meaningful Water Audit for any water supply system, it is necessary to use standard terminology that has been approved and accepted internationally. In this regard, the terminology used in the BENCHLEAK Model is based on the standard IWA terminology which is accepted and used throughout the world.

The basic water balance is depicted in **Figure 2.22** and has become the internationally recognised breakdown of water use for high-level water audits worldwide.

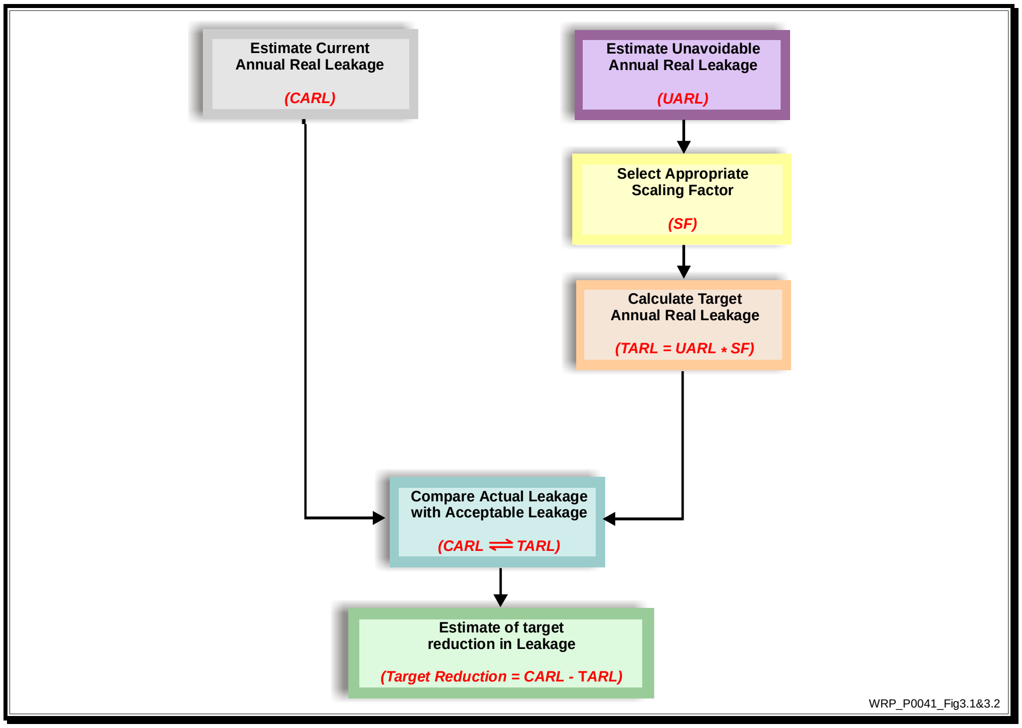


Figure 2.21: Procedure for Using BENCHLEAK

System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			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 2.22: Standard Water Balance

System Input

The System Input comprises the water supplied from the supplier's own sources as well as water purchased from other sources. A correction is allowed for the source bulk meters as well as any input from un-metered sources, which would usually be relatively small. The details are entered into **Section D4b** of the BENCHLEAK Model as shown in **Figure 2.23.**

D4b. System Input Volume

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

Figure 2.23: Components of System Input Volume in BENCHLEAK

Authorised Consumption

Details of the components of Authorised Consumption included in the BENCHLEAK Model are shown in **Figure 2.24.**

D4c. Components of Authorised Consumption

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

Figure 2.24: Components of Authorised Consumption in BENCHLEAK

From **Figure 2.24,** it can be seen that the total authorised consumption has been split into several components including exports, households, non-households, standpipes, fire fighting, mains flushing, building water and the option for adding another two user-defined categories. In most instances, the categories included will be sufficient to allow the supplier to provide a reasonable breakdown of the water use in the area of supply. Some of the items listed may be excluded or estimated since they may not be recorded directly. The various headings (billed metered, billed un-metered etc) are self-explanatory and no further details are necessary.

Water Losses

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

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

The **Total Losses** are estimated as the difference in the System Input and the Authorised Consumption as discussed in the previous sections. The Real and Apparent losses are defined in **Section 2.7** and the only potential problem area is in the estimation of the Apparent Losses, which is often based on a subjective assessment.

The Apparent Losses are generally considered to be losses associated with:

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

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 are based on the consumer meters. The individual components of the Apparent Losses are not listed separately in the model since few, if any, of the water suppliers will be in a position to supply reliable information in this regard. Instead, the Apparent Losses are simply considered a percentage of the Total Losses mentioned above. A value, to the order of 20%, is normally considered appropriate, although it can vary from system to system. The

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

The **Real Losses** are then calculated directly as the difference between the Total Losses and the estimated Apparent Losses.

2.12.4 Performance Indicators

The next step after having completed the high-level water audit is to determine whether the level of losses for a certain component is acceptable or not. This is normally achieved with appropriate key performance indicators. The standard approach to calculate performance indicators for water losses, as developed by the International Water Association (IWA), is recommended.

There are several Performance Indicators which each provide a different "picture" of the system being analysed. The three key performance indicators include:

- **"basic" PI**, expressed in losses/service connection/day or losses/km mains/day. If a system has more than 20 service connections per kilometre, the best "basic" PI is litres/service connection/day; if less than 20 connections per kilometre, m^3/km mains /day should be used. This PI does not allow for the actual density of connections, average length of private un-metered supply pipe or average system pressure;
- **"intermediate" PI**, expressed in litres/service connection/day/metre of pressure. This PI takes the average system pressure into consideration but does not allow for the actual density of connections and average length of private un-metered supply pipe; and
- **"detailed" PI** for smaller zones with greater variability in key parameters, the Infrastructure Leakage Index (ILI) will be used. The ILI is the ratio of the Current Annual Real Losses to the Unavoidable Annual Real Losses. Full details of the ILI calculation are provided in the original paper by Lambert (1999) and in

Appendix A.

In addition to the above performance indicators, the following more commonly used leakage rates can also be used.

- litres/hour/property or connection;
- cubic metres per hour per length of mains; or
- cubic metres per hour per kilometre of distribution system.

A typical example of the output from the BENCHLEAK model is provided in Appendix D for reference purposes. This model is considered one of the key tools for assessing the levels of leakage and wastage in any water distribution system and can be used to audit a whole utility or even a smaller portion of the full system. Where possible, the model should not be used for areas with less than 2 000 connections, otherwise the results may become unstable.

3 IMPORTANT CONSIDERATIONS

3.1 LEGISLATION

Legislation is used in many African countries to encourage and to some extent enforce more efficient use of water. In the case of South Africa, certain legislation was recently promulgated which will change the way in which water suppliers deal with their systems. While this legislation may not be applicable in other African countries, it may provide useful reference to other water regulators wishing to develop a culture of reducing wastage and leakage from their water supply systems. Details of the South African legislation are provided below for reference purposes.

Regulations under the South African Water Services Act, 1997

(Act 108 of 1997)

Water and Effluent Balance Analysis and Determination of Water Losses (11.1)

Within 2 years of the promulgation of these Regulations, a water services institution must every month:

- Measure the quantity of water provided to each supply zone within its supply area;
- Determine the quantity of unaccounted-for-water by comparing the measured quantity of water provided to each supply zone with the total measured quantity of water provided to all user connections within that supply zone;
- Measure the quantity of effluent received at each sewerage treatment plant; and
- Determine the quantity of water supplied, but not discharged, to sewage treatment plants by comparing the measured quantity of effluent received at all sewage treatment plants with the total measured quantity of water provided to all user connections.

Water and Effluent Balance Analysis and Determination of Water Losses (11.2)

A water services institution must:

- Take steps to reduce the quantity of unaccounted for water; and

- Keep record of the quantities of water measured and the calculations made.

In Windhoek, the capital of Namibia, "Water Supply Regulations" have been promulgated as far back as in December 1996, which comprehensively deals with WDM in all its details. (Municipality of Windhoek – Water Supply Regulations – Promulgated by Gen/Notice No. 367/1996 and Official Gazette 1463 of 16/12/96).

3.2 MANAGEMENT INFORMATION SYSTEMS

Accurate data on the system are required to make informed decisions and reduce non-revenue water. Various management information systems are currently available which can be interlinked and updated on a continuous basis. When selecting an appropriate management system the following factors should be taken into consideration:

- Availability and form of existing data required to support the applications;
- Update and maintenance procedures;
- Size of the database;
- Hardware platform/configuration;
- Number and sophistication of users;
- Organisational structure of the users and facility;
- Schedule;
- Budget; and
- Management support.

Various approaches can be followed in the set-up and development of a management information system. The three most commonly used approaches are as follows:

- Set-up complete management information system – high risk and high cost;
- Start with a pilot project – medium risk and lower cost;
- Outsource – low risk and low cost. No capital outlay required, time to market, low risk, flexible. Customised to individual needs, flexible, allows organisation to focus on core competencies, no staffing issues.

The various management information systems include, but are not limited to, the following:

Geographic Information System (GIS): a system that provides the link between the spatial layout of networks and the attribute data associated with the networks. It provides functionalities such as input, manipulation of data, management, query, analysis and visualisation;

Computer Aided Design (CAD) System: a system that provides electronic drafting and spatial layout of networks. It cannot be used for data manipulation, query and analysis, but is compatible with most GIS and network analysis software;

Network Analysis: a software program for the analysis and optimal design of a water distribution system. Typical packages perform steady state analysis, time simulation, water quality analysis, network and cost optimisation and reservoir and pump sizing;

Asset Inventory: a separate data information system for meters, valves, control valves, hydrants, air release valves, scour valves. Includes typical information on the position, make, type, size and date of installation, last date serviced/tested, supplier/service agent, spares inventory, etc.;

Automated Mapping and Facility Management (AM/FM): it is a specialised field of GIS that provides operational data against which future situations and results can be assessed. Typical use is to identify which valves must be closed to repair a burst pipe. This information can then be included with the job order;

Consumer Database: a system that contains information on all the consumers and usually includes a customer service centre. Typical information includes street address and number, position of the connection and meter relative to the property boundary, type and size of the connection, make, type, size and number of the meter, date installed, consumer's consumption, billing and complaints history;

Water Balance/Audit: a system that compares the volume of water entering system with the volume of water registered by the consumer meters. The purpose is to improve efficiency, management, cost recovery, etc. The quality of the water balance/audit is dependant on the consumer database and monitoring results;

Leak Detection and Monitoring Software: this includes all the software to undertake logging, correlations, acoustic logging, night flow analysis, pressure management, portable and electronic flow meters, bulk-meter reading/monitoring.

The interaction and links between the various elements of detailed Management Information Systems for managing a water supply area are shown in **Figure 3.1**.

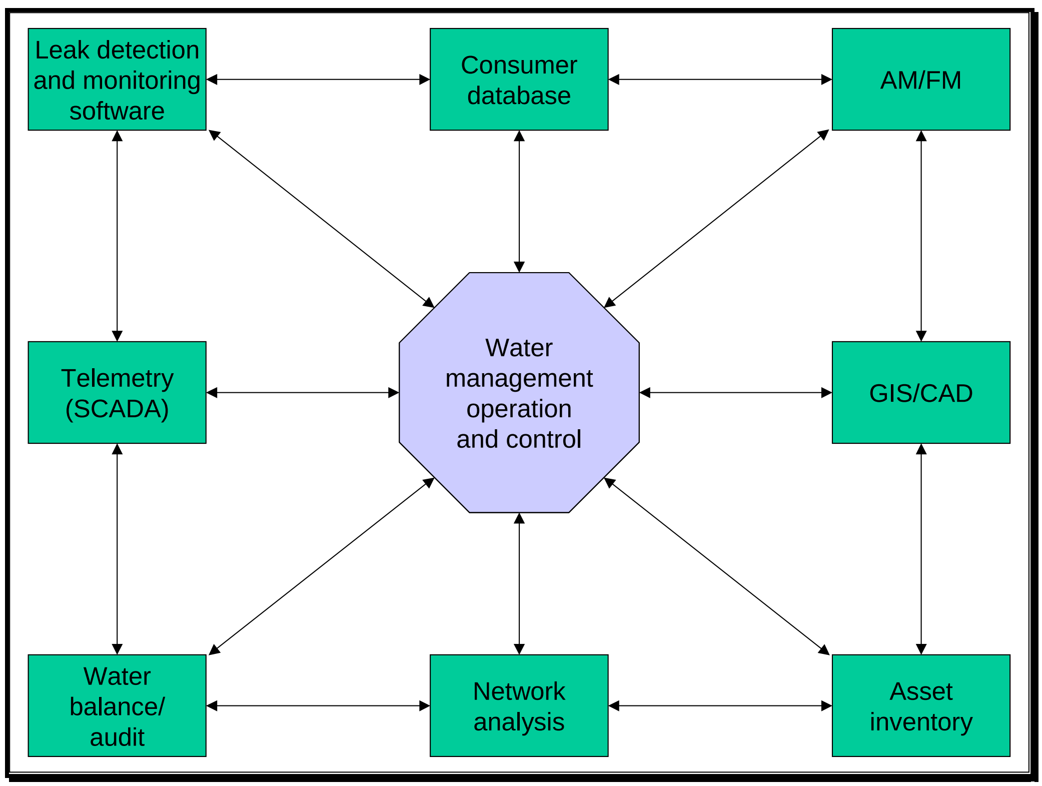


Figure 3.1: Interaction Between Components of a Detailed MIS (courtesy H Buckle)

3.3 TELEMETRY

Telemetry involves linking certain infrastructure components to a SCADA (Supervisory Control and Data Acquisition) system using some form of communication link. The communication can be via radio, public switched telephone network (PSTN), global system for mobile communication (GSM) or satellite communications, although new systems are continually being introduced.

Telemetry can be used for a variety of purposes and is particularly useful in situations where it is not possible or practical to have continuous monitoring by personnel from the water utility. Some typical applications include:

- Reservoir monitoring and level control from pump station or control valve;
- Pump station monitoring and control;
- Remote metering of bulk supply meters;
- Remote monitoring of pressures and flows at key points in the water supply network;
- Remote monitoring of sewer flows, etc.

There are many benefits to be gained from a properly installed and maintained telemetry system which include:

- Ability to set-up and/or alter control of equipment from a remote location;
- Ability to set alarm levels which will alert the water supplier if some water level, flow or pressure falls outside a pre-defined band;
- Ability to open or close valves according to the flow or pressure at some monitoring point;
- Ability to set adjustable timers on specific equipment to open or close according to a pre-defined time pattern;
- Ability to automate the supply of water throughout the system.

While telemetry is extremely useful in a wide variety of applications, as well as available in several levels of sophistication, there are some problems associated with its use, particularly in African conditions. The following potential pitfalls should be noted when considering the use of telemetry in an African water supply system:

- The equipment is often expensive and requires continuous maintenance and support. In many cases, such equipment may be supplied and commissioned through some form of International Aid and the long-term sustainability of the equipment is not catered for after the international specialist has returned to his/her country of origin. If such equipment is to be used, the long-term maintenance and support must be included as part of the package;

- Telemetry equipment often requires some form of energy, such as solar panels and/or batteries, which may be of value to the local community. In some countries the theft or vandalism of such equipment may be a problem and in such cases the equipment is often rendered inoperative soon after commissioning;
- Telemetry equipment provides a "high-tech" solution to certain problems. Such equipment requires a certain level of expertise to utilise it on a day-to-day basis and it is often necessary to train local personnel for this purpose. Also the continuity of skills within the Water Supplier's team is often a problem.

3.4 ANALYSIS OF MINIMUM NIGHT FLOWS

3.4.1 General

The measurement of the Minimum Night Flow in a water supply area can be compared to a medical doctor taking a patient's heart-rate in that it provides a valuable indication of the health of the area. The measurement of the Minimum Night Flow is one of the most important actions (if not the most important) that can be taken to identify leakage problems in an area. It is also one of the actions which most water suppliers do not consider as a high priority in the management of their systems.

The Minimum Night Flow is the lowest flow entering a water supply area during a 24-hour period, assuming that the availability of water during the period is sufficient to meet the demands. In cases where there is an intermittent supply, the Minimum Night Flow can only be assessed during the period of continuous supply and when all roof-tanks etc. have been filled. In cases of intermittent supply, the benefit of measuring the Minimum Night Flow will be lowered.

The Minimum Night Flow in most water supply systems around the world usually occurs sometime between midnight and 04:00 when the consumption in the network is at its lowest. **Figure 3.2** provides a typical plot of the flow entering a zone-metered area.

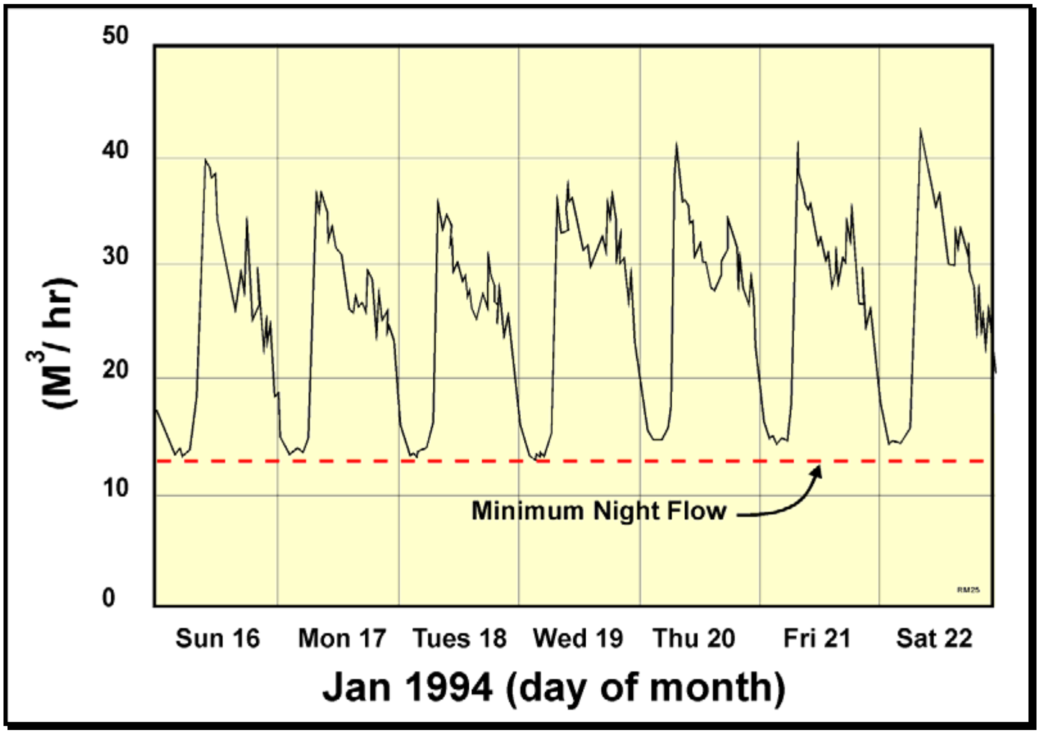


Figure 3.2: Example of Flow Entering a Zone Metered Area

Having logged a zone meter (installing an electronic apparatus on the water meter to measure, at preset intervals, the water flow through the meter) in order to establish the Minimum Night Flow, it is then necessary to try to estimate how much of the night flow is due to burst pipes. In order to achieve this, a very simple and pragmatic approach based on the component based leakage analysis procedures was developed. In this approach, the Minimum Night Flow can be considered to consist of three main components namely:

- Normal legitimate night use;
- Background losses;
- Burst pipes (both reported and unreported).

This breakdown is shown in **Figure 3.3**, from which it can be seen that the normal use and background losses have been further divided into smaller components.

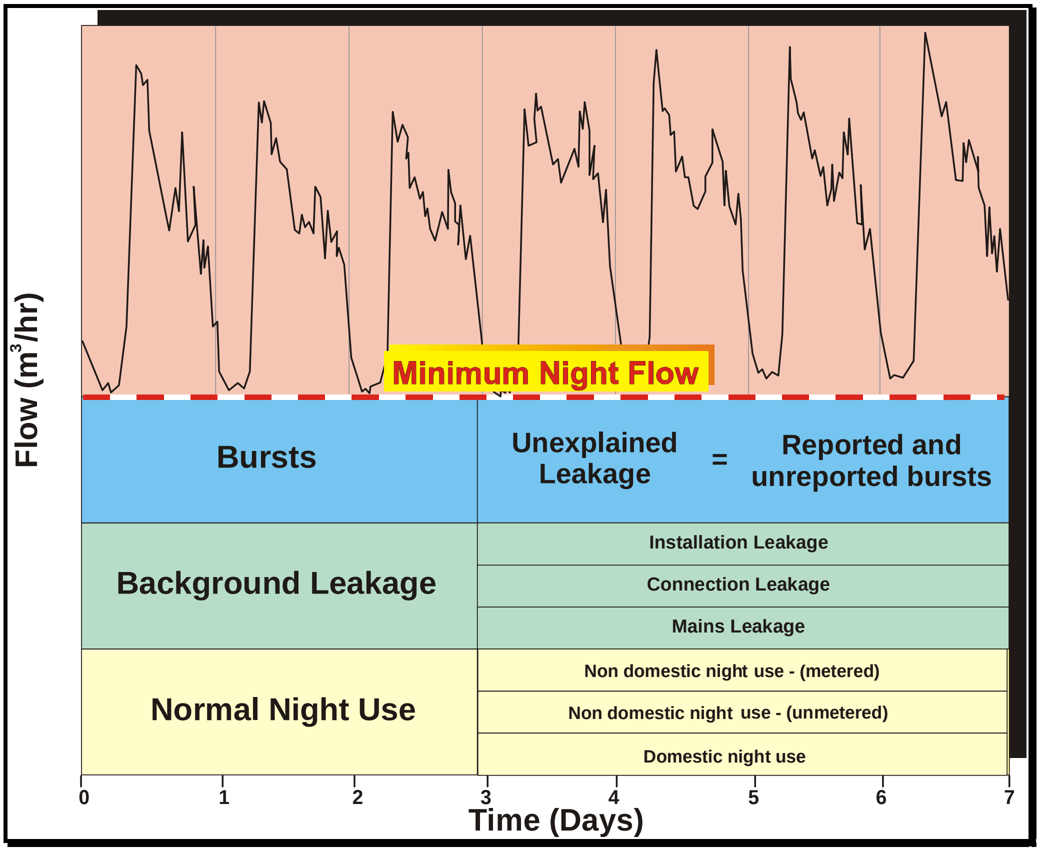


Figure 3.3: Components of Minimum Night Flow

3.4.2 Normal Night Use

In order to evaluate the magnitude of leakage from a zone (background and bursts) it is first necessary to quantify the level of genuine water use. As discussed previously the purpose of background night flow monitoring is to measure the minimum flow entering a zone, at which time the genuine water use will be at its lowest and the leakage losses at their highest (due to the higher than average pressure). The genuine water use cannot be measured accurately since it includes a large number of small users. It can, however, be estimated using guidelines derived from many surveys undertaken in various parts of the world.

The assessed night use can be split into three components namely:

- Normal domestic night use;
- Small non-domestic night use;

- Larger users (recorded individually).

Normal Domestic Night Use

Normal domestic night use represents the water used during the night in a household and is predominantly due to toilet use. The use of water for making coffee or tea represents a very small portion of the overall household use and is effectively ignored. In some areas of South Africa, garden watering or the filling of swimming pools may be of importance. In most cases, however, such water use is minimal between midnight and 04:00 when the night-flow monitoring is undertaken.

Experience in various parts of the world has shown that approximately 6% of the population is active during each hour (active is regarded as flushing the toilet) and that the average water use is in the order of 10 litres/flush. The average water use is based on a standard 10 litre toilet cistern and may vary from one country or region to another. In many African areas the water is supplied intermittently, or sometimes from communal stand pipes. In such cases the average use, based on a 10 litre toilet cistern, is inappropriate and a more appropriate value in such cases may be zero. The water supply manager in each specific area, in which he/she is knowledgeable, must assess each area individually and select an appropriate water use based on the level of service for the area.

The normal household night use can usually be estimated within reasonable limits from the product of the active population (i.e. 6% of the population per hour) and the average use per hour (e.g. 10 litres/flush).

Small Non-Domestic Night-Use

The small non-domestic night-use is more difficult to evaluate and depends largely on the type of businesses being run in the zone-metered area. Although each small non-domestic user is metered individually, it is impractical to record each of the meters during the night-flow exercise. Instead, the users are grouped into various categories and a typical night-use is assumed for the group. As an example, there may be several all-night garages, or all-night cafes, where the unit use is relatively small although, when added together, the total use may be significant.

A range of typical night use values for various different commercial enterprises has been produced **(WRC, Report E**) based on extensive studies undertaken overseas. All properties using more than 500 litres/hour are excluded from this section of the analysis since they are considered separately and the meters at each large user are monitored separately. Details of the suggested values are provided in **Table 3.1.**

Table 3.1 Average Values of Night Flow Delivered to Different Types of Non-household, Grouped by Similar Average Use (from WRC, Report E)

Group	Sample size	Number active	Average per active property (l/prop.h)	Average for all properties (l/prop.h)
A. Unmanned fire/police stations, telephone exchanges, banks, church/chapels, gardens and water/sewage treatment works.	123	16	7.0	0.9
B. Shops, offices, craft centres, laundrettes, depots, large domestic property, guest-houses, garage / filling stations, touring caravan sites, farms, smallholdings and cattle troughs.	2013	606	20.5	6.2
C. Hotels, schools/colleges, cafes/restaurants, public houses, social halls, residential caravan sites, livery stables.	505	244	26.0	12.6
D. Hospitals, factories (food and manufacturers), public toilets, works sites.	205	79	53.0	20.5
E. Old people's homes, small mines and quarries. An alternative for nursing homes and hospitals is 2.5 l/resident/h.	33	25	80.0	60.6

The figures provided in **Table 3.1** are taken from European case studies and are not considered appropriate for use in many African countries. They are included simply to provide an order of magnitude of water use that can be expected under certain circumstances. Any water supplier in Africa wishing to analyse their Minimum Night Flow should try to derive realistic estimates for the users in his/her area of supply. This can be achieved by monitoring the consumer meters at a few of the small users and then extrapolating the results to all of the small users.

Large Non-Domestic Users

In some zone-metered areas, it is often found that there may be one or more large water consumer whose consumption can influence the night flow analysis. In such cases, it is necessary to meter the consumer individually to determine how much water has been used during the night-flow exercise. Consumers falling into this category would include airports, large hotels, breweries, public swimming pools, etc.

3.4.3 Background Leakage

Background leakage is the cumulative leakage from all relatively small leaks that are individually less than 250 litres/hour at 50 m of pressure. Such leaks occur from valves, joints, hydrants, stop-taps, meters, dripping taps, toilet cisterns, roof tanks, etc. Individually such leaks are generally uneconomic to find and repair, with the result that background leakage is generally accepted as a fact-of-life (within certain limits).

Background leakage can be split into three main components namely:

- Background leakage from mains;
- Background leakage from connections;
- Background leakage from private properties.

Background Leakage from Mains

There will always be some background leakage from any distribution system, some of which occurs from the water mains. Small leaks often occur at the pipe joints or from small cracks or holes in the pipes and the magnitude of the leakage is dependent upon the condition of the infrastructure and the operating pressure.

For the purpose of the background night flows model; all process parameters are given at the standard operating pressure of 50 m, with the result that the background leakage from mains varies only with the condition of the infrastructure. Suggested values from the **WRC Report E** indicate an average value of 40 l/km of water mains per hour with a range of ± 50 % (i.e. 20 l/km/h to 60 l/km/h). Surprisingly, it has been found that the level of water mains leakage tends to be similar in most parts of the world and most European systems will have similar levels of water mains leakage as many African systems.

Background Leakage from Connections

Poor workmanship, coupled with general wear and tear, often results in leaks from pipe connections. In general, there will be one pipe connection to each property and the background leakage from connections is therefore expressed as an average loss per connection, where the number of connections is usually estimated directly from the number of properties. Connection leakage is considered either as the leakage occurring from the connection at the water main to the water meter at the property, or, in cases where no water meters exist to the property boundary. In most water distribution systems, the connection losses are often the major source of loss from the system.

Suggested values of background leakage from connections are provided in the **WRC Report E** as 3 litres per property per hour with a range of ± 50 % (i.e. 1.5 l/prop/h to 4.5 l/prop/h) depending on the condition of the infrastructure.

Background Leakage from Installations

The installation refers to all pipe-work, plumbing, fittings and fixtures both inside and outside the building located on the consumer side of the billing water meter. It does not include leakage from the meter since the meter generally remains the property of the water supply utility.

A certain portion of background leakage occurs on the individual properties from either the pipe entering the dwelling from the water meter or from the various plumbing fittings inside the building. In most cases, such leakage will be lower than that occurring from the water mains connection (as discussed in the previous section). In Africa, however, there are occasions where the leakage from the installations is dominant and represents the largest component of leakage.

Unless information that is more reliable is available to suggest higher (or lower) leakage rates, the value recommended in the **WRC Report E** (Table 4.1) is 1.0 litres per property per hour with a range of ± 50 % (i.e. 0.5 l/prop/h to 1.5 l/prop/h), depending on the condition of the infrastructure. The leakage is usually assumed to be equally divided between the pipe from the meter to the building and the internal plumbing fittings.

3.4.4 Burst Leakage

Having measured or estimated the various components of normal night use and background night use, the two figures are added together and then subtracted from the measured minimum night flow. The difference is the sum of the known burst leakage and any unexplained losses that are attributable to either unreported bursts or to errors in the assumptions made during the calculation.

Example Calculation

To demonstrate the use of the Component Based Leakage Management procedures in helping to establish the level of leakage in a particular zone metered area, it is easier to make use of a simple example. In the first example, a case will be used where the average zone night pressure is at 50 m, which is the base pressure where no pressure correction factors are required. The base data for the example are provided in **Table 3.2.**

Table 3.2: Base Data for Night Flow Example 1

Description	Value
Length of mains	9 300 m
Number of connections	600
Number of properties	672
Estimated population	3 000
Average Zone Night Pressure (AZNP)	50 m
Measured Minimum Night Flow (MNF)	14.4 m^3/h

Before the night flow can be analysed, it is necessary to decide on the values of the various loss parameters to be used in the analysis. Normally default values are adopted unless the person undertaking the analysis, based on previous experience, has some indication of alternative values. Items that can be taken into consideration when determining the loss parameters will include: pipe material, age, ground conditions, quality of workmanship, etc. For this example, the values given in **Table 3.3** were selected.

Table 3.3: Default Loss Parameters for Night Flow Example 1

Description	Value
Background losses from water mains	40 l/km/h
Background losses from connections	3 l/connection/h
Background losses from private properties	1 l/connection /h
% of population active during night flow exercise	6%
Quantity of water used in toilet cistern	10 l
Number of small non-domestic users	30
Average use for small non-domestic users	50 l/h
Use by large non-domestic users	1.2 m^3/h
Background losses pressure exponent	1.5
Burst/leaks pressure exponent	0.5

Having established the default loss parameters it is now possible to estimate both the normal night use and the background leakage. The respective calculations are provided in **Table 3.4** and **Table 3.5.**

Table 3.4: Estimation of Normal Night Use for Night Flow Example 1

Description	Calculation	Value
Domestic night use	3 000 @ 6%/h @ 10 l	1.8 m^3/h
Small non-domestic use	30 @ 50 l/h	1.5 m^3/h
Large non-domestic use	1 @1.2 m^3/h	1.2 m^3/h
Total normal night use		**4.5 m^3/h**

Table 3.5: Estimation of Background Leakage for Night Flow Example 1

Description	Calculation	Value
Mains losses	9.3 km @ 40 l/km/h	0.37 m^3/h
Connection losses	600 @ 3 l/connection/h	1.80 m^3/h
Property losses	672 @ 1 l/property/h	0.67 m^3/h
Total background leakage at 50 m pressure		**2.84 m^3/h**
Pressure correction factor	$(50/50)^{1.5}$	1.00
Total background leakage at 50 m pressure		**2.84 m^3/h**

It should be noted that a pressure correction factor is indicated in the above table. In the case of this example, the operating pressure is known to be 50 m, which is considered the standard pressure. At standard pressure, no pressure corrections are required and it can be seen that the pressure correction factor is calculated to be 1.0 (i.e. no change). The influence of- pressure on the burst and background leakage was discussed in **Section 2.10** and is not discussed further in this section.

Now that the two water use components have been estimated, it is possible to calculate the difference between the measured minimum night flow and the estimated legitimate use – note that background losses are considered to be legitimate since they cannot be eliminated completely from any system. **Table 3.6** provides the calculation that identifies the level of unexplained leakage in the given zone metered area.

Table 3.6: Estimated Unaccounted-for Leakage at 50 m Pressure

Description	**Value**
Expected background leakage	2.84 m^3/h
Expected normal night use	4.50 m^3/h
Total expected night use	**7.34 m^3/h**
Measured minimum night flow	14.40 m^3/h
Unaccounted-for-leakage (14.40 – 7.34)	**7.06 m^3/h**

As can be seen from the table, it is estimated that in this example the sum of the known burst leakage and the unexplained leakage is in the order of 7 m^3/h.

As mentioned previously in **Section 2.10**, one of the most important factors influencing leakage is pressure. In general, it is recommended that a power exponent of 0.5 should be used for all burst flows since a burst pipe is usually a fixed area discharge. In the case of the background losses, however, the leaks are likely to be variable area discharges, in which case a larger power exponent should be used. A power exponent of 1.5 is usually used for the background losses, which is considered to represent a collection of leaks that have factors of between 0.5 and 2.5. If all of the pipe work is known to be plastic, a higher value may be appropriate and conversely, if the pipes are made from cast-iron, a lower value (e.g. 1.0) should be used. The impact of the pressure correction factors can be seen by repeating the example calculation given above with an average system pressure of 63 m in place of the 50 m used previously.

In this case, the basic system data (see **Table 3.2**) and default parameters (see **Table 3.3**) remain unchanged, with the exception of the system pressure, which has been increased to 63 m.

The normal night use remains the same as before, since it is assumed independent of pressure and therefore no pressure correction factor is applied to the normal night use (see **Table 3.4**). The background leakage is, however, dependant on pressure and in this case, a pressure correction factor must be used, as shown in **Table 3.7**.

Table 3.7: Estimated Background Leakage at 63 m Pressure

Description	Calculation	Value
Mains losses	9.3 km @ 40 l/km/h	0.37 m^3/h
Connection losses	600 @ 3 l/connection/h	1.80 m^3/h
Property losses	672 @ 1 l/property/h	0.67 m^3/h
Total background leakage at 50 m pressure		**2.84 m^3/h**
Pressure correction factor	$(63/50)^{1.5}$	1.41
Total background leakage at 50 m pressure		**4.02 m^3/h**

It should be noted that a pressure correction factor is now required in order to estimate the background losses since the loss parameters are always specified at the standard pressure of 50 m. In the case of the example, the average zone night pressure is now at 63 m with the result that a pressure correction is required to increase the estimated losses. The calculation of the unexplained leakage is given in **Table 3.8**.

Table 3.8: Estimated Unaccounted-for Leakage at 63 m Pressure.

Description	Value
Expected background leakage	4.02 m^3/h
Expected normal night use	4.50 m^3/h
Total expected night use	**8.52 m^3/h**

Measured minimum night flow	14.40 m^3/h
Unaccounted –for leakage (14.40 – 8.52)	**5.88 m^3/h**

As can be seen from the table, it is now estimated that the reported bursts and unexplained leakage is in the order of 5.9 m^3/h compared to 7.06 m^3/h in the previous example at 50 m of pressure. This demonstrates the influence of pressure in the calculation of the unexplained leakage from the recorded Minimum Night Flow.

3.4.5 Estimation of Pressure Exponent (N1) from the MNF

The Minimum Night Flow can often be used to estimate the sensitivity of leakage in an area to changes in pressure. As mentioned in **Section 2.10**, the leakage in some areas is very sensitive to pressure while in other areas the leakage is relatively insensitive to changes in pressure. In order to assess the sensitivity of leakage in an area, to changes in pressure, it is necessary to monitor the Minimum Night Flow while changing the pressure during the period of Minimum Night Flow – typically between midnight and approximately 04:00. In such cases the pressure exponent calculated from the analysis is a lumped parameter representing the variation of leakage to pressure, for the system as a whole, where burst and background leakage is considered together. From various tests undertaken around the world, it appears that the average N1 value for a system is in the order of 1.15 and for the purpose of a pressure management analysis, it is generally appropriate to adopt a conservative value of 1.0 unless information is available to calculate the true value from recorded data.

In some cases it is possible to establish the true N1 value for a system through a series of pressure “step-tests” which should, preferably, be carried out during the period of minimum night flows. To carry out the tests, the user drops the pressure by 10 or 20 m and allows the system to settle down to the lower pressure. The minimum night flow is continually monitored, as are the pressures at the inlet, to the zone, average zone point and critical point. From the information recorded, it is possible to establish the N1 value several times, from which an average value can then be selected.

Undertaking a pressure step test can be problematic in some areas since it requires personnel from the water utility to spend several hours at the site of the pressure reducing valve. In many parts of South Africa, working in a manhole between midnight and 4 am can be dangerous and in such cases an alternative procedure is recommended.

The recommended approach involves using a time-modulated controller to drop the pressure at night while logging the pressure at the average zone point and inlet point together with the flow entering the zone. This procedure should be undertaken over 2 or 3 consecutive nights and the pressure lowered by an additional 5 to 10 m each evening. In this manner, it is possible to get similar results to the pressure step-test without having to have personnel on site during the exercise. While this may not be an ideal approach, it does provide realistic results in cases where the zone is relatively stable i.e., the minimum night flow shows little variation when logged over a 7 to 10 day period.

Again, this approach is best explained using a practical example. In this example, a zone was logged continually over a period of several weeks as part of a pressure management initiative. The initial logging was undertaken to establish the base conditions as part of the auditing procedure in order to establish the true benefits from the pressure management initiatives when eventually implemented. During the pre-commissioning phase of the project, no form of advanced pressure control was implemented and the pressure-reducing valve was not adjusted in any way during the period under consideration.

The results from the logging are shown in **Figure 3.4** and it can be seen that they are not consistent with a normal stable pressure-reducing valve installation. While this set of logging results was not intended for use in establishing the N1 value for the zone, it was found that due to failure of the valve mechanism the results are in fact ideal for this purpose.

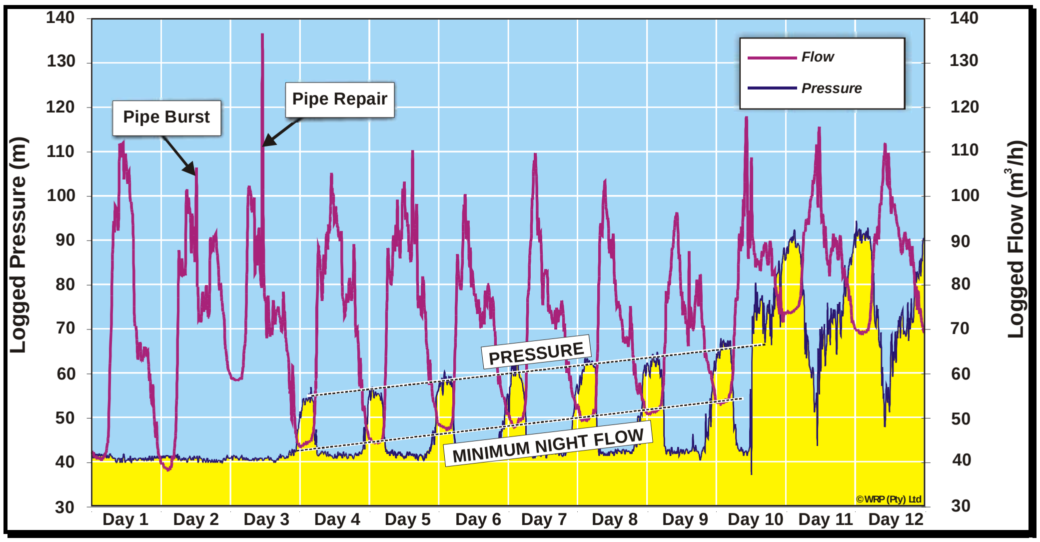


Figure 3.4: Logging Results from Test Data used to Calculate N1 Value

Before proceeding to calculate the N1 value, it is useful to explain what happened during the period of record depicted in the figure.

- For the first two days, the pressure-reducing valve is stable and the minimum night flow is relatively consistent at approximately 40 m^3/hr.
- On day 2 at 12:00, a major burst occurs which is evident by the sudden increase in flow of approximately 20 m^3/hr, which also clearly shows up on the minimum night flow, which has also increased to 58 m^3/hr.
- The leak is repaired on day 3 at 12:00, as indicated by the sudden spike of flow caused by the opening of fire hydrants to either reduce the pressure while repairing the leak or to flush the system after the repair. It can be seen that the

minimum night flow returns to approximately 44 m^3/hr indicating that the leak has either not been repaired properly or another small leak has also occurred in the system.

- Following the repair of the leak, the pressure-reducing valve starts to fail during the high pressure and low flow period that occurs during the night – at the same time as the minimum night flow occurs. This is evident from the sudden rise in pressure from midnight on day 3 until approximately 06:00 on day 3 and similarly for each day thereafter. It can also be seen that the maximum pressure occurring each night is gradually increasing from day 4 until day 10, when the valve finally fails completely and the full system pressure is experienced in the zone.
- Because of the increasing pressure at night, the minimum night flow also increases since a significant portion of the night flow is due to pressure dependent leakage. As the pressure increases, so too does the pressure dependent leakage.

This is an extremely interesting example for a number of reasons. Firstly, it highlights the value of continuous logging in a zone-metered area. If the logging results had been available on a real-time system, the problem would have been picked up and corrected before the valve failed completely. The failure of the valve in the zone resulted in several new leaks forming and caused considerable inconvenience to consumers, not to mention significant loss of water. The example also clearly shows the relationship between pressure and flow. This can be used to estimate the N1 value for the zone in the same way that a normal pressure step-test would be used. The basic data used to estimate the normal night-use is shown in **Table 3.9** while the flow and pressure data used to calculate N1 are shown in **Table 3.10**.

Table 3.9: Calculation of Expected Normal Night Use

Description	Value	Units
Population in zone	6 525	No.
Percentage of population active during MNF	3	%
Average water use per toilet flush	10	Litres per flush
Sum of water use by exceptional users	0	Litres/hr

Expected Normal Night Use (6 525 * 0.03 * 10)	**1 957**	**Litres/hr**

From the information provided in **Table 3.9** and **Table 3.10** it is possible to estimate the N1 value by simply selecting between 2 and 4 pairs of pressures and flows and inserting them into the appropriate cells in the Hour Day Factor (HDF) model. It should be noted that this section of the HDF model is optional and need not be used. It is however, useful in cases where the water supplier has the necessary data and would like to estimate the sensitivity of the zone to changes in pressure.

A high N1 value (between 1.0 and 2.5) indicates a zone in which the leakage is sensitive to changes in pressure, while a low N1 value (0.5 to 1.0) indicates a zone in which the leakage is relatively insensitive to changes in pressure.

Table 3.10: MNF and Pressure Data used to Estimate N1 Value

Day	Minimum Night Flow (m^3/ hr)	Pressure at AZP at Minimum Night Flow
Day 4	43.4	54.0
Day 5	45.5	56.0
Day 6	46.5	58.0
Day 7	48.2	60.0
Day 8	49.8	61.5
Day 9	51.5	64.0
Day 10	53.5	66.0

Population :	6525	number	Normal Night Use :	1.96	m^3/hr
% Active during MNF :	3.0	%	Exceptional Users :	0.00	m^3/hr
Cistern Capacity :	10.0	litres	Expected Night Use :	1.96	m^3/hr

Stage	Start Time (hr:m)	End Time (hr:m)	Measured Night Pressures		Zone Inflow (m^3/hr)	Night Consumption (m^3/hr)	Distrubution Losses (m^3/hr)	Calculated Values of N1			
			Inlet Point (m)	AZP (m)				Stage 1	Stage 2	Stage 3	Average
Start				54.0	43.4	1.96	41.44				
Stage 1				58.0	46.5	1.96	44.54	1.0			1.0
Stage 2				61.5	49.8	1.96	47.84	1.1	1.2		1.1
Stage 3				66.0	53.5	1.96	51.54	1.1	1.1	1.1	1.1
										Calculated N1 Value	1.1

Figure 3.5: Sample Calculation of N1 from the HDF Model

It can be seen from the calculation in **Figure 3.5** that an N1 value of approximately 1.1 is appropriate for this zone. This is a typical value for a normal system in which there are both plastic pipes and some steel or iron pipes.

3.5 LEAKAGE FROM BULK STORAGE STRUCTURES

3.5.1 Causes

Bulk storage structures (see **Figure 3.6 and 3.7**) are often the source of significant losses from a water supply system. In many cases, water is pumped into the reservoir or tank according to certain switching equipment such as a tilt-switch, level recorder or telemetry system. Invariably such equipment will malfunction at some or other time and since much of the filling of the reservoir/tank takes place at night, the water supply engineer may not be aware that the reservoir is overflowing. Such losses can be significant and can often run unchecked for many months if not years.

Another source of leakage from a reservoir or tank can be due to a physical leak caused by a crack or poor seal in the structure itself. Such leaks are even more difficult to detect since the water is seeping from the structure and can run unnoticed for many years.

Figure 3.7: Typical Bulk Storage Reservoir (24 Ml)

Figure 3.8: Overflow from a Bulk Storage Reservoir

3.5.2 Quantifying Leakage from a Reservoir

Most bulk storage structures are designed with an under-floor drainage system to prevent hydrostatic pressure built-up underneath the structure and to determine if the floor is leaking. The first step in checking reservoir leakage would be to undertake a physical examination of the outside of the structure as well as to complete a detailed inspection of the inside when an annual cleaning is scheduled. Thereafter one also needs to inspect all manholes to ascertain if leakage is evident, such as the under floor drainage manhole. The volume of water leaking from the structure can be measured by undertaking a “drop test” analysis. This analysis is shown in **Figure 3.7** and is relatively simple and straightforward to complete, requiring little or no specialised equipment.

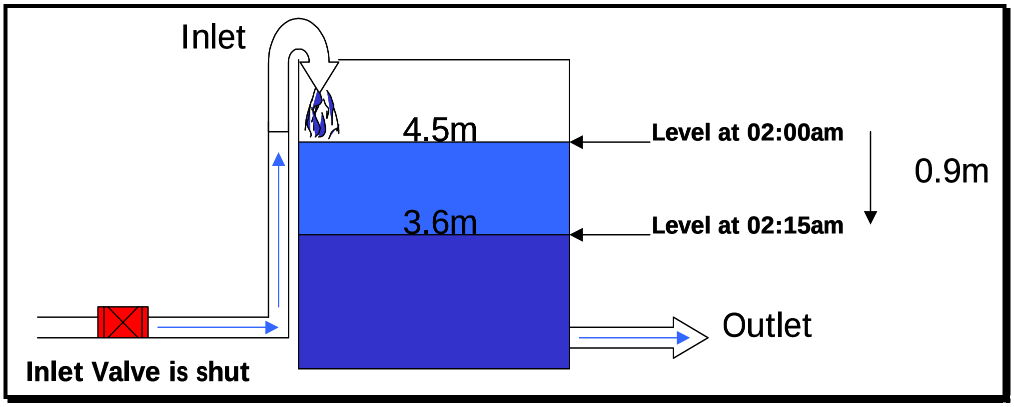


Figure 3.7: Drop Test Analysis

The Drop-Test analysis can be performed in a number of ways including:

- Measuring the time to fill a controlled volume;
- Measuring the drop in surface water level over a specific period, with both the inlet and outlet from the reservoir isolated. This should preferably be undertaken after midnight to cause minimal disruption to consumers;
- Measuring both the inlet to and outlet from the reservoir over a specific period. The difference between the two measurements indicates the leakage from the structure. The water surface level should be the same at the beginning and end of the test to account for storage volumes.

If it is found that a reservoir is leaking, it is necessary to take action to repair the fault. Such action may include:

- Repair of faulty inlet control valve. There are various types of reservoir control mechanisms including level control, altitude control, pressure transducers or solenoid control with on/off or modulating control. Your local control valve supplier should be able to assist;
- Repair of the concrete surface using paint coats, impregnation solutions, sealers and coatings. Cement mortar, concrete, pre-formulated commercial repair systems or resin systems should be considered for the replacement of substantial depth loss. In extreme situations, an internal lining can also be considered;
- Repair of cracks and joints using resin injection (inactive cracks) or bandaging

(active cracks).

Reservoir repair is a specialised field and repairs should only be undertaken by experts.

3.6 ADDRESSING LEAKAGE FROM THE RETICULATION NETWORK

3.6.1 General

It has already been explained that leakage from the reticulation network occurs through either bursts or background leakage. Each type of leakage must be addressed and treated separately. Before the leakage is treated, it must be analysed and quantified to assess the magnitude of the problem, after which the resources appropriate to address the problem can be determined. The leakage can be quantified using either the overall Water Balance Approach (Top Down Method) as discussed in **Section 2.12** or through the analysis of the Minimum Night Flows (Bottom Up Approach) as discussed in **Section 3.4.**

3.6.2 Corrective Measures

The different types of leakage require different approaches to address and reduce the water being lost. In the case of Background Leakage the following measures can be considered:

- **Pressure Management** – this is one of the most effective measures for reducing background leakage since such leakage tends to be very sensitive to pressure (i.e. the pressure exponent is usually around 1.5 – see **Section 2.10**). A well-implemented pressure management installation can often reduce the background leakage in the zone by 50% or more.
- **Pipe Replacement** – this is normally a last resort when trying to reduce background leakage and tends to be one of the most expensive measures that can be considered. The replacement of pipes would normally only be considered if all other measures have failed to provide the savings required. In any well-maintained system, a pipe replacement policy, where at least 1% of the capital value of infrastructure in reticulation is replaced annually, is imperative. In most African cities visited by the authors, the pipe replacement levels were well below the 1% level and the systems were gradually falling into serious decay.

In the case of Burst Leakage, there are more options open to the water supplier and these include:

- **Pressure Management** – in this case the pressure management is used to reduce the maximum system pressure, which occurs at night. This measure can be very effective due to the sensitivity of the number of new burst pipes to the maximum pressure as discussed in **Section 2.10**. It should be noted that pressure management has less impact on the quantity of water lost through an existing burst since the pressure exponent for burst pipes is usually around 0.5 compared to 1.5 for the background leakage.

- **Pipe Replacement** – once the frequency of burst pipes in a particular section of pipe becomes excessive, it is often an indication that the pipe has reached the end of its useful life and needs to be replaced. Under such circumstances, pipe replacement is appropriate although expensive. The replacement of pipes is often prioritised according to the frequency of pipe bursts in a particular section of pipe. This highlights the importance of keeping accurate records of all pipe bursts in a system – preferably tied to an effective GIS or CAD system.

- **Leak Detection and Repair** – this measure is appropriate in many systems on a regular basis - normally every 2 to 4 years. It involves undertaking three sweeps of a system. The first sweep is a visual sweep to pick up all visible but unreported leaks. Having eliminated all visible and reported leaks, a sounding exercise is undertaken to identify sections of pipe which have one or more pipe bursts which do not show up on the surface. The third sweep involves using some form of Leak Pin-pointing equipment, normally a leak/noise correlator or noise loggers (see **Section 4.8**)
- **Step Testing and Sectorisation** – step testing is a useful approach for identifying areas in a system which are likely to have bursts. The technique does not identify the exact location of the leak but, based on the minimum night flow, will identify the zones which have a high probability of leaks. A pre-requisite for Step-Testing is proper sectorisation of the network into small and manageable sections. Without proper sectorisation, step-testing cannot be

implemented. More details on Step-Testing and Sectorisation are provided in **Sections 4.8.4 and 4.1**.

- **Corrosion Protection** – many leaks in metal pipes are caused by small pinholes, which are often caused by corrosion. Once a pipe has corroded to the state at which there are many corrosion leaks, there is little option except to replace the pipe. If the pipe is relatively new, however, the water supplier may consider taking preventative corrosion protection measures to avoid leaks, rather than taking action only after the leaks occur. This is particularly relevant when dealing with Bulk Mains and any specific sections of pipe, which are of strategic importance (e.g. a supply to a power station or hospital etc).

3.6.3 Leakage from Maintenance Measures

A certain amount of water is lost annually through various maintenance measures which are undertaken on the water distribution system by the water supplier itself. Typical maintenance measures would include:

- Mains flushing (see **Figure 3.8**);
- Air scouring;
- Swabbing;
- Scraping and relining;
- Commissioning and testing new pipes and Storage Structures;
- Cleaning of pipes and storage structures.

Figure 3.8: Mains Flushing to Remove Silt from Pipeline

The quantity of water lost through such maintenance procedures will vary from system to system. The following figures provide an indication of the volumes involved:

- **Mains Flushing** - 3.0 times the volume of section to be flushed;
- **Swabbing** - 2.5 times the volume of section to be swabbed;
- **Scouring** - 2.0 times the volume of section to be scoured;
- **Relining** - 4.0 times the volume of section to be relined;
- **Commissioning and Testing** - 3.0 times the volume of section to be commissioned;
- **Reservoir Cleaning** - 20% of the full volume of the reservoir.

In order to minimise the volume of water that is wasted during any of the pipe maintenance measures, the water supplier should try to isolate the pipe section to the smallest possible section of the network.

3.6.4 Common Maintenance Problems

Maintenance measures can often create new leaks in the process of addressing existing leakage problems. The creation of the new leaks can often be avoided through simple and straightforward measures undertaken by the repair teams. Some common problems experienced during maintenance procedures are discussed below:

Isolating Valves

Surges in pipelines are caused when valves are opened or closed too quickly. The last portion of valve closure often has a major effect on flow reduction, causing surges in the pipeline and subsequent bursts. The maintenance team should open all valves slowly and ensure that the final stage of closure is also undertaken slowly to avoid pressure surges.

Excessive force applied to a valve spindle (often using a metal rod etc to gain leverage) can damage the spindle or the handles (see **Figure 3.9**), with the result that the valve may leak or not seal properly. In such cases it is often necessary to isolate a larger section of the network causing higher losses during maintenance operations.

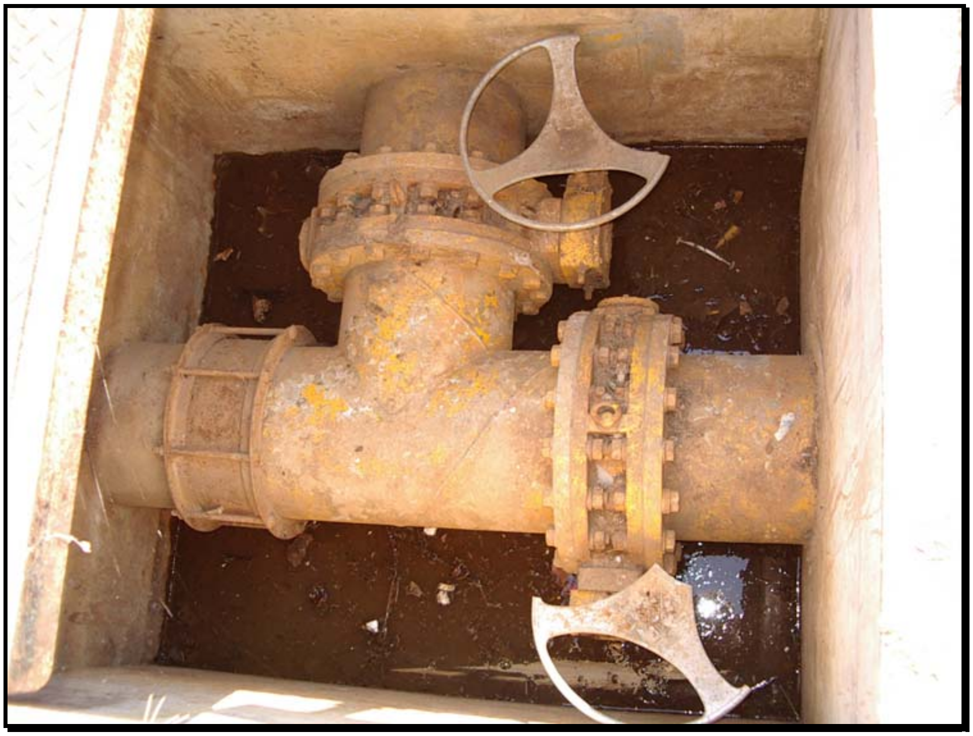


Figure 3.9: Leaking butterfly valves with broken spindle handles

(photo courtesy BIGEN Africa)

Maintenance teams should be careful that they do not exert excessive force on the valve spindle which should only be turned using manual force unaided by other mechanical devices. Problems often occur in systems where both right-hand and left-hand closing valves are used without proper identification. In such cases, the maintenance crews invariably damage valves by turning the spindle in the wrong direction when the valve is either fully open or fully closed. In such cases, the water utility should replace certain valves to ensure that all valves in the system close in the same manner.

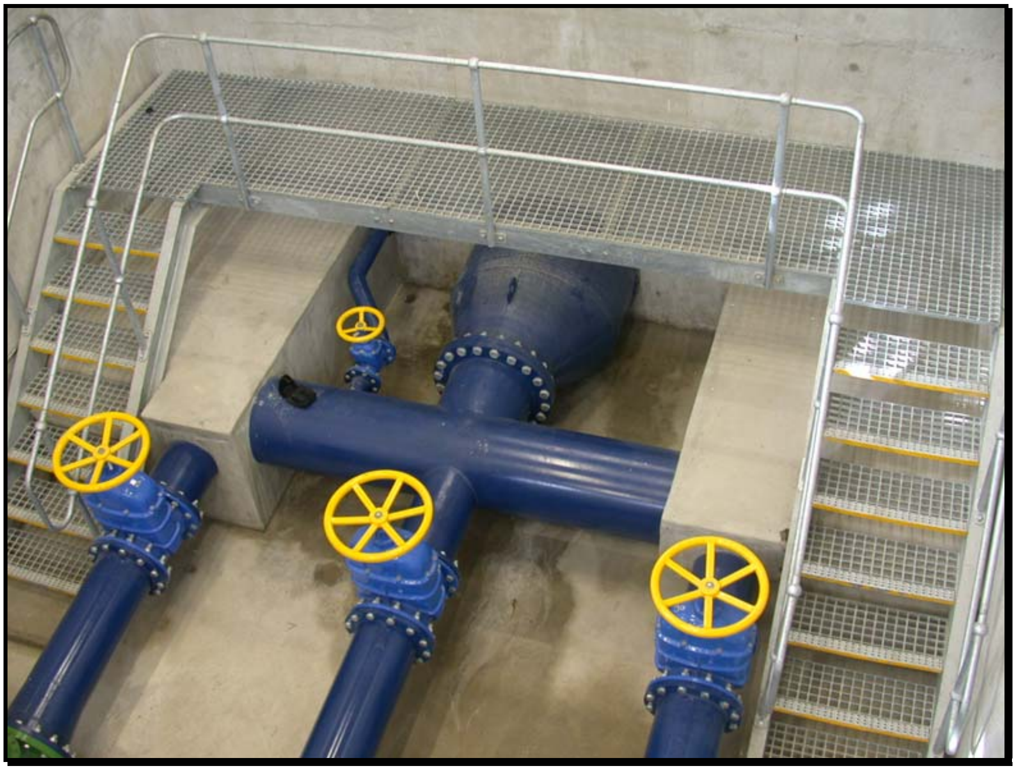


Figure 3.10: Typical Isolating Valves (four gate valves)

Control Valves

Control valves such as pressure reducing, pressure sustaining, pressure relief, flow control, level control, check and pump control valves require regular maintenance to ensure they are operating properly. Control valves play an integral part in the quality of the distribution system, and failure usually results in large water losses through pipe bursts and reservoir overflows. This failure also causes damage to various appliances, including pumps, household appliances and especially pressurised roof-tanks.

Control valves should not be used as isolating valves. If the cock-valve on the outlet of the control pipe-work on a control valve is closed, the control valve itself will close. Rapid opening of the outlet cock-valve creates surges and subsequent pipe bursts.

Control valve failure, resulting in rapid pressure rise, can often cause significant water losses as well as damage to the reticulation system. In view of the importance of control valves in a system, they should be maintained regularly, to ensure that they are operating properly and do not fail. Maintenance on control valves should be proactive and undertaken on a regular basis. They should not be used as isolating valves during maintenance procedures and only qualified staff should be permitted to undertake maintenance on them. A typical pressure reducing control valve (with orifice plate) is shown in **Figure 3.11**.

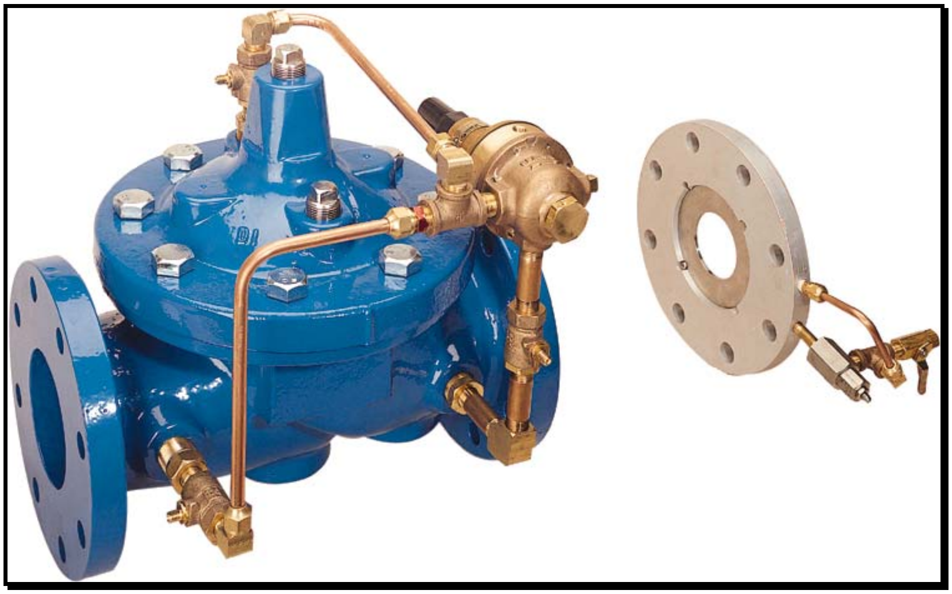


Figure 3.11: Control Valve (Courtesy Dynamic Fluid Control).

Meters

Turbine water meters are often damaged if the valve on the upstream side of the meter is closed suddenly, causing silt and waste particles to lift into suspension and eventually enter into the meter mechanism. Strainers are often installed upstream of the meter to protect the meter from large particles entering the pipeline but these must be cleaned regularly to prevent blockages or damage to the sieve. A typical water meter is shown in **Figure 3.12.**

Figure 3.12: Mechanical Water Meter **(Courtesy Invensys)**

Air Valves

Air valves are installed to prevent air entrapment in the system and to allow air to enter the system when the system is drained. If the air valves are blocked or inoperative, negative pressures can develop in the pipeline during maintenance operations. This can cause the pipeline to fail or surrounding groundwater, which is often toxic, to be sucked into the line and cause a health hazard. This is a serious issue particularly in cases where there is an intermittent supply. In such cases the water in the pipeline often contains harmful bacteria, which in turn can cause diseases such as cholera and typhoid. Air valves are often rendered inoperative due to vandalism and/or theft. Since they appear to have little influence on the water distribution system, they are often left in a broken or damaged state. Water suppliers should ensure that all air valves are maintained regularly and stay fully operational, otherwise serious problems can result. For this reason air valves should always be installed with an isolating valve for easy removal and repair, as shown in **Figure 3.13**.

Figure 3.13: Typical Air Valve (Silver/Red) on Top of Isolating Valve (Blue)

(Courtesy Pressure Management Services)

Scour Valves

Scour valves are required to drain the pipeline to undertake maintenance work. Scour valves are often left open after maintenance procedures, or even vandalised to provide water to communities and livestock. The problems experienced with scour valves are similar to those experienced with isolating valves and include:

- Opening and closing of isolating valves too fast, causing surges in the system;
- Excessive force used on valves during opening and closing, resulting in damage to the valve;
- Insufficient maintenance of the valves, with the result that they leak after use.

A typical scour valve that has been vandalised, to provide a constant flow of water for stock watering is shown in **Figure 3.14**.

Figure 3.14: Leaking Scour Valve (vandalised to provide for stock-watering)

(Courtesy Bigen Africa)

3.7 FIRE SERVICES

Fire services can be a serious source of "lost" water from the system since most fire hydrants are not metered, specifically to ensure that the meter does not impede the flow of water in the event of a fire. As a result, water can be taken from a fire hydrant without it being metered and this often results in considerable theft of water by individuals for purposes other than fire fighting.

This is a particularly difficult problem to overcome since most water suppliers do not wish to tamper with fire hydrants in case there is a problem with water supply in the event that a fire does occur. In many cities that experience intermittent water supply, the concept of metering a fire hydrant is less problematic as there is no water for much of the time. In many other areas the hydrants are vandalised for scrap since the connection piece is often a brass fitting with a scrap value of several dollars.

The problem of water theft from fire hydrants should be dealt with on a case-by-case basis since many areas experience different problems. If permission can be obtained from the fire department, it is often worthwhile installing meters on all fire hydrants in areas where theft is known to be a problem. In other areas, the cost of the meters far outweighs the water losses and in such cases the hydrants should be left unmetered and an estimate of the water use for fire fighting made in the overall water balance calculation. It is also possible to install a small domestic water meter in the pipeline feeding the fire hydrant on a venturi principle. If water is used illegally from the hydrant, this meter will register and the user/owner could be fined. To be able to use this effectively, regulations in this regard must be promulgated and the meters must be read.

Properties with separately metered fire services should be closely monitored for meter drift or movement, which may indicate that water is being used for purposes other than fire fighting. Use of fire services for car washing, for the washing of buildings, premises and driveways, and even cooling down buildings on hot summer days should not be permitted. All fire services should be tested regularly to ensure that the stagnant water in the pipe does not encourage corrosion and that the valves are functional. Water left stagnant in a pipe for any significant period will become stale and sometimes even toxic. If the hydrant valves are only used in an emergency, it may be found that they seize due to infrequent use, which can lead to breaking of the spindle or the valve itself.

In cases where roof tanks are used to store fire fighting water, they should be checked regularly by closing the inlet valve and observing any drop in the water level. Care must be taken to re-open the inlet valve after checking to ensure that the water is available in the event of a fire. Unmetered fire services should be tested for leakage and functionality at least every second year. New installations should be tested twice a year until the water services authority is satisfied that the system is fully functional, while older systems (+20 years) should be tested annually for leaks.

Properties whose fire service is supplied through the revenue meter should be tested in the same manner as a normal installation as should the on-site storage. The use of water from small dams and rivers for fire fighting should be encouraged

3.8 PARKS AND PUBLIC GARDENS

Considerable wastage and leakage can occur from public parks and gardens, since those maintaining the areas seldom have any interest in water use efficiency or conservation. In many public areas, the water used is not metered and it is a common sight to see water running down paved areas and roads due to over-irrigation or simply negligence.

The solution to this problem is to ensure that all connections into public areas are metered and that someone or some organisation is held responsible for payment of the water – even if it is from one department in a municipality to another department. Each department within the municipality should budget annually for its water use and regular audits on the actual water used should be undertaken. It is essential that the local municipality is not seen to be wasting water or it will be very difficult to encourage the paying consumers to adopt water efficient lifestyles.

Local municipalities should also be encouraged to set an example when it comes to public gardens and swimming pools by introducing indigenous vegetation, which tends to be drought resistant in many cases compared to certain alien plants which require more water and must be irrigated during dry conditions.

The water used by parks and public areas should be recorded and monitored in the usual manner, using flow loggers to determine how much water is being used and when it is used. In this manner the magnitude of the consumption can be determined, after which action can be taken if required. In the case of swimming pools and ponds, the wastage/leakage can be calculated in a similar manner to the leakage from a bulk storage reservoir (see **Section 3.5.2**)

To minimise wastage and leakage in parks and public areas the following points should be considered:

- All connections to parks, gardens and open spaces should be metered;
- Swimming pools should be covered when unused for prolonged periods (e.g. autumn and winter in most areas). It should be noted that it is often difficult to cover large and Olympic-sized pools. In Windhoek, Namibia, such pools were excluded from the regulations on the covering of pools;
- Leakage from pools, ponds and fountains should be identified and repaired (see leakage from storage structures, **Section 3.5.2**);
- Water-wise gardening practices should be adopted (see **Section 5.4**);
- Alien plants, which require more water than indigenous plants, should be avoided or concentrated in the one area.

3.9 WASTAGE DUE TO LACK OF ACCOUNTABILITY

Water is often supplied free of charge to consumers with no associated responsibility or accountability for use. This is particularly a problem with various forms of holiday accommodation such as hotels and caravan/camping sites. This includes caravan parks and holiday accommodation operated by the authority, staff quarters and housing schemes, staff washing and toilet facilities.

Many companies provide housing with free services to certain key staff members. There is no incentive for these consumers to care about the use of water in efficient ways.

Wasteful Endpoint Fittings

There are often many wasteful devices in water supply systems. Old toilet cisterns, which use 13 to 15 litres of water for a single flush, are still being used and manufactured. Tip-tray urinals in public buildings have been measured to consume 1 124 litres of water over a 24-hour period.

The older type of showerheads can consume water at a rate of up to 24 litres per minute. Two ways exist to address this – either replace this with a showerhead using 10 litres per minute, or shower in a shorter time. The latter requires a change of habit or lifestyle.

Un-metered Supply

If the water supply to an erf/plot is un-metered, and the consumer thus pays only a flat rate for his/her consumption, there is no incentive for the efficient use of water or change of habit. It is important for the water supply to each consumer to be metered. This will encourage users to reduce wastage.

Corrective Measures

Payment for services: Inducing people to pay for water is imperative for sustainability of the service. Even if people are poor, but they are prepared to pay at least a token amount for the water they consume then it is preferable to no income being received at all. If a person does not pay for a service, it immediately places a burden on someone else to subsidise him/her. This burden may become too large for a community to bear, with the corresponding collapse of the service. If a consumer does not pay for water, he/she will not be worried if water is leaking on the property through leaking taps or toilet cisterns. This leakage, if magnified a thousand-fold, places a large financial burden on a municipality.

While leakage in general, in the reticulation network and on private property, may be an engineering/plumbing problem, payment for services is a political problem, and requires both political and community support. It is relatively easy to address leakage from a technical viewpoint with the correct equipment and expertise. The problem of non-payment for water or blatant wastage by those who do not pay for water is a serious problem and one that requires careful and time-consuming attention since the issues are often very complicated. In some parts of Africa, certain government departments promote the development of small informal irrigation schemes to grow basic vegetables and maize to support the local population. In some cases the resulting irrigation takes place using potable water and cases of individual properties using 400 m^3/month are relatively common. The water distribution systems are not designed for such use and the consumers at the end of the system invariably receive no water. This is a very sensitive issue in some areas and involves poverty alleviation through food production while attempting to supply all consumers with a reliable supply of safe drinking water. It requires a clear policy statement from the politicians after which the engineers can tackle the technical issues.

A recent study in Gauteng, South Africa, by Rand Water, has shown that disposable income is being used for cellular phone use, the South African lottery, gambling in casinos as well as satellite television. The study highlighted that payment priority amongst the low income consumers is allocated in order of priority to, housing, food, and electricity before any allocation is made for water.

Staff Training and Education

Numerous hotels display notices requesting clients to save water by various means, including:

- Re-use of towels when staying for more than one night;
- Re-use of bed linen when staying for more than one night;
- Turning off taps;
- Use of showers instead of baths;
- General “save water” notices.

Removal of Wasteful Water Devices

Some wasteful devices are difficult to remove due to the damage that would be caused during the replacement. This is often the case when attempting to replace a toilet cistern without replacing the toilet pan and it is generally necessary to replace the whole fixture.

At present, there is little if any incentive for suppliers to stock a wide range of water efficient devices since most African governments do not try to support or encourage the use of such devices through the typical incentive schemes used elsewhere in the world. The main problem is funding and clearly few African governments have funds available for WDM incentive schemes when they are struggling just to provide basic water to the consumers.

Installation of Meters

The key solution to manage leakage and wastage is through proper metering both at the bulk level as well as the consumer level. If the water is not metered it cannot be managed. Water meters can be installed for an individual consumer, or for a number of consumers. If large quantities of consumers are not metered, the process can be initiated by installing water meters at all supply points and ensuring that the zone is discreet (ensuring there are no unmetered cross-boundary connections). Over a period of time more water meters can be installed, creating smaller zones, and in such a manner developing an understanding of water use patterns.

3.10 TARIFFS

Payment for water services is an important issue and one that causes problems in many areas. There are numerous models for water tariffs and the model selected for a specific area should be tailored and modified for the area in question. Without a reasonable level of payment for water, the water supplier will eventually fail and the water supply system will fall into disrepair, requiring massive injections of capital. Consumers must therefore pay for water services to ensure sustainable and equitable development, as well as efficient and effective management thereof. The tariff structure should be realistic and generate adequate revenue to fund operations capital expenditure and repayment of loans and should be structured to include, amongst others, the following:

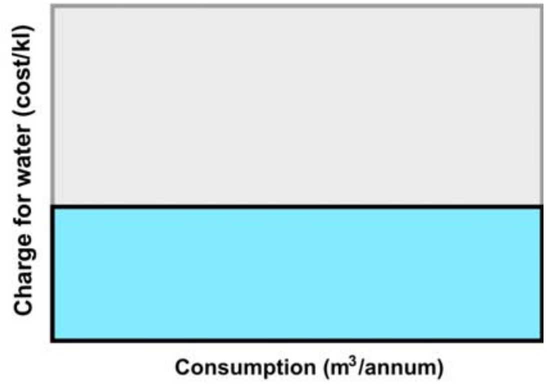
- Recovery of the cost of water purchases;
- Recovery of overheads including operational and maintenance costs;
- Recovery of capital costs not financed through any grant, subsidy or donation;
- Provision for the replacement, refurbishment and extension of water services works;
- Depreciation of existing assets.

Various tariff models can be considered including:

Flat Rate

Customers are charged a fixed amount according to property value, number and type of appliances, service size, etc.

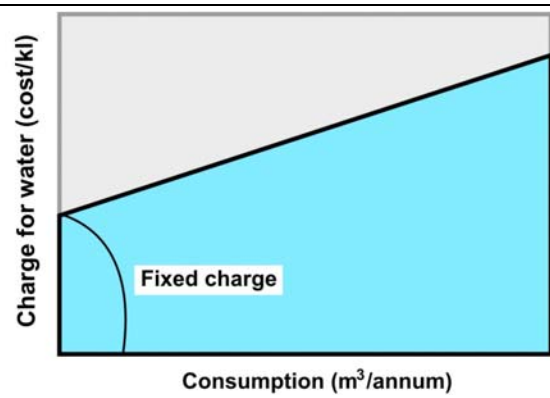
- Simple and easy to administer, provides predictable revenue base (if payment received).
- Provides no incentive to use water efficiently and often results in increasing demands.
- Consumption is far higher than the norm due to leaks on private property with no incentive for consumers to repair leaks or curb use.



Two part tariff

Consists of a fixed charge and a usage charge based on the volume of water used as measured at the customer's meter.

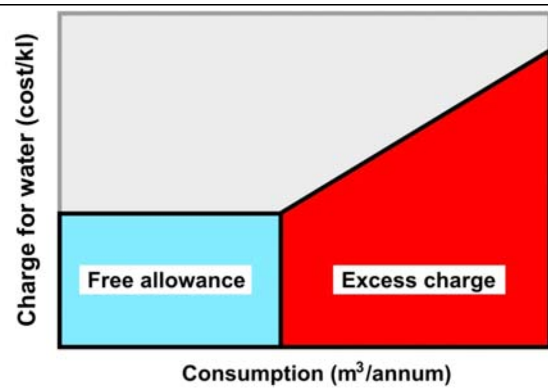
- Simple and easy to administer.
- Provides incentive to use water efficiently.
- Fair and equitable in that the consumer pays for what he uses.



Three part tariff

Consists of a "free water allowance" to a certain volume. Usage above the free water allowance is then charged per volume plus a fixed charge.

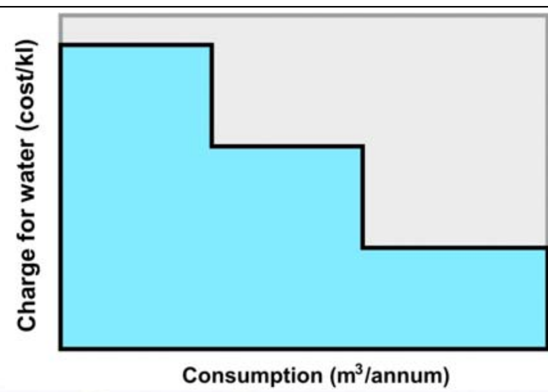
- Simple and easy to administer.
- Provides incentive to use water efficiently.
- Access to free basic services.
- Allows cross subsidisation from those using high volumes of water to those using lower volumes – i.e. affluent users pay for the lower income users.



Declining block tariff

Customers are charged less per kilolitre for consumption above certain levels.

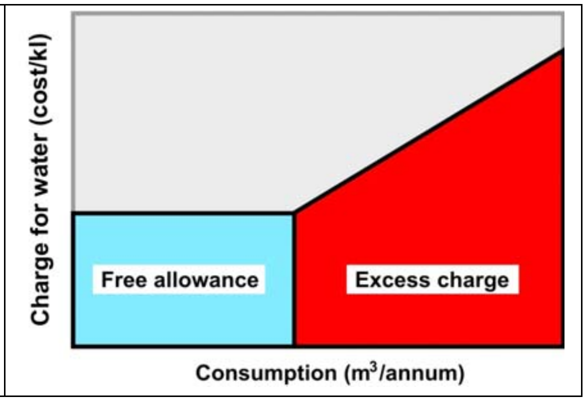
- Results in increased and inefficient use of water.
- Causes over-investment in supply network
- Used by municipalities to lure investment in industry.
- Very counter-productive from a WDM viewpoint
- The poor subsidise the affluent which is totally inappropriate especially in Africa.



Inclining block tariff

Customers are charged an increased rate for consumption above certain levels.

- Simple and easy to administer
- Provides incentive to use water efficiently.
- Can include a basic free amount of water.
- Must be used carefully to avoid sudden drastic reducing of consumption by consumers due to price elasticity.
- Used to cross-subsidise from the affluent to the poor – ideal for use in Africa



3.11 RE-USE OF WATER

The quality of water discharged into the waterways from sewerage treatment plants has improved considerably in recent years due to stricter legislation. In some areas the quality has improved to such an extent that the water discharged is now suitable for industrial, domestic or agricultural applications. The benefits of re-using water include:

- Improving the reliability of water supply;
- Increasing the available capacity of water supply and treatment facilities;
- Deferral of new augmentation schemes;
- Adding value to sewage effluent;
- Allowing lower treatment standards than required for discharge;
- Water can be treated and supplied to meet a specific market;
- Reduced nutrient load of waterways;
- Supplement baseline flows in waterways; and
- Enable decentralisation of water supply and treatment facilities.

The factors that should be taken into consideration when considering re-use of sewage effluent include:

- Potential markets may have seasonal demands requiring storage facilities;
- A separate distribution system is required with associated costs;
- Potential harmful effects on products (staining, corrosion, chemical reaction and contamination, decay), equipment (corrosion, erosion, scale deposition) and the environment (eutrophication, acidity);

- The potential harmful effect on human health (waterborne diseases, infections), safety (poor visibility, profuse plant growth) and aesthetic impacts (changes in water taste, odour, colour, discolouration and staining, foaming, nuisance plants).

While there are clearly many potential problems to be taken into account when considering the re-use of sewage effluent, it has been implemented with great success in many parts of Africa. In Windhoek, for example, the effluent from the Goreangab Sewage Treatment Plant is processed to such a high standard (using activated carbon filtration in conjunction with ozone disinfection and ultra filtration, amongst others) that the water is directly re-used for primary human consumption. In the case of Windhoek, Durban and Cape Town, treated sewage effluent is being used for the irrigation of sports fields, parks and golf courses as well as for large industrial users. Potential markets for reclaimed water therefore include the following sectors:

- **Agriculture:** secondary treated reclaimed effluent can be used to irrigate crops, provides a reliable source of water and is high in nutrients for fertilisation;
- **Urban landscape irrigation:** secondary treated reclaimed water can be used for irrigating parks, public gardens, race-courses, school yards, roadway medians, cemeteries and golf courses;
- **Industrial sector:** reclaimed water can be used for cooling; stream production, process water and boiler feed water, wash down water, miscellaneous use such as site irrigation, mine site re-vegetation and dust control;
- **Recreation:** reclaimed water can be used for recreational impoundments and fisheries;
- **Environment:** reclaimed water can be used to supplement lakes, ponds wetlands and for stream flow augmentation;
- **Non-potable urban use:** tertiary treated reclaimed water can be used for toilet flushing (constant demand), outdoor use such as garden watering and car washing, air conditioning and fire protection (seasonal variation);
- **Groundwater recharge:** this is a process whereby groundwater aquifers are artificially recharged through infiltration or injection with surface water. With

infiltration, the recharged water is confined to the surface of the aquifer. Infiltration provides further treatment of secondary treated effluent. Recharging through injection is more complex and care should be taken not to contaminate the existing aquifer. Groundwater recharging replenishes groundwater reserves, controls saltwater intrusion and subsidence control and has been implemented in Windhoek, Namibia;

- **Potable urban re-use:** process whereby all reclaimed effluent is treated and redistributed for potable use. Potable water re-use can be either direct or indirect and involves treatment of effluent and returning it directly to the potable supply or mixing it with the raw water supply.

It should be noted that there are often strict laws and local by-laws concerning the re-use of sewage effluent to protect the consumer. Some typical issues that would normally have to be addressed would include:

- A water supplier must ensure that the use of effluent for any purpose does not pose a health risk before approving that use;
- All taps or points of access through which effluent or non-potable water can be accessed, must be clearly marked with a durable notice indicating that the effluent or non-potable water is not suitable for potable purposes;
- Pipelines carrying semi-purified sewage effluent for irrigation purposes should be colour coded to differentiate them from the potable water reticulation systems.

When considering the benefits of using treated sewage effluent, care should be taken to look holistically at the issue. Many inland areas allow sewage effluent to be transported via rivers to downstream users where the water is re-used in any event. By re-using it at the source, the water utility may be taking away from one user to supply another with little net benefit. Coastal cities on the other hand, often discharge the effluent into the sea in which case it is a genuine loss from the system. Re-use of sewage effluent in such cases will result in a genuine gain and can often defer costly water resource augmentation schemes. Examples where sewage effluent is being used to great benefit include Durban and Cape Town. Reducing the discharge into the sea also has clear environmental and financial benefits.

4 LOSSES FROM THE RETICULATION NETWORK

4.1 MANAGEMENT ZONES

The purpose of a management zone is to create a discrete area into which the flow of water can be monitored and measured. Through proper measurement and careful analysis, the water supplier can identify problems quickly and address them efficiently. Any new leaks developing in the zone will be identified from the analysis of the water use in the zone. Through careful monitoring, it is possible to reduce wastage and losses through water leaks that can otherwise run unchecked for months, if not years. A management zone can be a either a district, sub-district or zone:

District: a unique area with individual bulk supply and boundaries usually fixed by topographical constraints. This would include various consumer categories (typically 30 000 connections);

Sub-district: subdivision of a district, identified by reservoir, tower, pump, PRV zone (typically 2 000 to 10 000 connections). This would include various consumer categories;

Zone: subdivision of a sub-district, identified by areas of similar characteristics (typically not larger than 2 000 connections).
The difference between districts, sub-districts and zones is illustrated in **Figure 4.1.**

Setting-up and maintaining management zones presents a major challenge to most water suppliers and is possibly one of the major issues requiring attention in most African water distribution systems. Even if an area has been properly sectorised into smaller zones, the management of the zones often collapses due to boundary valves being left open after dealing with a local supply problem. The zone in question is then compromised and no longer operates as a zone, leading to further problems.

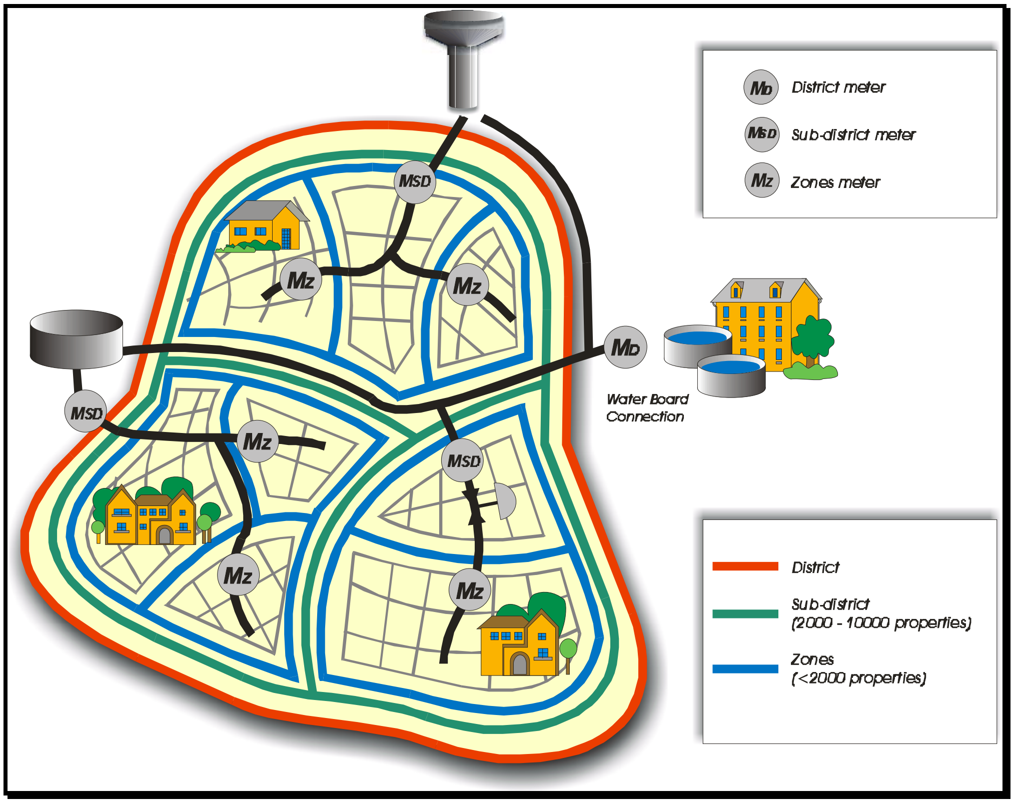


Figure 4.1: Districts, Sub-District and Zones

In order to maintain the integrity of water supply zones the following actions are recommended:

- Installation of valve-locking mechanisms on all zone valves to avoid unauthorised opening and closing;
- Filling valve chambers of all boundary valves with sand and covering with a thin concrete screed. This prevents unauthorised opening of the boundary valves and it is easy to identify boundary valves which have been opened at some time and may not have been closed;
- Relocation of all boundary valve connections above ground in the form of hydrants. If two zones must be connected as an emergency procedure, the two hydrants are simply linked with a hose, thus creating a visible indication of the connection between the two zones;
- Clearly indicating all boundary valves by colour coding the valve boxes in conjunction with monthly inspections to ensure that the valves are closed;

- Use of intelligent valve keys and valve caps which are linked to an information system. This is an expensive approach and would probably be inappropriate for most water supply systems in Africa where there are often more serious issues to address using the available funds;
- Removal of all closed valves by cutting and capping all pipes of diameter 150mm and smaller. The zone boundary can then only be breached in an emergency by installing a new section of pipe.

4.2 PRESSURE MANAGEMENT

4.2.1 General Concepts of Pressure Management

Most water reticulation systems are designed to provide a minimum working pressure at all points in the system throughout the day. In addition, they are designed to meet this pressure during the day with the maximum demand during the year.

Water distribution systems experience significant fluctuations in demand throughout the day, with morning and evening peaks, coupled with periods of low demand during the night and sometimes also during the early afternoons. Many systems also experience seasonal fluctuations. This is caused by climatic factors that influence irrigation requirements, or by holiday migration that can significantly influence the demand for periods of days or weeks at a time.

Since most systems are designed to provide a set minimum pressure throughout the day, they are generally designed to meet this pressure requirement during periods of peak demand, when the friction losses are at their highest and inlet pressures are at their lowest. Because of this design methodology, most systems experience higher pressures than necessary during the remaining non-peak demand periods. This is evident from the fact that in most areas the major pipe bursts tend to occur during the late evening and early morning periods when system pressures are at their highest.

This concept is shown graphically in **Figure 4.2,** which represents a typical pressure situation for a zone at peak demand periods, where the minimum pressure required is 20 m.

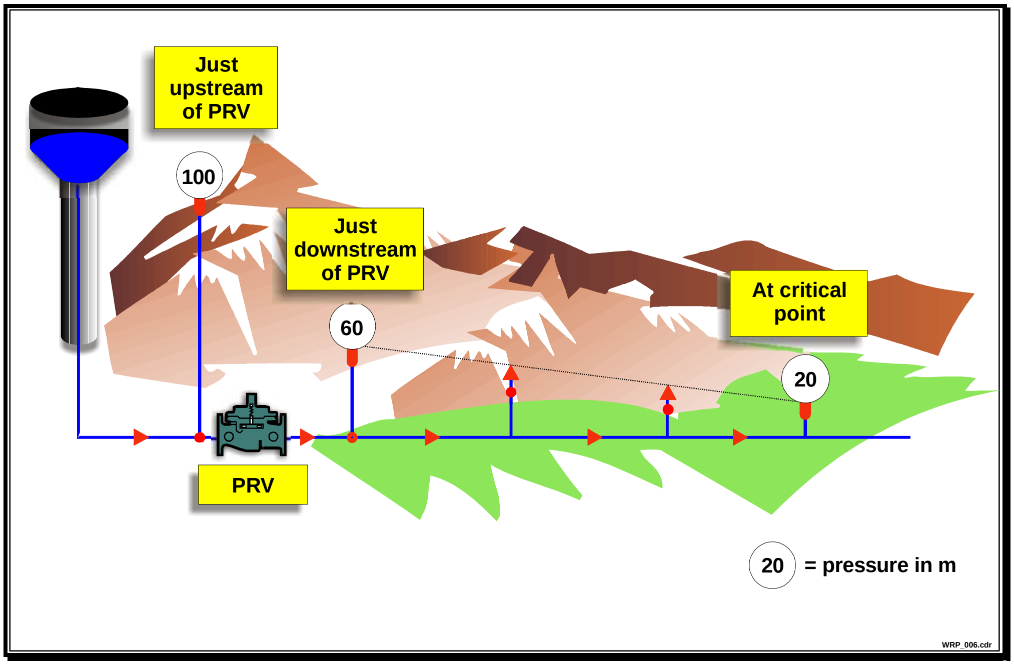


Figure 4.2: Typical Zone Pressure Distribution during Peak Demand Periods

The same zone is shown again in **Figure 4.3** for periods of low demand, typically experienced during the late evening and early hours of the morning (assuming that the properties use direct feeds with little or no roof storage).

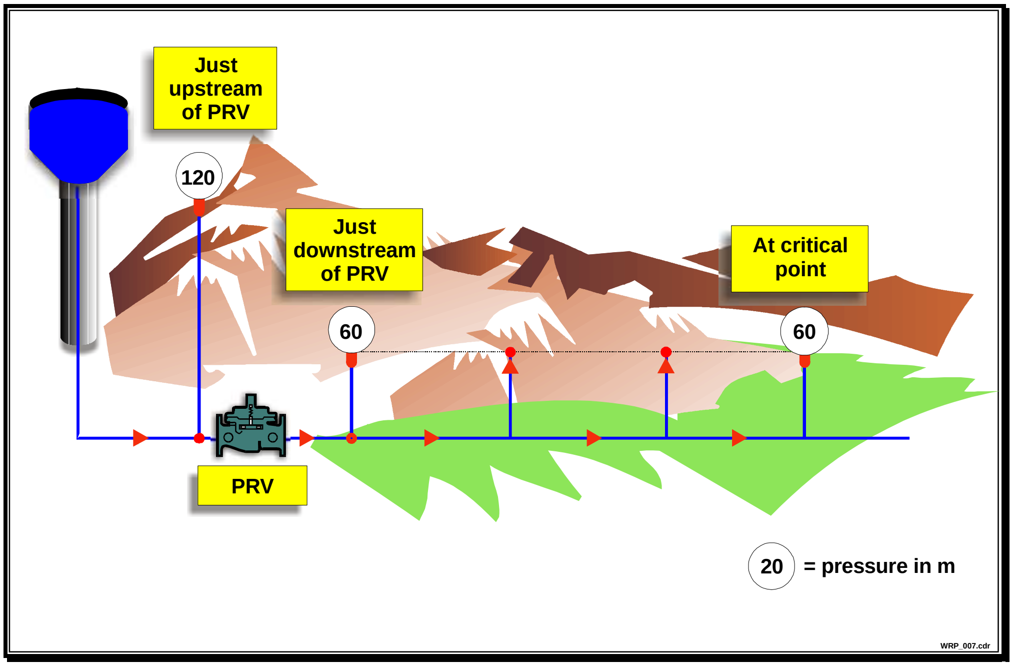


Figure 4.3: Typical Zone Pressure Distribution during Low Demand Periods

From **Figure 4.2 and 4.3** it can be appreciated that, for most of the time, the pressure in a water distribution system is likely to be considerably higher than required (unless some form of active pressure management has already been implemented). If it is also accepted that leakage increases with increased pressure (see **Section 2.10**), then it can be concluded that leakage levels in most systems are higher than they should be during most of the time.

If the excess pressure in a system can be reduced, then so too can the leakage, which, in turn, will save money and conserve water. This is the basic philosophy governing pressure management in potable water distribution systems and is often the most effective and cost efficient form of WDM that can be applied to a particular system. It should be noted, however, that pressure management is not the answer to leakage reduction in all zones. It is important to analyse each case carefully to ensure that the solution being proposed addresses the underlying problem and not only the overlying symptom. If leakage should also occur on private properties, pressure management can assist in alleviating the problem of water losses but cannot address the real issues.

4.2.2 Concepts of Active Pressure Control

The main objective of active pressure control is to minimise the excess pressure in a water distribution system, which, in turn, will reduce leakage as well as the frequency of burst pipes. This simple objective is often difficult to achieve in practice due to numerous external factors that must be taken into account such as fire fighting requirements, high-rise buildings etc. In general, however, significant savings can often be made and there are many examples throughout the world where active pressure control has been extremely successful. In view of the importance of pressure management, a detailed case study has been included in Appendix F to demonstrate one particular area where the implementation of pressure management was extremely successful.

It should be noted that there is often a misconception that pressure control is aimed at reducing the levels of service to the consumer. While pressure management can be very effective in reducing customer demand, this is generally not the primary objective of a pressure management intervention. As mentioned above, the main objective is to reduce the "excess pressure" during periods of low demand. If this can be achieved through proper and careful pressure management measures, it should be possible to reduce leakage and burst frequency without any detrimental effect to either the consumer or the fire fighting services. Obviously there are numerous potential problems and pit-falls. However, through experienced planning it should be possible to overcome most of these.

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

At the same time as the research into pressure management was being completed, several new pressure control devices were also being developed which were able to modulate the pressure at a Pressure Reducing Valve (PRV), based on either time of day or the flow through the valve. By using such controllers, it became possible to reduce the pressure during periods of low demand and thus reduce leakage without adversely affecting the level of service to the consumers. There are various other techniques of achieving the same goals and several of the large valve manufacturers have developed their own techniques, many of which are hydraulically based.

With the aid of the new software and the use of the new PRV controllers, it became possible, for the first time, to accurately assess the potential savings that can be achieved from the various pressure management options. In this manner, the savings can first be estimated and then used to motivate the implementation of the physical devices. It also prevents the installation of expensive equipment in cases where it will not be cost-effective.

There are several types of PRV controllers available, both electrically-operated and hydraulically-operated. For the purpose of this manual the following three forms of pressure control are considered:

- Fixed outlet PRV controller;
- Time-modulated PRV controller;
- Flow-modulated PRV controller.

Fixed Outlet PRV Controller

The first option is simply a normal PRV, which is used to provide a continuous pressure at the inlet to a zone as shown in **Figure 4.4**.

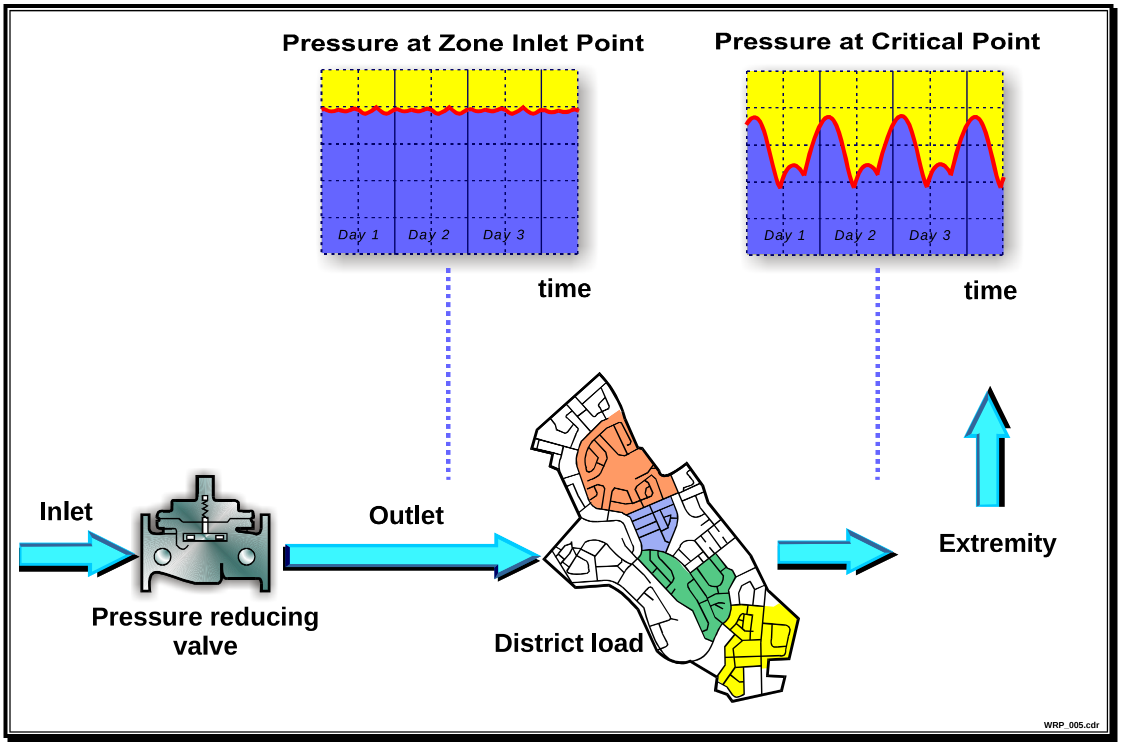


Figure 4.4: Pressure Control using Conventional Fixed Outlet PRV Controller

Time-Modulated PRV Controller

The time-modulated controller is the simplest form of Advanced Pressure Control and the least expensive. A timing device can be attached to the controlling pilot on any normal PRV to reduce the outlet pressure at certain times of the day. It is a simple and compact device, that can accommodate four switching periods each day and two pressure levels: a high level dictated by the PRV itself and a low level as set on the controller. This is a simple but effective method of reducing pressures in systems where there is some consistent pattern of demand on a daily basis. It is an ideal solution for reducing excessive pressures at night, when most of the consumers are asleep and the demand for water is minimal. In such cases, the night-time pressure can often be reduced significantly, without lowering the normal levels of service to the consumers.

Up to two time periods can be specified (see **Figure 4.5**) per day although, in most cases, only one is needed. A typical installation of a time-modulated controller is shown in **Figure 4.6** and the general principles are shown in **Figure 4.7**.

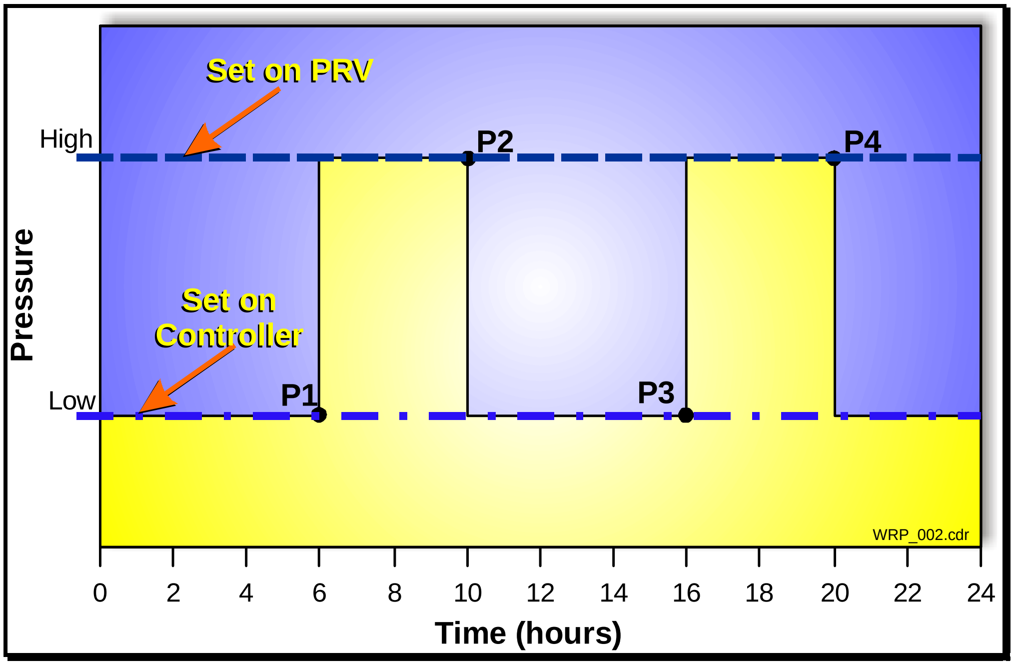


Figure 4.5: Typical 4-point Time-Modulated Pressure Profile

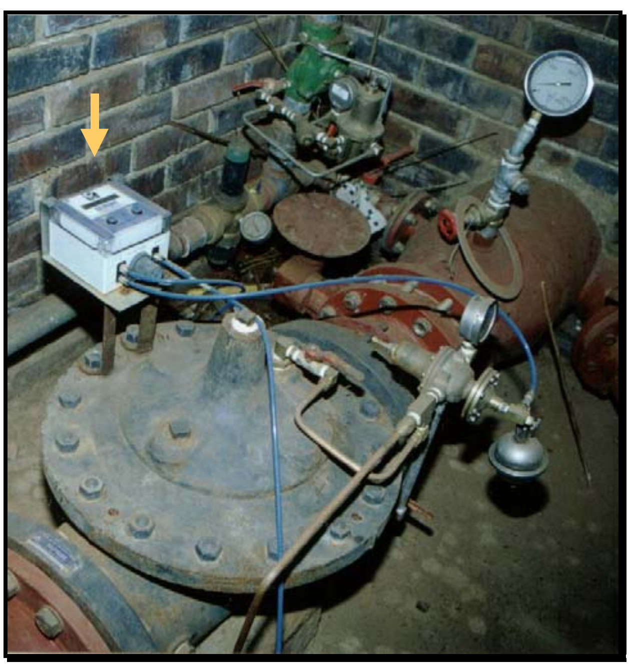


Figure 4.6: Typical Installation of a Time-Modulated PRV Controller

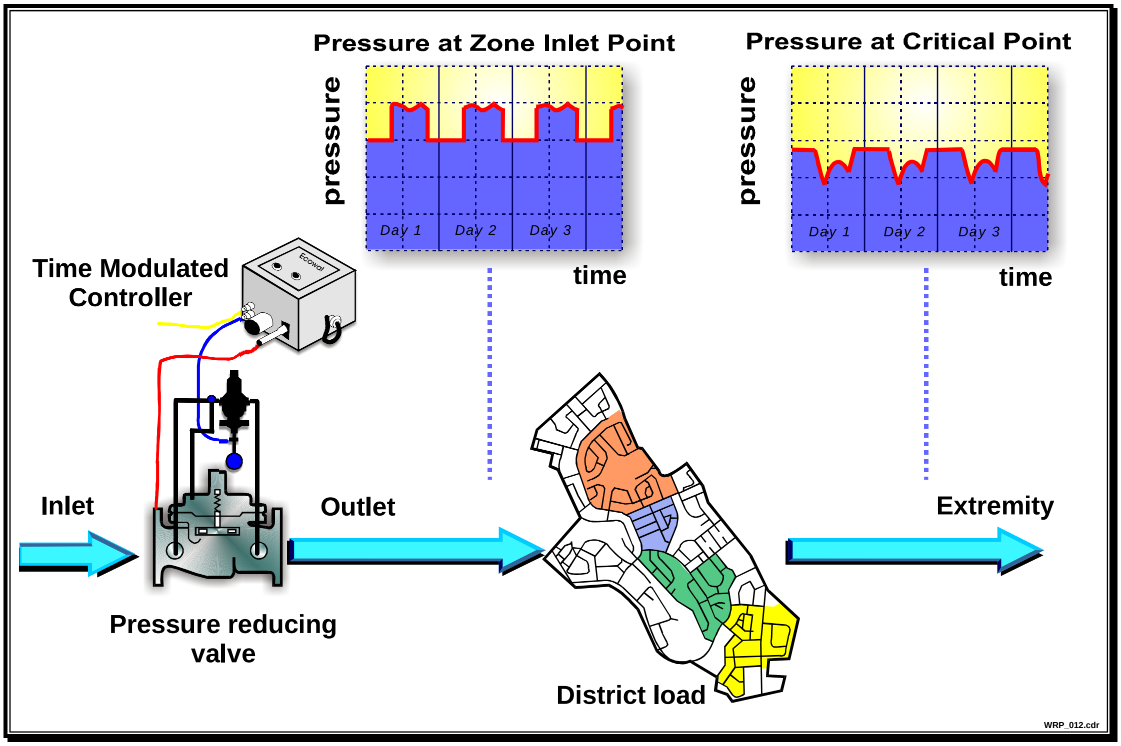


Figure 4.7: Pressure Control using a Time-Modulated PRV Controller

It should be noted that the time-modulated controller shown in **Figure 4.6** (see arrow) is a simple and self-powered unit, which can operate for approximately 5 years on a single battery. It is programmed using two buttons on the fascia, much in the same way as one sets a normal watch or alarm clock.

The main application of the time-modulated PRV is to reduce pressures during periods of low demand when the system pressures tend to be higher than necessary, resulting in excessive pressures at the critical point. With such a controller, it is possible to cut out some of the high-pressure peaks, especially during night-time periods.

The most potential problem with the time-modulated controller concerns the fire fighting requirements. The controller cannot react to an increase in demand caused by the opening of a fire hydrant, with the result that there could be problems if a fire breaks out during the period of low pressure. In many parts of South Africa, however, it appears from discussions with various fire departments that this is not a problem since there are either no fire hydrants or they have been vandalised to the extent that they are inoperable. Under such conditions, the fire departments bring in their own water and do not try to use the fire hydrants even if they are available. Another limitation of the time-modulated controller is that the pressure difference between the high and low settings should ideally not exceed 20 m, otherwise water hammer and/or cavitation may become problem issues.

Flow-Modulated PRV Controller

The second and more complex controller is the flow-modulated controller, which provides greater flexibility and control than that offered by the simpler time-modulated controller. Unfortunately, the greater flexibility is accompanied by a higher cost and the flow-modulated controller is approximately double the cost of the time-modulated version. The typical components required for a flow-modulated PRV installation (meter, PRV and controller) are shown in **Figure 4.8**.

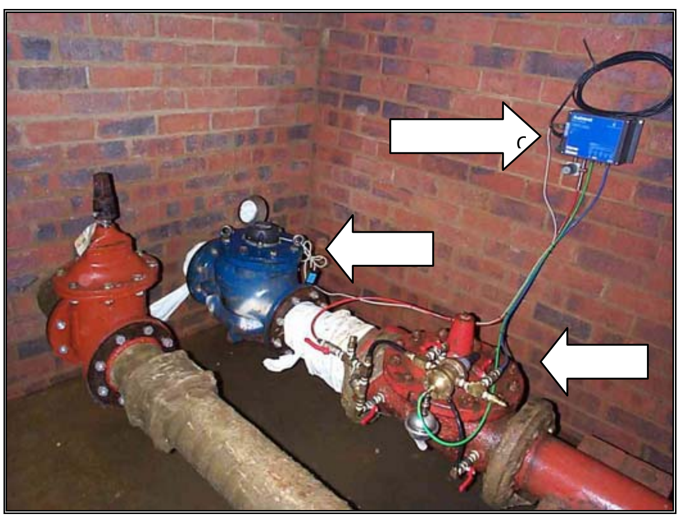


Figure 4.8: Typical Flow-Modulated PRV Installation
(courtesy Pressure Management Systems)

The flow-modulated controller will control the pressure at the inlet point in accordance with the demand being placed on the system. During peak demand periods, the maximum pressure as dictated by the PRV will be provided, while at low demand periods the pressure will be reduced to minimise excess pressure and the associated leakage. The principles of the flow-modulated controller are shown in **Figure 4.9**.

The flow-modulated controller can easily be equipped with a telephone or radio link to the critical point and, in this manner, the inlet pressure can be adjusted to ensure that there is virtually no excess pressure at the critical point at any time throughout the day. This will provide the most effective control possible (without reducing the size of the zone) and is depicted in **Figure 4.10.**

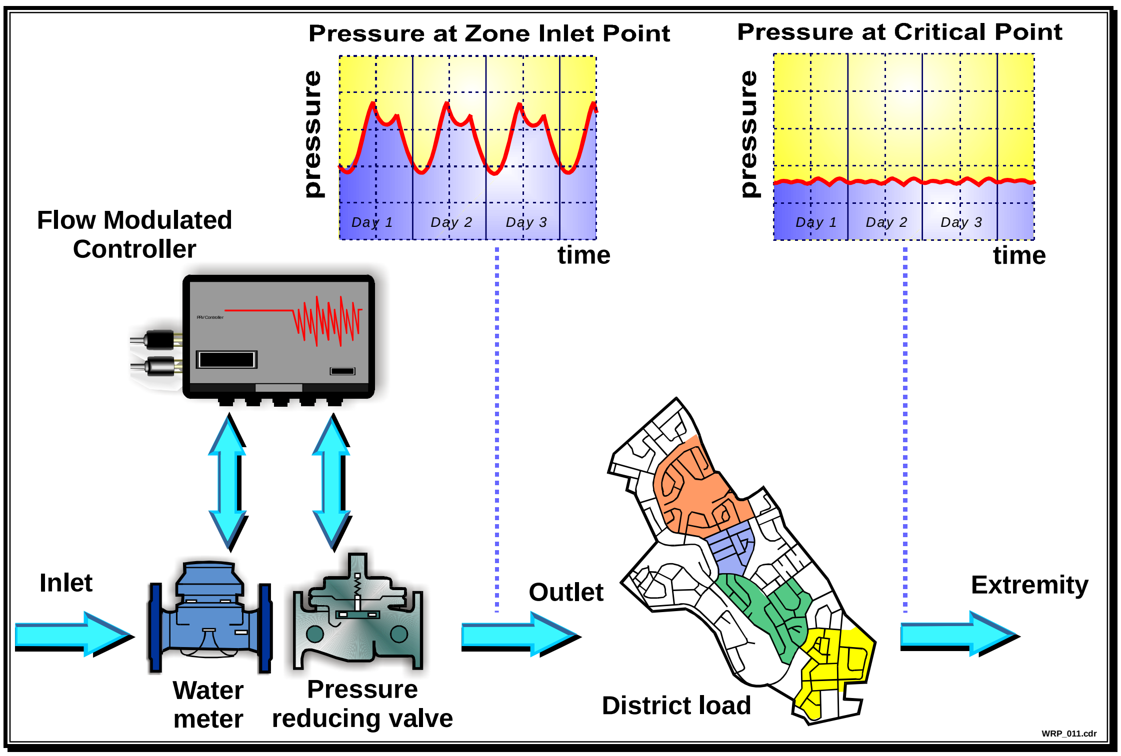


Figure 4.9: Pressure Control using a Flow-Modulated PRV Controller

Ideally, pressures in a reticulation system should not drop below 300 kPa (30 m) and not rise above 600 kPa (60 m). In areas with low levels of cost recovery, the pressure can be reduced to as low as 150 kPa (15 m) and still deliver an adequate supply of water. Careful consideration should be given to fire fighting requirements before reducing the pressures. Especially in high-rise building areas where rooftop tanks require filling at night. In cases where water is supplied intermittently, pressure management can be an effective measure in reducing leakage (and use) in certain areas in order to allow water to be supplied to other areas. If properly implemented, it is often possible to provide some water to everyone all of the time and can eventually lead to a system which is pressurised continuously.

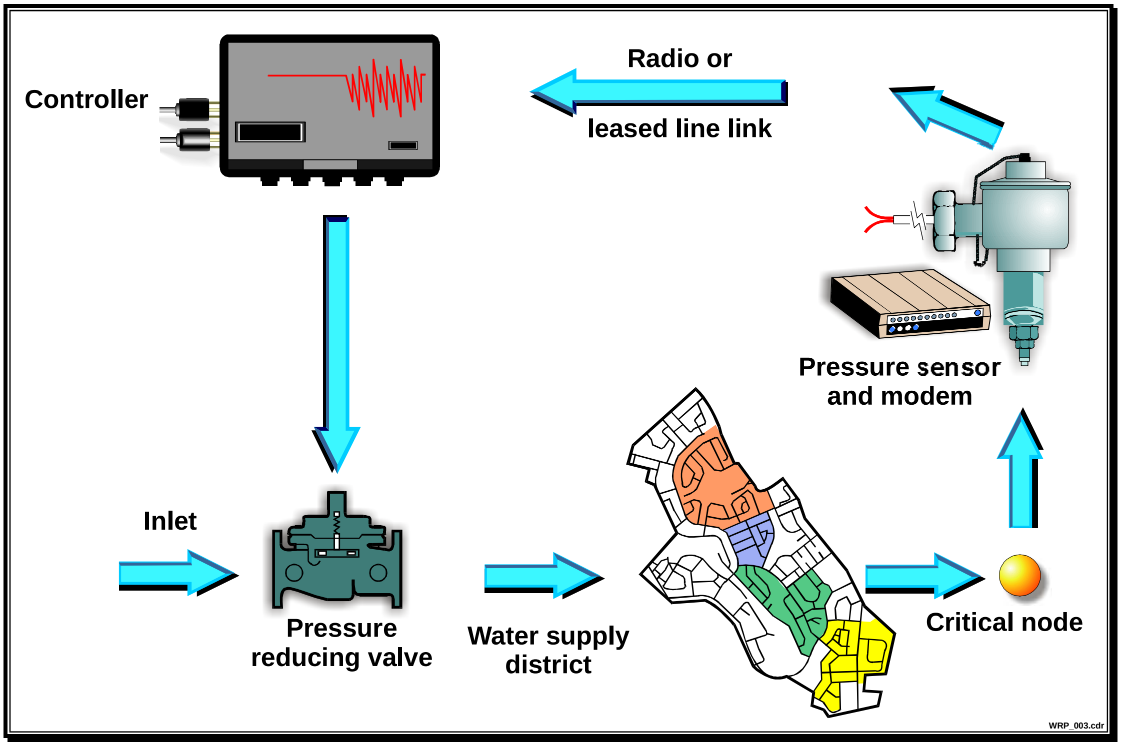


Figure 4.10: Pressure Control using a Telemetry Linked Flow-Modulated PRV Controller

4.2.3 Implementing Pressure Management

Before undertaking any form of pressure management, the water services provider must first gain a proper understanding of the selected zone. By following a systematic approach, results that are more realistic are often obtained and quantified. Alternatively, if a "trial-and-error" approach is adopted, problems are likely to be encountered and a negative impression of pressure management may result. In order to achieve success, the following seven steps are recommended:

- Step 1: Selection of suitable pressure management zones;
- Step 2: Capture of basic information;

- Step 3: Field investigations and retrofitting;
- Step 4: Logging of flows and pressures;
- Step 5: Analysis of logging results;
- Step 6: Selection and installation of pressure controllers;
- Step 7: Monitoring and auditing of the results.

Each step is discussed in detail in the remainder of this section.

Step 1: Selection of Suitable Pressure Management Zones

Most districts, sub-districts or zones are suitable to some extent for pressure management. Zones with the following characteristics will generally produce the greatest savings:

- The zone should be discrete **–** with all zone inflows metered and zone valves closed. Pressure management will not achieve the desired savings if the zone is not discrete.
- The zone inflow should be metered **–** and the meter should be functional. Effective metering is a pre-requisite for pressure management in order to undertake the pressure analysis and calculate the savings achieved. In the case of flow-modulated pressure control, it is essential that the meter be sized properly, since the controller relies on the pulse from the meter, to select the appropriate pressure.
- The zone inflow should be controlled with a pressure-reducing valve – and the valve should be functional and stable. Care should be taken to ensure that the pressure-reducing valve is correctly sized and operating within its design parameters. Oversized valves are unstable at low flows, resulting in cavitation, pressure surges, excessive noise and destruction of pipe work.
- The size of the zone **–** small zones tend to produce small savings, whereas large zones tend to produce large savings. The main problem associated with large zones (2 000 to 10 000 properties), however, is that such zones are often very difficult to manage, due to multiple supplies (and control points) and non-uniform consumers. Small zones (less than 2000 properties) are easier to manage, often have a single supply (with a single

control point) and tend to have uniform consumers.

- High leakage and high pressure zones – often result in the greatest savings. Areas subjected to high pressures generally experience high burst frequencies and high levels of minimum night flow. Such zones are ideal pressure management zones and should be targeted first. Use of the SANFLOW model is recommended for analysing the minimum night flow (WRC, 1999).
- Fire flow considerations – the fire risk should be carefully assessed and discussed with the fire department. Industrial areas and areas with high-rise buildings should be avoided unless the authorities are certain of the influence and consequences.
- Zones without strategic industries and/or special facilities **-** in general it is best to avoid any zones with large or strategic industries, as well as zones with hospitals and other buildings, which may have special requirements with regards to water pressure. While pressure management can be introduced in such areas, the risks often outweigh the benefits. The risks of the pressure management activities being blamed for any problems with the water system are high, despite the fact that they are most likely beneficial to the operation of the system.

Step 2: Capture of Basic Information

A desktop study should be undertaken to obtain a complete understanding of the system. The resulting information should be verified during field investigations and is required for use in the PRESMAC model (WRC, 2001). Some of the information required can often be obtained form a Geographic Information System (GIS). The basic information required includes:

- Length of mains;
- Number of residential properties;
- Number of non-residential properties;
- Large non-residential users and their demands;
- Number of connections;
- Condition of the network;

- Population; and
- Pressure exponent for the system as a whole.

The following issues should also be verified during the field investigations:

- Position, type and size of the flow meter(s);
- Position, type and size of the pressure-reducing valve(s);
- Zone valves and their location; and
- Logging points and their elevation.

Step 3: Field Investigations and Retrofitting

Field investigations and retrofitting are required prior to logging to ensure that the zone is operating as expected. Typical problems that are identified during the field investigation include:

- Water meters are not operational or unsuitable for logging;
- Zone valves are open or broken;
- Chambers require cleaning and securing;
- Hydrants are leaking, broken or require maintenance;
- Pressure tapping points are required for logging; and
- Minor plumbing is required at household connections to undertake logging.

It is often found that a pressure-reducing valve is malfunctioning and is fully open. It is recommended that the zone be logged before setting the pressure-reducing valve in order to demonstrate the effect of the open PRV and the importance of proper maintenance.

Figure 4.11: Valve Chamber Requiring Cleaning and Securing

Step 4: Logging of Flows and Pressures

A 24-hour logging profile is required to undertake the pressure analyses. Logging results at the following points are required:

- PRV downstream pressure/s;
- Zone inflows;
- Pressure at critical point;
- Pressure at average zone point; and
- Pressure at lowest point (alternative).

The average zone pressure is difficult to predict and, in most cases, the average between the critical and lowest point is used as the pressure at the average zone point. It is recommended that logging is undertaken over a 7-day period to ensure varying daily demands and peak flows are taken into account.

Logging is usually undertaken on fire hydrants or house connections. The difference between logging on a fire hydrant or house connection is illustrated in **Figure 4.12.** The pressure at a fire hydrant is less susceptible to consumer demand

and a smooth curve is obtained. The house connection is however, susceptible to consumption on the property with the result that an erratic result is obtained. Typical fire and house connections are shown in **Figure 4.13.**

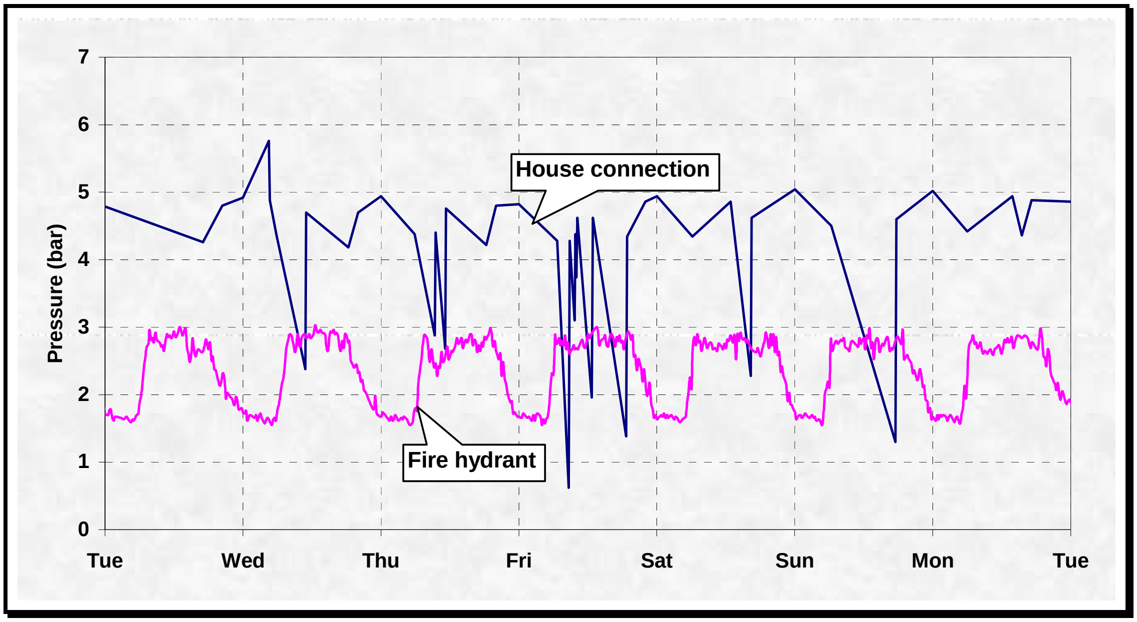


Figure 4.12: Typical Pressure Loggings from a Fire Hydrant and House Connection

Figure 4.13: Pressure Logger Installation on a House Connection and Fire Hydrant

Step 5: Analysis of Logging Results

On completion of **Steps 1 to 4**, the logging results can be analysed using software, such as the PRESMAC model, which is freely available from the Water Research Commission of South Africa. The use of the model is described in detail in the PRESMAC User Guide (WRC, 2001) and is not discussed further in this manual.

Step 6: Selection and Installation of Pressure Controllers

Based on the analyses of the logging results, the model can be used to identify the most cost effective method of pressure management for the selected zone. It should be noted that pressure management is not feasible in all cases and can often result in very poor financial returns.

There are various types of pressure controllers on the market, each with it own merits. In selecting a pressure controller, the following should be taken into consideration:

- Time or flow modulation control;
- Ease of programmability;
- Compatibility with existing meter and pressure reducing valve;
- Battery or current power supply;
- Technical support;
- Robustness and security of the unit;
- Integral logging facility for flow and/or downstream and/or upstream pressure;
- Submersible design (IP68);
- Fully open or fully closed failure mode;
- Cost;
- Remote communications (GSM, telemetry, radio, etc.); and
- Programming/management software and hardware requirements.

Step 7: Monitoring and Auditing of the Results

The correct performance of the pressure management installations is critical in terms of:

- Return on the capital investment;
- Savings in reduced water losses; and

- Future pressure management installations.

It is recommended that a controller, with an integral logger, be installed to enable continuous monitoring. The logging data can then be downloaded on a monthly basis and checked against the design parameters. The management of the controller installations requires commitment and technical expertise, which can only be developed over time. The use of electronic controllers is neither appropriate nor recommended for use in many parts of Africa due to a lack of technical expertise. Without proper maintenance and support, such controllers will invariably cause problems and be de-commissioned as soon as they become problematic.

4.2.4 Pressure Management at Domestic Level

While the previous sections have discussed Pressure Management at zone level, it is also possible to reduce pressure, as the water enters private properties, through individual pressure reducing devices. The concept of using flow restrictors has been widely accepted and used for many years. The flow restrictor is simply some form of plug with a small hole, which restricts the flow of water into the property. The size of the hole and the system pressure dictate the maximum flow into the property.

The main problem with the simple orifice-type flow restrictors is that the flow limit into the property will vary from one part of the zone to another according to the property elevation and the distance from the supply point. It will also vary throughout the day as the system pressure changes in accordance with the level of demand, with higher pressures at night and lower pressures during peak periods.

To overcome this problem, a new range of simple and inexpensive flow restrictors was developed, which is capable of delivering the same flow rate over a wide range of pressures. These restrictors are generally of plastic construction and can be fitted into a wide range of devices such as domestic water meters, low flow showerheads and taps. One such device is a new plastic water meter equipped with a flow restrictor to provide a maximum flow rate to the consumer, irrespective of the system pressure. In certain cases, this is very useful, since it can provide a uniform level of service to everyone in the same zone, (or water supply system). This is despite the fact that some of the consumers are located in close proximity to the supply point where pressures are high, while others may be located some distance away where pressures are lower. Previously in such areas, those near the supply point would be able to use more water than those at the end of the system, who often receive little or no water.

There are several products offering the ability to provide pressure management at the domestic level, some of which include the domestic flow meter. One such device is shown in **Figures 4.14 and 4.15**.

The figures show a cut-away version of the unit to enable the various components to be viewed. This particular unit can be equipped with or without a cartridge flow meter, which is a very useful capability. In some cases a meter is not required if the consumers are using less than a certain quantity of water each month, or are being charged on a fixed rate tariff. In such cases, it would be normal practice to install the meter for a month or two in order to monitor the consumption. After the consumption has been checked, the meter can either be left in place or removed and used elsewhere if it is found that the consumption is below a certain value. Some characteristics of the product shown in **Figures 4.14 and 4.15** are:

- One-piece manifold housing unit, water-tight below ground, complete with “O”-ring sealing hinged lid;
- One-piece meter manifold unit, complete with one flow control insert, security lock ring and blanking plug;
- Provides for various colour-coded flow control inserts, which can be fitted, or exchanged, in-situ without disturbing the housing or pipe connections;

- Provides for system flushing prior to meter installation;
- Standard ¾” BSP threaded female inlet/outlet adaptors;
- Built-in ¼ turn stop tap, repairable in-situ without disturbing the housing or pipe connections;
- All-plastic, no scrap value construction, factory assembled and leak tested to 240 m;

- System connection depth to 320 mm.

Figure 4.14: Internal View of the Pressure Management Box Without Meter Showing Internal Elements **(courtesy Aqualoc, SA)**

Figure 4.15: Internal View of the Pressure Management Box Without Meter Showing Internal Elements **(courtesy Aqualoc, SA)**

4.3 MAINS REPLACEMENT

Depending on the age and condition of the reticulation network, a mains replacement programme should be undertaken. The replacement programme should be based on sound economical principles. The ECONOLEAK model, developed through the South African Water Research Commission, can assist water service providers in analysing their system and deciding when to undertake active leakage control. The model also recommends when to replace the mains rather than continue repair work.

The criteria for the mains replacement programme should take the following considerations into account:

- Condition and age of the network;
- Burst and leak repair frequency;
- Potentially aggressive soil conditions;
- Aggressiveness of the potable water; and
- System pressures.

Various approaches can be followed during a mains replacement programme, each with its own merits, which include:

Abandon and remove existing mains and replace;

- There is no confusion between old and new systems;
- Allowance has to be made for the installation of the new system as well as the removal of the existing system.

Abandon existing main and replace without removing old pipes;

- Confusion can exist between the old and new system;
- Connections are not always changed onto the new system with the result that the old system is not decommissioned.

Slip-line the existing mains with plastic pipe

- Eliminates excavation and backfilling of trenches;
- The flexibility of the plastic pipe allows long lengths of pipe to be handled;
- Most plastic pipes have high corrosion resistance;
- Approximately a third of the original pipe volume is lost;
- Skilled labour is required to make waterproof connections and joints;
- Obtaining access to the existing system can be problematic.

4.4 LOW LEVEL WATER AUDITS

The process of high-level water audits was discussed in some detail in **Section 2.12**. The high-level water audits are normally used by a water supplier to summarise the leakage and non-revenue water situation for the whole water supply system, which in some cases can include large areas serving populations of several million. While such high level audits are very important and provide valuable information for the top management of the water utility, they do not provide information on the smaller management zones, which is often the level at which key problems can be identified.

To overcome this problem, low-level water audits should be undertaken, which involves assessing the water balance components at management zone level. This can only be undertaken for zones equipped with management meters, which are used to establish the water entering the zone. The billing records are then used to establish the water metered and billed to the customers and the basic water balance is then similar to that of the high-level audit.

In practice, the same water audit model can be used as was discussed in **Section 2.12** and in this manner, the various performance indicators can be calculated for each management zone. This will in turn highlight the zones with problems and those that are being managed properly.

The low-level water audits can be undertaken for areas down to approximately 2000 connections as long as the areas have reliable water meters and some indication of the metered consumption of the consumers. It is often very useful to undertake such audits for areas where the water supplier suspects that there may be a problem but is unable to quantify the problem properly. Through such an audit, it is often possible to establish the magnitude of the leakage and non-revenue water, which can then provide sufficient motivation to the financial managers to undertake remedial and corrective action.

4.5 WATER METERS

4.5.1 General

Proper metering is a pre-requisite for the management of any water supply system. Without reliable metering, the water supply managers will have little control over the losses in the system since they will be unable to identify and quantify them. When considering metering, many factors must be taken into account. Some of the key issues are as follows:

- Initial capital costs;
- Operating costs;
- Maintenance costs;
- Maintainability;
- Accuracy;
- Reliability;
- Facility for logging;
- Head loss through the meter; and

- Turn-down (flow range) range of meter.

Meters are required throughout the distribution system to establish the volume of water harvested, treated, imported, exported, stored and consumed. Metering of the following should be considered:

- Source or raw water;
- Bulk flow, production or purchase;
- Districts;
- Industrial, commercial, and non-domestic users;
- Domestic/residential users;
- Own use (of the supplier) inclusive of fire fighting and flushing of pipe lines e.g. after repairs.

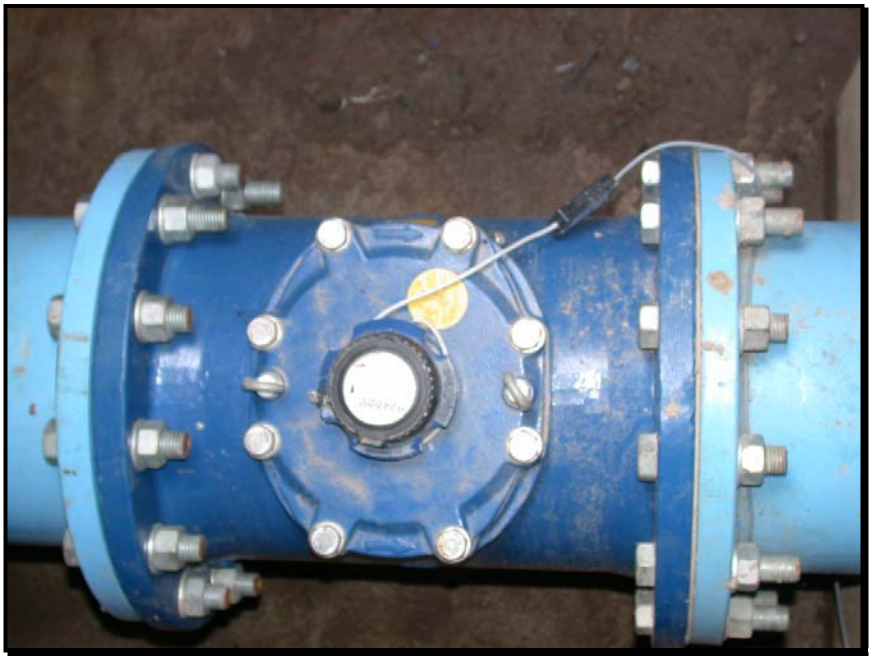


Figure 4.16: Typical Turbine Flow Meter

To ensure meters are accurate and reliable, the water services provider must ensure that:

- The meters are selected correctly for the specific application;
- The meters are correctly installed – correct straight pipe lengths, suitability for

vertical, horizontal and inclined installations and meter head installation requirements are adhered to;

- Correctly sized – specific consideration should be given for measuring low flows;
- Systematic and cost effective maintenance/replacement schedules are developed;
- Appropriate and systematic reading schedules are developed to ensure efficient information flow and revenue collection.

4.5.2 Bulk Meters

Bulk meters are usually used for billing purposes. They should comply with the relevant specifications as well as other requirements for the specific country in question. Most countries have their own standards, which can vary, although the general specifications tend to be based on the same approach. Bulk meters, used for billing purposes, often generate the largest portion of income to the water supplier. For this reason they should be checked for accuracy on a regular basis – e.g. every two years.

In cases where mechanical meters are used, they will tend to under-record as they become older and parts become worn. In such cases, it is important to replace or re-calibrate the meters regularly. This will avoid large losses of income to the water supplier. It has been shown in many cases that the replacement of the bulk meters is an extremely cost effective measure and will usually result in paybacks of less than one year. There are various types of bulk meters, which are designed for different conditions. It is important to select the correct meter for the specific installation and not simply pick the first meter from the catalogue. One of the most important considerations of meter choice is the range of flows that the meter must measure (turn-down range). Different meters have different ranges. If the correct meter is not selected it may stall at low flows, in which case any water passing through the meter below a certain flow rate may not be recorded and therefore represent a loss to the water supplier. Typical types of bulk meters include:

- Turbine water meter (Woltmann type);
- Electromagnetic flow meter;

- Insertion meters;
- Ultrasonic flow meter; and
- Volumetric or semi-positive displacement meter.

Where water is supplied by a bulk service provider, it is strongly recommended that a check meter be installed by the water services institution. This meter should be read independently of the bulk service provider meter and should be used for auditing.

4.5.3 Zone Meters

Zone meters record the flow into the various water management zones which are typically smaller areas with up to 2 000 properties, compared to the district meters which often measure water supplied to more than 30 000 properties. With the bulk meters it is difficult, if not impossible, to identify medium sized leaks from the analysis of the minimum night flows. With the zone meters, however, it is often possible to identify an individual connection pipe burst, which will often show up clearly as an increase in the Minimum Night Flow. Zone meters are therefore very useful for analysing minimum night flows and identifying zones with cross boundary connections.

The value of zone meters cannot be overstated and they often pick up problems, which may otherwise remain undetected indefinitely.

4.5.4 Consumer Meters

Consumer meters are required if customers are being charged for the water used, being one of the key elements of any WDM strategy. If consumers are not charged in accordance with their use, there is no incentive to use water efficiently and in many parts of Africa it has been found that the consumer will use two to three times the volume of water that they would use under normal conditions. Domestic meters are therefore essential in most situations throughout Africa. For example, in certain areas of the Western Highveld region, north of Pretoria in South Africa, it has been estimated that the average monthly use in some villages exceeds 60 kl/month with individual household use as high as 400 kl/month. In adjacent areas there is no water available through the distribution system and water must be supplied by tanker at great expense. This is typical of areas where water is not metered and consumers either do not pay at all for their water or pay a fixed monthly tariff. This type of problem is experienced throughout South Africa and various other countries in Africa. The only solution to this problem is to ensure that if consumers use more than a certain amount of water (as dictated by the appropriate legislation) they must be held responsible for payment. This in turn requires the use of domestic meters and so it can be seen that without domestic metering, there is little control on the domestic water use.

There are several domestic water meters available which can offer different capabilities. When selecting a domestic meter, the following points must be noted:

- **Make of meter:** in low income areas, meters with brass fittings may be vandalised for scrap. In such areas plastic meters and fittings may be more appropriate;
- **Billing for water used**: in areas where billing is based on meter readings, the meters must be accurate and reliable. In other areas where water is not billed according to the metered consumption, it may be appropriate to use cartridge type meters, which can be taken out and used elsewhere. They would only be used to check consumption from time to time;
- **Pre-paid meters**: in some areas pre-paid meter systems are requested by the consumers and can be very successful. In other areas, such meters cause endless problems and are eventually replaced with conventional meters. It is important to work closely with the consumers and not to implement an expensive metering system which cannot be maintained or supported by the quantity of water used. With a pre-payment meter system, an awareness and education campaign to inform consumers is of utmost importance;
- **Automatic meter reading systems**: some metering systems use advanced automatic meter reading technology. While this can work well in some areas, particularly well-developed areas with a stable consumer base, it may not function properly in many of the less formal low-income areas throughout Africa.

4.6 PIPELINE PROTECTION

Pipeline corrosion is the chemical attack of the pipeline material which can take place from the outside or the inside of the pipe. In some areas, the ground conditions are extremely aggressive and the pipes must be well protected from the chemicals in the soils. In other areas the water itself contains chemicals and even bacteria which attack certain pipe materials, especially steel and in some cases also copper. There are various pipeline protection methods, which include:

Bitumen coatings

- Bitumen (cold application);
- Bitumen (hot application);
- Bitumen dip;
- Spun bitumen lining;
- Glass fibre and bitumen coatings.

Epoxy coatings

- Epoxy coal tar paint (not suitable for potable water);
- Copon EP2300 (suitable for potable water);
- Copon Hotcote DW Fusion bonded epoxy lining;
- Plastic tape outer wrap.

Cement mortar linings

In some cases, a cement mortar lining is used to provide protection to the pipe. This approach is normally used on large diameter steel and iron pipes where the lining can be replaced during the life of the pipe if required. Problems can occur if the lining is damaged or starts to flake off the pipe, which results in pieces of concrete or mortar moving through the distribution system. This may cause damage to meters and valves or blockages to connection pipes downstream.

Cathodic protection

Cathodic protection is a specialised field, involving protection of steel or iron pipes, through the use of an electrical charge. This can be provided from a formal electricity supply or by connecting sacrificial materials to the pipe which will corrode in preference to the pipeline and therefore provide protection to the pipe.

In some countries, stray currents can originate from the electricity network or more commonly from an electric railway network. Such currents can cause serious damage to pipelines unless they are properly protected. Cathodic protection is usually only used for large trunk mains which are of strategic importance. Certain companies are available which specialise in this form of pipeline protection.

4.7 LOGGING AND LOGGING RESULTS

Data logging plays an important role in the management of the distribution system. Logging results can provide information for:

- Night flow analysis;
- Pressure analysis;
- Calibration of network analysis;
- Identifying possible cross boundary connections;
- Indicating performance and functionality of control valves, pumps, meters, pressure controllers, etc;
- Sizing of equipment such as meters, control valves, etc;
- Confirmation of design criteria for upgrading of infrastructure;
- Calculation of peak factors.

The result of an open zone valve is illustrated in **Figure 4.17**. The zone is supplied through a PRV with a fixed outlet pressure of 75 m and a minimum night flow of 12 m^3/h. On the Wednesday, a zone valve was opened which increased the night pressure to 90 m and closed the PRV in the process, resulting in zero flow logged at the inlet. The zone inflow is now from an un-monitored cross-boundary feed.

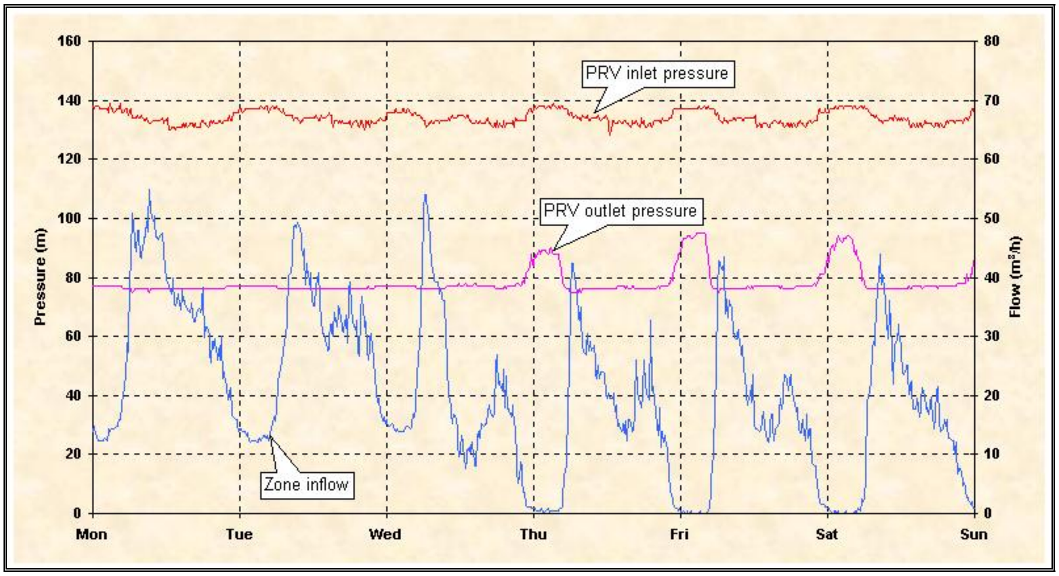


Figure 4.17: Result of a Cross-Boundary Connection

It is important to log both the flow and pressure in a zone, as the pressure/flow relationship for each system is different. No proper evaluation can be made if only pressure or flow is logged.

Various recorders are available which can be used to log flow and pressure. When selecting a recorder the following aspects should be taken into consideration:

- **Event, frequency, parallel, state, count, analogue recording modes** – each model has its own merits and application and it is recommended to consult your supplier;
- **Statistical recordings** – this function can be useful with time-based recording, as it provides statistics such as minimum, maximum and standard deviation records over the logging interval;
- **Battery life and ease of replacing batteries** – typical battery life is three to five years. Battery replacement varies from standard cells that can be replaced by the user to lithium cells which can only be replaced by the supplier;
- **Robustness and securing** – recorders have to be robust as they are often moved and exposed to knocks and bumps. In areas with security problems, it is also useful if the recorder can be secured to the pipe work with a chain and lock;

- **Compatibility with remote communications** – remote communication by GSM, PSTN and radio is becoming increasingly popular. The main advantage of remote communications is that technicians can now download recordings from their office, make an immediate evaluation and eliminate travel time;
- **Accessories** – pressure transducers, pulsers, frequency converters, level sensors, etc are required to undertake logging. These accessories have a limited lifetime with substantial cost.

Figure 4.18: Installation of Loggers **(courtesy Pressure Management Systems)**

The management/programming software is equally important and the following should be taken into consideration:

- **Ease of programming/downloading** – the programming interface should be easily understandable and programmable using desktop, portable or handheld computers. Loggers programmable from portable or handheld computers have the advantage that they can be programmed and downloaded in the field;
- **Database functionality (temporary or permanent logging)** – some loggers are designed for permanent installation whereby the data is appended to the existing dataset when downloaded. If this logger is used for temporary logging at a certain point, care must be taken not to append datasets from various logging points. Loggers designed for temporary logging creates a new data file

each time the logger is downloaded but has the disadvantage that numerous files are created for a single site;

- **Compatibility with other software** – the software should have export capabilities to use data in spreadsheets and presentations, etc.;
- **Data analysis capabilities** – the software should provide basic statistical analysis software, zoom and printing.

When evaluating logging results the following aspects should be checked:

- The logger must be programmed with the correct flow factor for the specific meter. It is recommended that the meter reading is taken before and after the logging exercise and checked with the total volume logged;
- The maximum logged pressure should be equal or less with regard to the maximum static pressure for the specific zone;
- Ensure the date and time is correct;
- Ensure the absolute pressure is logged (atmospheric = 0 kPa);
- Ensure the logger is switched on before installation;
- Check that the logger is active before leaving.

4.8 LEAK DETECTION AND REPAIR

4.8.1 General

From the analysis of the Minimum Night Flow, it is possible to identify zones with high leakage and also to split the leakage into Bursts and Background leaks. If the analysis reveals a high level of burst leakage, the next step is to locate the leaks and repair them. After the leaks have been located and repaired, the Minimum Night Flow analysis is repeated to verify that the burst leakage has been eliminated. It should be remembered that while burst leakage can be eliminated, background leakage cannot be eliminated completely but can be reduced by various WDM measures.

There are numerous approaches to leak location, each of which has its advantages and limitations. The water supplier must select the most appropriate form of leak detection for the zone or system being investigated and in general, one or more of the following approaches could be used:

- Sounding (Listening Sticks and Geophones);
- Leak Noise Correlation (LNC);
- Step Testing;
- Modified Step Testing;
- Ground Penetrating Radar (GPR);
- Noise loggers (e.g.Aqualogs and Zonescans).

A short description of each method is provided in the remainder of this section.

4.8.2 Sounding (Listening Sticks and Geophones)

Sounding (see also **Section 2.5**) of a water distribution system is undertaken using a listening stick (**Figure 4.19**), which is placed against all valves and hydrants to detect noise emitting from possible leaks. This approach will not identify the position of the leak but will normally indicate if there is a leak on a certain section of pipe. Sounding is normally used for an initial sweep of the area indicating sections of the system, which must be investigated in more detail using one of the more accurate techniques for pin-pointing the location of the leak. It is normal practice to scan the whole water distribution system using the Sounding Stick. Thereafter approximately 20% of the system should be investigated in more detail, using more sophisticated leak location equipment such as a leak-noise correlator.

Figure 4.19: Manual and Electronic Listening Sticks (Courtesy Radiodetection (Pty) SA)

A Geophone (**Figure 4.20**) is an instrument, which comprises a very sensitive microphone, an amplifier and headphones. Water leaks are detected by listening for noises made in pipelines caused by water escaping through the wall of the pipe. Usually there are two types of microphone. The first is a wand-type microphone (or listening stick) to permit contact with fittings such as valves and hydrants. The second type is a ground microphone, which is moved along the ground or road surface on top of the line of the pipe. The leak is pinpointed at the position of greatest noise intensity as detected by the ground microphone.

Figure 4.20: Ground Microphone **(Courtesy Radiodetection (Pty) SA)**

4.8.3 Leak Noise Correlation

A leak noise correlator (**Figure 4.21**) is a device that can locate (pinpoint) the position of a leak by measuring, at two different locations on the pipe, the noise that arrives at these points having travelled along the pipe from the leak. Microphones or transducers are placed in contact with the pipeline (usually at fittings). During the correlation scan, the leak noise will reach the closer transducer first and the signal is progressively delayed until the more remote transducer receives a similar leak noise. The time delay, the difference between the times that the leak noise reaches the two transducers, is measured, and the accurate position of the leak can be computed as shown in **Figure 4.22**. The leak noise correlator is used after the initial sweep has identified a suspected leak along a specific part of the main.

Figure 4.21: Leak Noise Correlator (Courtesy Radiodetection (Pty) Ltd SA)

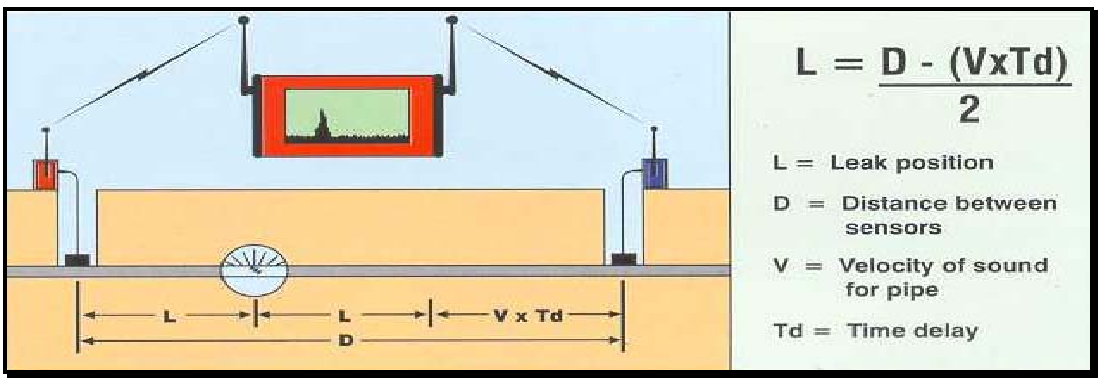


Figure 4.22: Theory of Leak Noise Correlation (Courtesy T Waldron, Wide Bay Water)

4.8.4 Step Testing

Step testing is an indirect method of locating leaks that involves the measurement of water flow in discrete areas. The flow in each discrete section is measured during the period of Minimum Night Flow, when the water used by the consumers should be low. Sections of the zone are eliminated by closing the isolating valves while the Minimum Night Flow is recorded continuously. If there is a substantial drop in the Minimum Night Flow when a particular section of the zone is cut off, it suggests that there is a leakage problem in that area. The approach is shown in **Figure 4.23**, which indicates four steps from which it can be seen that there is a noticeable drop with steps 2 and 4 suggesting possible leakage in these areas.

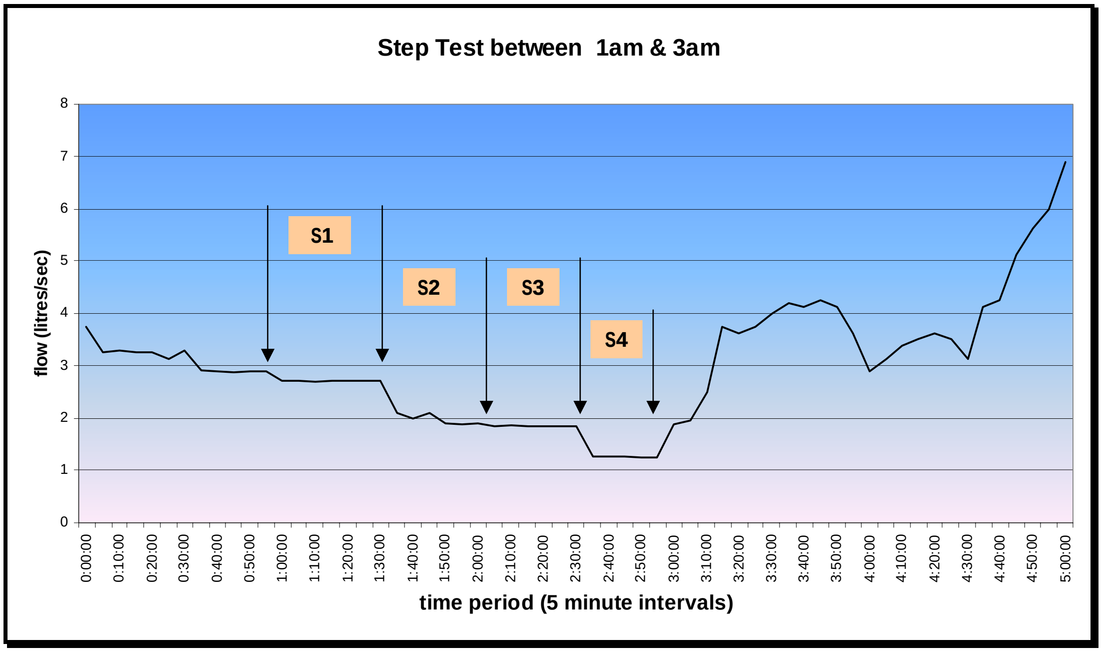


Figure 4.23: Typical Results from a Step-Test Analysis **(courtesy T Waldron, Wide Bay Water)**

4.8.5 Ground Penetrating Radar

Ground Penetrating Radar (**Figure 4.24**) operates on the principal of emitting a radar pulse through an antenna into the ground. This pulse is reflected back from the various interfaces in the ground. By moving an antenna slowly over the surface, a picture is built up of what is below the surface (**Figure 4.25**). The picture can be viewed on a monitor whilst scanning is in progress. The data can be recorded on tape for further analysis and record purposes. Water in the ground is particularly reflective to radar, which thus enables radar to be used to locate water in the ground. Further investigative work is then required to determine if the water is groundwater or leakage from pipelines.

Figure 4.24: Ground Penetrating Radar **(Courtesy RVM Surveys)**

Figure 4.25 shows the image of a leak discovered by acoustic methods and confirmed by GPR. The additional water in the ground is very reflective to radar and shows up as the brighter blue and purple areas, with the main at the top, apparently rising and falling due to the compressed scale of the image.

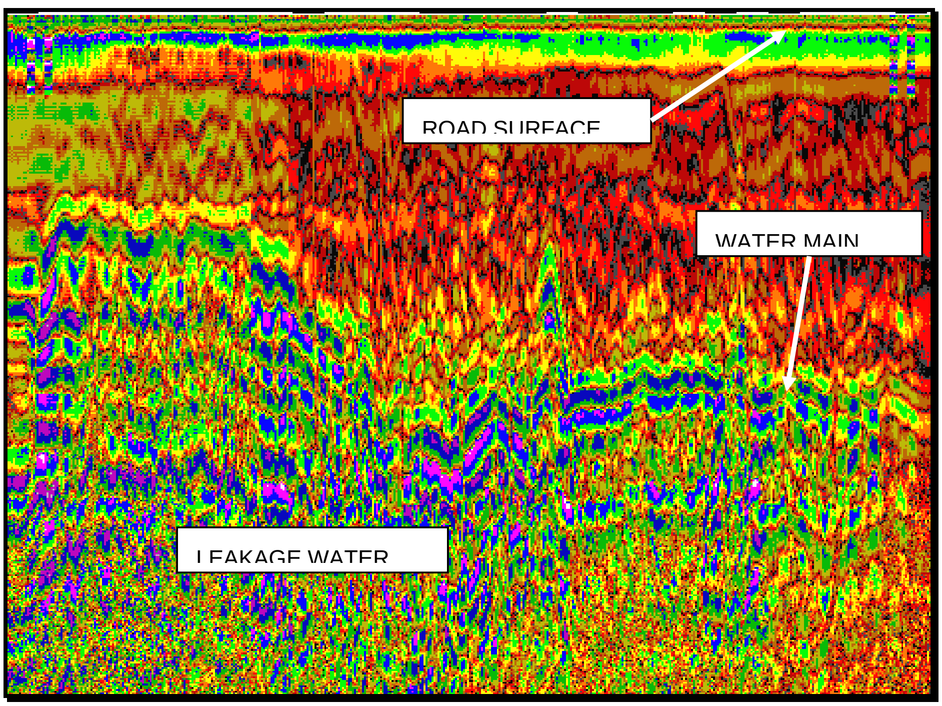


Figure 4.25: Leakage Image created with GPR **(Courtesy RVM Surveys)**

4.8.6 Noise Loggers (Aqualogs and Zonescans)

Noise loggers are a relatively new and innovative technology that is rapidly being accepted by many large water suppliers. The basic approach involves attaching (magnetic) the self-contained noise logging devices to various hydrants and valves throughout the water distribution system. The units each record any leakage noise during a pre-determined period and the information can be captured remotely from a vehicle equipped with a receiver. In this manner the information from all of the noise loggers can be captured quickly and efficiently by one technician. After the information has been captured, it is processed using accompanying software, which provides an indication of the likelihood of a leak in the vicinity of each noise logger. The Zonescan (**Figure 4.26**) and Aqualog (**Figure 4.27**) systems are not used for pinpointing leaks, but rather for identifying areas where a leak is likely to be found. The location of the leak must again be determined using a correlator.

Figure 4.26: Zonescan (Courtesy Gutterman International, Switzerland)

Figure 4.27 Aqualog System (Courtesy Radiodetection (Pty) Ltd SA)

4.8.7 Leak Detection Summary

In most situations, it is found that there is no single technique, which will find all leaks in a system and the personnel using the equipment are often more important that the equipment being used. The most effective approach for leak detection is often to make use of a combination of techniques. In most cases, this will involve a broad sweep of the area using sounding, GPR, Step Testing, Aqualogs or Zone Scans. After the initial sweep is completed, the Leak Noise Correlator and/or the Ground Microphone are the best techniques for pin-pointing the leaks.

Leak detection should not be regarded as a "once-off" exercise. Different size leaks emit different noise intensities. Small leaks generally emit a higher intensity of noise and are generally picked up first. Larger leaks may still be present. Once initial leak repairs have been undertaken, the area should be tested again to ensure that larger leaks have not been overlooked.

The best approach for undertaking a leak detection exercise, especially in a central business district (CBD) area, is to make use of a combination of techniques. Some methods are better suited for a rough first time sweep of an area, while others can be used to pin-point the exact location of leaks.

5 LOSSES ON PROPERTIES AFTER THE METER

*It should be noted that some of the figures quoted in **Section 5** were based on information provided in the reference book written by A Vickers (Handbook of Water Use and Conservation, ISBN 1-931579-07-5). The authors wish to acknowledge the work of Ms Vickers as a valuable source of information and thank her for permission to refer to her work. Every water supplier should own a copy of this book for reference purposes.*

5.1 WATER SAVINGS IN TOILETS

5.1.1 Water Saving in Toilet Cisterns

The four most basic measures to reduce water use by toilets are:

a) Low-volume toilet cisterns;

b) Dual flush toilet cisterns

c) Waterless and composting toilets;

d) Toilet retrofit devices.

Each of the above measures is discussed in further detail.

a) Low-volume toilet cisterns

Low flow toilets, typically use 6 litres of water of water and are available in the same operating designs as high volume (10 to 13 litre) toilets. There are three types of low flow toilets: gravity tank toilets, flushometer-tank toilets and flushometer-valve toilets. (The flushometer toilets require high pressure to operate and in many parts of Africa this cannot be guaranteed and is therefore not considered a viable alternative for the African market). Only the gravity tank toilet, which is the most common form of low volume toilet and most appropriate for consideration in Africa will be discussed in further detail.

The gravity tank toilet, as shown in **Figure 5.1**, operates when the handle is pulled, causing the flush valve at the bottom of the tank to open and start releasing water from the tank into the bowl. The rushing water creates a vacuum or siphon that pulls solid and liquid wastes from the bowl, through the outlet and into the sewer. While the bowl is being emptied, the flush valve inside the tank closes and the automatic fill valve is tripped to allow water to refill the tank.

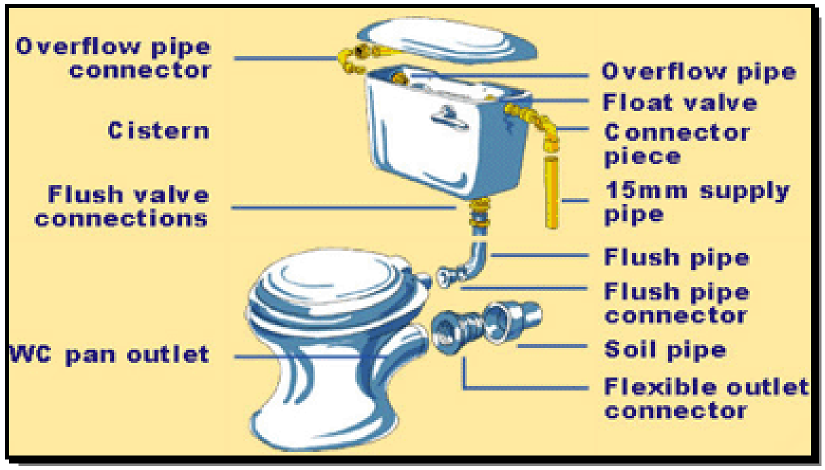


Figure 5.1: Schematic Layout of Gravity Flush Toilet (Courtesy www.waterwise.co.za)

b) Dual flush toilet cisterns

The dual flush toilet operates in the same manner as the normal gravity toilet but also allows the user to select either a full flush (±9 litres) for solids or a half flush (±4,5 litres) for liquids. Some designs operate with two handles (levers) and others with one handle that can be turned or depressed in two directions for the full of low flush respectively.

The estimated water use by high-volume, low-volume and dual flush toilets is shown in **Table 5.1**, assuming 5 flushes per person per day and a ratio of half flush to full flush of 4 to 1. While **Table 5.1** indicates the average percentage reduction per flush, the actual saving for a household will depend on the number of people in the household and the number of people home during the day.

Table 5.1: Potential Savings from Various Toilet Cisterns (Beith and Horton 1998)

Toilets	Water Usage (Litres per person per day)	Percentage reduction
11 litre full flush	55	STANDARD
9 litre full flush	45	18
11/6 litre dual flush	35	36
6 litre full flush	30	45

9/4.5 litre dual flush	27	51
4.5 litre full flush	23	58
6/3 litre dual flush	18	67

Note: Based on assumption of 5 flushes per person per day and a ratio of half flush to full flush of 4 to 1.

Benefits - low volume toilet cisterns can save thousands of litres of water per year. In addition, dual flush toilets can save even more water by allowing a minimal flush for liquids. The savings often provide payback on the installation costs within a matter of months.

Potential pitfalls - although many low volume models have been reported to provide excellent performance, there are certain situations where problems can be experienced. The main problems include:

- Poor-quality mechanical parts (ball-cock assembly, fill valve, flush valve and related components) are sometimes used in otherwise well designed gravity tank toilets, causing leaks and unnecessary water waste;
- Larger than normal volumes of waste flushed by gravity toilets, can result in temporary clogging problems or double flushing;
- In low income areas, newspaper is often used in place of toilet paper, and this invariably results in blockages especially when used with certain low-flush and dual flush toilets;
- Users must be educated to avoid flushing rubble and other refuse down the toilets;
- Poor installation may result in failure or excessive leakage soon after commissioning.

Conclusions - low volume toilets and especially dual flush toilets can save significant amounts of water if correctly installed by plumbers, based on applicable rules and practices. Care should be taken in selecting a product with good performance and durability and ensuring that the conditions under which the toilets are to be used are suitable for the product being considered.

Some typical toilet installations from the various Leakage Reduction projects undertaken by Rand Water in South Africa are shown in **Figure 5.2**.

Figure 5.2: Dual Flush Toilets (courtesy Ayanda Consulting)

c) Waterless and composting toilets

Waterless toilets use no water for flushing and require only small amounts for periodic cleaning and maintenance. The most common types are incinerator and composting toilets. Incinerator toilets make use of high temperature electric or propane heat to burn wastes to fine ash and, therefore, will fail to work without electricity or gas. This is clearly not an appropriate option for the African market and therefore only the composting toilet, which uses radiant heat to break down the human waste, will be discussed in further detail.

Composting toilets provide the ideal environment for human waste to break down through a natural process into an inoffensive compost-like material. The system utilises radiant heat and adequate ventilation to pass through the waste within the sealed container, thus converting solid waste, via stimulated bacterial and biological activity, into a compost-like material. The product, usually removable by a clean-out tray, should be odour free and safe if the process has been correctly managed.

Benefits - a composting toilet can be beneficial for the following reasons:

- It does not use water or chemicals;
- It operates on a closed circuit system;
- It is odourless if correctly managed;
- No sewage treatment plant or network is required;
- There should be no flies if it is properly maintained;
- It uses no energy;

- Operating costs are low; and
- It can be used indoors or outdoors.

Potential pitfalls - while composting toilets are very attractive for a number of reasons, they have certain disadvantages, which may well limit their use particularly in the African environment:

- They can be expensive to install;
- Poor workmanship during installing will result in failure of the system and odours;
- If the system is not properly maintained it will fail – a key consideration in most parts of Africa.

Applications - composting toilets can be used in the following situations:

- Domestic (both peri-urban and rural);
- Schools;
- Holiday cottages and farms;
- High water table areas; and
- Underground mining areas.

Conclusions - composting toilets can provide a viable means of reducing water use for human waste removal, but are significantly different from conventional flush toilets and require careful selection, installation and ongoing maintenance to operate reliably and safely. It is unlikely that composting toilets will be practical in low-income areas throughout much of Africa due to the associated costs as well as the potential problems that will be experienced if the toilets are not properly installed and/or maintained.

Figure 5.3: Waterless toilet installations **(Courtesy WRP (Pty) Ltd)**

d) Toilet retrofit devices

Toilet retrofit devices are used in residential and non-residential water conservation programmes to reduce the amount of water needed to flush high volume toilets that use 10 to 13 litre cisterns. Low volume cisterns (6 and 9 litres) as a rule cannot accommodate retrofit devices, however, in some instances they can be adjusted with dual flush devices for low volume toilets. The most common devices and adjustments include:

- Displacement devices;
- Early closure devices; and
- Dual flush adaptors.

Displacement devices

Toilet displacement devices such as bags, bottles and bricks are commonly used in gravity tank toilets because they are easy to install, generally reliable and inexpensive. Displacement devices save water by occupying a part of the toilet tank that would otherwise be filled with water, thereby reducing the amount held in the tank and released for each flush.

Figure 5.4: Typical toilet displacement device **(Courtesy Save a Flush)**

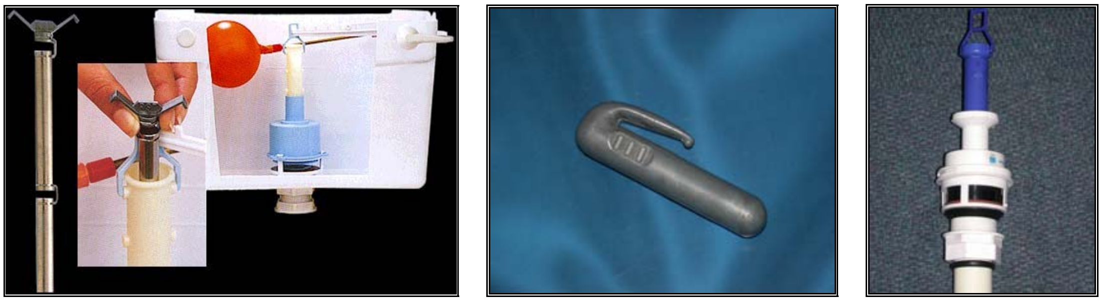
Benefits - the benefits of using volume displacement devices include:

- Water is saved with each flush. Depending on the volume of the object inserted, approximately 1 to 2 litres of water is saved each time the toilet is flushed;
- The devices are generally reliable; and
- They are easy to install, requiring no plumbing experience.

Potential pitfalls - volume displacement devices can cause problems or even result in greater water use in some cases if they are not installed properly and the design of the toilet pan is so inefficient that the lower flush volume causes blockages or results in a second flush being required. Sometimes these devices also interfere with the flushing mechanism if not regularly checked.

Early closure devices

Early closure devices can be installed in most high volume gravity tank toilets to replace or amend the original flush valve or mechanism. When the toilet is flushed, the early closure device forces the valve to close early, releasing a reduced amount of water but with enough velocity for a complete flush. Early closure devices are available in various styles and patterns.



(a) (b) (c)

Figure 5.5: Early Closure Devices -(a) Toilet Stop, (b) Counterweight, (c) Multi-Flush **(Photo (a) Courtesy Toilet Stop and Photos (b) and (c) courtesy WRP (Pty) Ltd)**

Benefits - the benefits of using early closure devices are:

- They can be used in most high volume (10 to 13 litre) gravity tank toilets;
- Water is saved each time the toilet is flushed;
- Generally low cost; and
- With some of the devices, the user can decide when to stop the flush.

Potential pitfalls - some organisations appear to be unhappy with early closure devices while others are extremely happy with their performance. Like most devices, it is important that they are properly installed and each situation should be judged on its own merits. If such devices are incorrectly installed, they can lead to leakage of the flush valve or early closure, both of which will eventually lead to greater water use rather than savings.

Dual flush adaptors

Dual flush adaptors can be installed in many gravity tank toilets to provide alternative low and high volume flush controls. Further details on dual flush toilets are provided in **Section 5.1.1.**

Conclusions - toilet retrofit devices can save significant volumes of water if correctly installed. Care should be taken in selecting a product with proven performance and durability.

5.1.2 Water Saving Urinals

The three most basic measures to reduce water use by urinals are:

a) Low-volume urinals;

b) Waterless and composting urinals;

c) Urinal retrofit devices.

Each of the above measures is discussed in further detail.

a) Low-volume urinals

Low volume urinals typically use 3 litres per flush as opposed to 8 to 12 litres used by high volume urinals. High volume flushometer-valve urinals can be replaced with these low flow units, often with no modifications to the bowl or to wall floor connections. Other types of high-volume urinals (such as siphonic, washout and washdown urinals, **Figure 5-6**) require removal of the old flushing apparatus and installation of an entirely new fixture and valve.

Benefits – the benefits from low volume urinals include the following:

- Any flushometer-valve urinal can be replaced with a low volume urinal, often with no modifications required to the bowl;
- Other types of urinals require removal of the old fixture and installation of an entirely new fixture;
- Low volume urinals can save thousands of litres of water per year which can pay back the cost of installation within months

Figure 5.6: Siphonic (tip-tray) Urinal **(Courtesy Ayanda Consulting)**

Potential pitfalls - although most models have been reported to provide good performance there are some models, which have problems with splash back and staining.

b) Waterless Urinals

Waterless urinals require no water for flushing and can often replace conventional fixtures connected to standard 50 mm drain lines. One type of waterless urinal is the Waterless Company's No-Flush® urinals, as shown in **Figure 5-7.** The No-Flush urinal is designed to have no odour and to minimize bacterial growth on dry surfaces. No-Flush uses a special drain insert (the Eco Trap®) containing a thin biodegradable liquid (Blueseal®), which floats in the urinal trap and forms a barrier barring the escape of sewer vapours, as illustrated in **Figure 5-7.** The sealing liquid must be replenished at 1 500 use intervals.

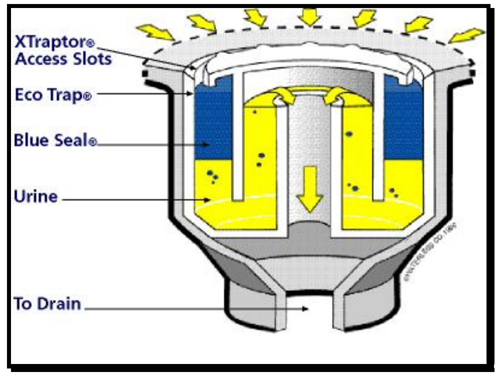


Figure 5.7: Waterless urinal (courtesy Waterless Company)

Benefits - the benefits of waterless urinals include the following:

- They use no water at all;
- They are odourless if correctly commissioned and maintained;
- They are touch-free;
- No water pressure required.

Potential pitfalls - although some models have been reported to provide good performance there are some models, which have problems with splash back and staining. Maintenance personnel need to be instructed on how to replace the trap seal when necessary and how to wash the fixture. First time users can be confused by the absence of a flush valve or water pipes.

Applications - waterless toilets are ideal for use in the following situations:

- Institutions and schools;
- Industries;
- Commercial premises;
- Sports facilities;
- Airports, railway stations and bus terminals.

Composting Urinals

Composting urinals require no water and are connected to composting toilet systems (see section on Water Saving Toilets and Devices.) Urine deposited in a composting urinal is conveyed by gravity through a vertical drain directly to the composter. The fan used to vent the composter creates a negative pressure that continually draws air from the urinal drain, preventing the escape of odour and gases. More information on the benefits and potential pitfalls is provided in **Section 5.1.1** under "Composting Toilets".

c) Urinal retrofit devices

The four main types of urinal retrofit devices are as follows:

- Flush-valve replacement and retrofit;
- Flash-valve efficiency adjustments;
- Timers for siphonic-jet and blowout – valve urinals;
- Infrared and Ultrasound Sensor Activated Flush Controls.

Flush-valve replacement and retrofit

For high volume urinals, the flush valve can be replaced with a 3 litre flush valve, although not all types might be suitable for retrofitting. The installation may require some modifications to the connection and, in some cases, replacement of the urinal bowl.

Flush-valve efficiency adjustments

Water use by conventional, high volume flush valves in urinals can sometimes be reduced by turning the adjusting screw under the cap located on the horizontal portion of the valve. This adjustment can save up to 3 litres per flush and should not adversely affect the fixture's flushing performance.

Timers for siphonic-jet and blowout-valve urinals

Timers or time clocks can be used to control the frequency of flushing or water flow can be installed on urinals that flush periodically or continuously, such as siphonic jet and blowout-valve urinals. The timer can be set to operate only when a building or facility is in use. Push buttons should always be installed on existing siphonic urinals to flush the urinal only after use. The replacement or retrofitting of automatic flushing urinals is often a very effective form of WDM and the payback is generally a matter of several months. All automatic flushing urinals should be identified and replaced as a matter of priority especially in schools and other communal buildings.

Figure 5.8: Push button Urinal (courtesy Ayanda Consulting)

Infrared and ultrasound sensor activated flush controls

Infrared and ultrasound-activated controls may be used to reduce double flushing on urinals. Although the primary value of these controls may be reducing exposure to germs, the water conservation benefits of these devices are uncertain. Some installations have been reported to perform well while others are prone to malfunction and double flushing.

Figure 5.9: Infrared activated Flush controls (courtesy Sentinel Systems)

Benefits

The benefits of infrared activated flush controls include:

- Water can be saved with each flush if the units are operating properly;
- The infrared sensors are hygienic and reduce exposure to germs.

Potential Pitfalls

The potential problems associated with infrared sensors include:

- They are a high-tech and relatively costly option which may not be appropriate in many African situations;
- The timers and infrared sensors must be checked periodically to ensure that they are set properly and are not causing double flushing;
- The infrared sensors require electricity supply and in many African situations this is neither practical nor affordable.

5.1.3 Taps

The most basic measures to reduce water use by taps are:

a) Low volume taps;

b) Tap retrofit devices;

c) Aerators;

d) Metered-valve, self-closing and sensor activated taps; and

e) Repair of leaking taps.

a) Low volume taps

Low volume kitchen and lavatory taps look similar to conventional, high volume fixtures. Reduced flows can be achieved through the use of aeration, flow control, and/or spray devices.

b) Tap retrofit devices

The flow control devices found in low volume taps are also available for most high volume taps. In most cases, retrofitting a high-volume tap is less expensive than replacing the entire unit, often with similar water savings.

c) Aerators

Tap aerators are circular screen disks, usually made of metal as shown in **Figure 5.10** that are screwed onto the head of the tap to decrease flows. Aerators reduce flows by mixing air with water, giving the sensation of ample water yet at reduced volumes. An aerator is a simple economical and effective device for reducing water use by taps.

Figure 5.10: Typical tap aerators (Courtesy RST Water Saving Systems)

Benefits - tap aerators are beneficial for the following reasons:

- They reduce water consumption significantly;
- They are easy to install if the tap has a suitable thread;
- They are relatively inexpensive;
- They provide sufficient water for washing purposes and the consumer will normally be unaware that they have used less water than with a normal tap.

d) Metered-valve, self closing, and sensor-activated taps

The following description explains the working of each of the above retrofit devices:

- Metered-valve taps deliver a preset amount of water before shutting off;
- Self-closing (spring loaded) taps feature a spring-loaded knob that automatically shuts off the water when the user releases the knob;
- Sensor-activated taps contain light and motion sensing devices that cause water to flow once the sensors detect motion directly in front of them. When the user steps away, the tap should turn off. The sensor-activated taps require a power supply to drive the sensors, which may be a limitation in certain situations.

Figure 5.11: Self-Closing Taps installed at a school (Courtesy Ayanda Consulting)

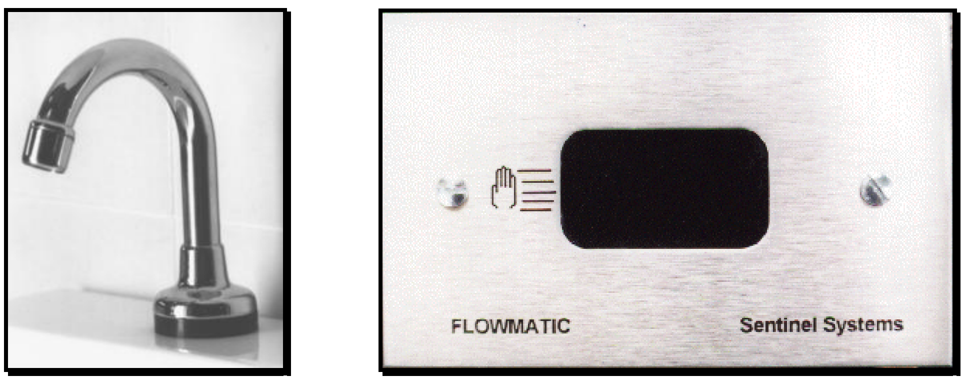


Figure 5.12: Typical sensor activated tap (Courtesy Sentinel Systems)

Benefits - sensor activated taps have the following benefits:

- They are more water efficient than many other taps because they operate only as long as required;
- They are hygienic since no contact is made with the tap.

Potential Problems - sensor activated taps are unlikely to be practical in many situations, particularly in Africa for the following reasons:

- They offer a relatively expensive and "high-tech" solution which may be too expensive for use in many parts of Africa;
- They require a power supply;

- If the volume setting of the taps is set too low it may result in higher than normal water use;
- The spring in the self closing tap should not be so hard that small children cannot open the tap;
- Periodic cleaning of sensor-activated taps is required to minimise malfunctions caused by sediment obstructions.

e) Repair of leaking taps

Leaking taps are one of the most common sources of water wastage in many households. Taps should be checked regularly for leaks at the tap head and for seepage at the base and on connections. Tap repairs normally include the following measures:

- Replacement of worn washers. Dripping taps or those losing a steady stream of water are most often caused by a worn washer, which is quick and inexpensive to replace.
- Tightening or repacking tap. Leaks at the tap stem (just below the handle) or base usually indicate that the fixture needs to be tightened or that new packing needs to placed in the packing nut. Again, this is quick and inexpensive.

Benefits - the benefits of repairing leaking taps include:

- Significant quantities of water can be saved;
- Washers are cheap and commonly available;
- A low level of skill is required to repair the taps and unskilled personnel can be trained very quickly to carry out such work – ideal for job creation.

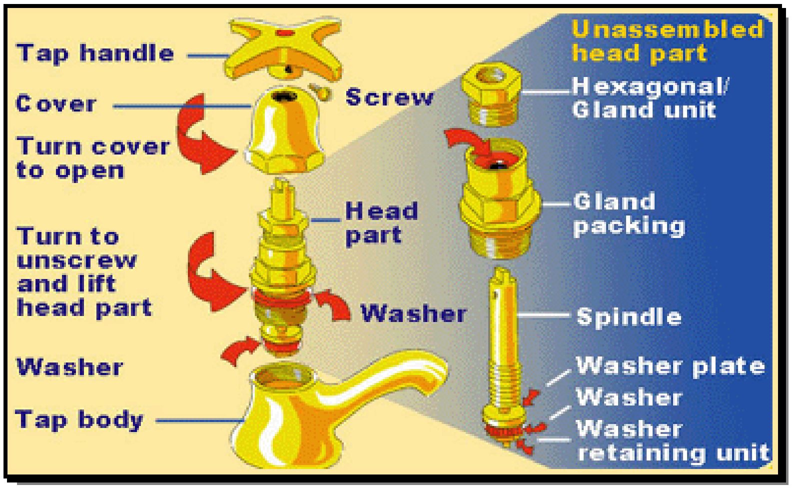


Figure 5.13: Schematic illustration demonstrating how to repair a tap washer (Courtesy Rand Water)

Potential Pitfalls - there are no real pitfalls to replacing leaking tap washers. The only main consideration concerns the underlying cause of the leaking taps. If the cause of the problem is high pressure, then repairing the taps will reduce leakage for a short period after which the leaks will re-appear and the leakage problem will persist. In such cases, it is often advisable to address the underlying problems, being a high water pressure, before spending time and effort addressing the symptom.

5.1.4 Showerheads

Considerable savings can be made using a quality "low-flow" showerhead in both domestic and commercial installations. Care must be taken to ensure that the low-flow showerheads are of a high quality, or the individual using the shower will not be satisfied and may change back to the original showerhead. Considerable research has been carried out on the issue of low flow showerheads and it is conclusive that the use of such devices will save significant quantities of water without reducing the quality of service to the user.

The three most basic measures to reduce water use by showerheads are:

a) Use of low-volume showerheads;

b) Use of showerhead retrofit devices; and

c) Adjusting showerheads to use less water.

a) Low-volume showerheads

Low volume showerheads improve water use efficiency compared with high volume showerheads through such features as improved spray patterns, better mixing of air with water, and narrower spray areas to give the user the "feel" of water without high-volume flows. A variety of spray and other designs options are available for low-volume showerheads. A typical flow rate pressure relationship is shown in **Figure 5-13** for a universal showerhead and a range of water efficient showerheads.

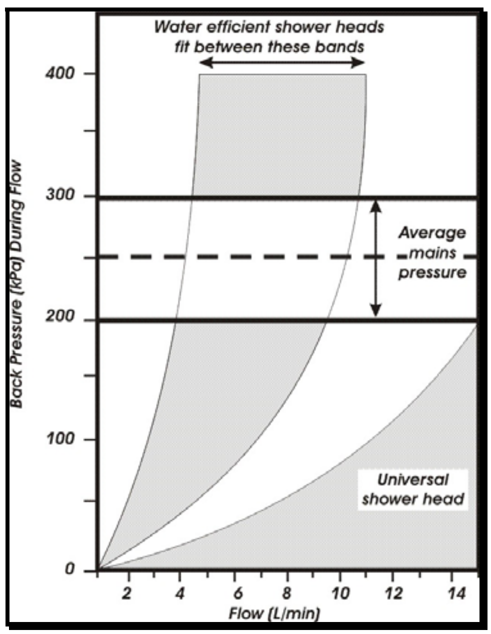


Figure 5.14: Typical Flow Rate- Pressure Relationship for a universal showerhead and a range of water efficient showerheads (Adapted from Beith and Horton 1989)

Showerheads using a flow restrictor often cost less than fixtures that have a flow control device. A showerhead flow-control device is a disk containing an elastic O-ring that is controlled by pressure. Under high pressure, the O-ring flattens and reduces water flow, under low pressure the O-ring relaxes and allows a higher flow, providing smoother changes in spray pattern compared with flow restrictors.

Benefits - the benefits of using low flow showerheads are substantial and include the following:

- Significant water savings are normally achieved;
- Significant energy savings (and therefore also CO_2) are achieved;
- Fittings are easy and quick to replace;
- Consumers do not notice the difference if quality fittings are used.

Figure 5.15: Low Volume Showerheads (Courtesy RST Water Saving Systems)

Potential Pitfalls - although many products have been reported to provide good performance, there are some products, which have problems with low flows or uncomfortable sprays patterns. Showerheads using a regulator to provide constant flow at variable pressure tend to be the most appropriate although they can be relatively expensive when compared to conventional showerheads.
Care should be taken, when a new showerhead is installed to ensure that the shower neck does not break inside a wall when too much leverage is used in removing the old showerhead.

b) Showerhead retrofit devices

Two devices are commonly used to restrict flows on high volume showerheads: temporary cut-off valves and flow restrictors.

Cut-off valves

Cut-off valves can be attached to existing showerheads to reduce water use, but should be used only if they are designed and installed properly because they can cause scalding.

Showerhead Flow Restrictors (Disk Inserts)

Showerhead flow restrictors (disk inserts) are typically inexpensive plastic or metal disks with a small hole in the centre. It reduces the flow of water and can be fitted into the coupling of some older, high volume showerheads. This will be where the shower arm is connected.   Due to the relatively crude design, many disk inserts are not compatible with the varied flow and spray characteristics of existing showerheads. Disk inserts are generally no longer considered an acceptable water conservation measure.

c) Shower adjustments

In addition to replacing inefficient showerheads, two adjustments can be made to reduce their water use:

- Reducing the water pressure will reduce water used in the shower, unless the consumer increases the length of time taken to shower. In general, reducing water pressure will result in water savings.
- Lowering the hot water temperature setting can save on energy costs but may not result in water savings.

Adjustments such as these should be made by qualified plumbers to ensure that proper safety and operating standards are maintained.

5.1.5 Pressure reducers

Pressure reducers (see **Figure 5.16**) can be installed to reduce pressures in a building either at the supply point into the building or at certain points inside the building in the case of larger premises. By reducing the water pressure (within flow requirements for each floor and water supply connection) the flow to taps and other fixtures can be reduced.

Benefits - the benefits of using individual pressure reducers in houses and buildings are:

- Water consumption will be reduced if pressures can be lowered;
- Fittings such as taps, toilet cisterns, tanks etc. will last longer when operated at lower pressures;
- The frequency of burst pipes will be lower.

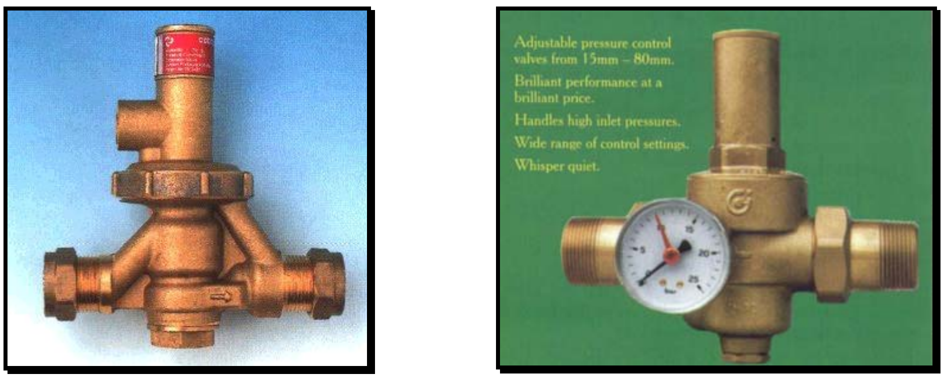


Figure 5.16: Typical pressure reducers **(Photographs courtesy Cobra and Caleffi)**

Pitfalls - when considering the use of pressure reducers, the following issues should be considered:

- Pressure reducers must be installed by a qualified plumber;
- Pressure reducers are relatively expensive;
- Incorrect installation can damage the local pipe network;
- Pressure reducers require maintenance;
- Incorrectly installed pressure reducers can lead to low pressures.

5.2 GREY WATER USE

In most cities where the water supply system is operational, the water supplied to the consumer is of drinking water quality, although less than one percent of that water is used for drinking. The remainder is used for gardening, cooking, washing, bathing and for toilet flushing. In most cases, it is not necessary to use high quality water for gardening or toilet flushing and the term “grey water use” is therefore used to describe the re-use of certain household water for garden irrigation and/or toilet flushing. It is a contentious subject and while it has been successfully used in some areas, it is not permitted by law in others. Grey water should not contain significant amounts of faecal pollution (i.e. not sewage discharges) and typically consists of water discharged from baths, showers and hand washbasins. Most of this water would normally be returned into the water borne sewerage system where it is treated. This water can be used for purposes that do not require such a high quality standard such as flushing toilets and irrigation. Grey water recycling and use has potential water conservation benefits and economic savings.

When considering grey water use, the following issues should be taken into account;

- **Costs.** Grey water recycling involves additional pipe work and storage tanks, which can be expensive. The costs may not be recovered from the water savings from the consumer’s perspective. In some countries, the water supplier provides grants to encourage consumers to develop grey water systems;
- **Health.** Grey water use can pose a health hazard in some cases, especially if it is not implemented correctly. In hot climates, where germs breed faster than in cooler climates, this can be a hazard. Water borne diseases can be particularly dangerous and Grey Water use can create conditions conducive to such diseases, if certain contamination of the water is not prevented. Some water suppliers prefer to ban the use of Grey Water, rather than manage the associated risks.
- **Environment.** While the use of Grey Water represents a form of water conservation, which can be considered beneficial to the environment, it also poses certain risks of contamination of the groundwater and/or surface water, which is potentially damaging to the environment. It is therefore necessary to carefully consider the benefits and risks associated with Grey Water use.
- **Technology.** Grey water use is not the low technology solution to water

conservation that many consumers believe. To be implemented properly and safely, grey water use is based on a number of simple concepts, which require a certain level of technology if the process is to operate properly. In many parts of Africa, the technology is either unavailable or outside the financial resources of the consumers.

- **Existing Effluent Re-use**. In some areas, the effluent from the sewage treatment works is discharged to the ocean where it simply mixes with the seawater. In other cases, it is discharged back into rivers or even supplied to industries or irrigation schemes. The overall impact of household grey water use on the water demand of an area will therefore depend on the situation applicable to the area under consideration. The overall savings may not be as high as anticipated if the existing sewage effluent is already being re-used.

The benefits of using a grey water system include:

- **Performance of Septic Tanks**. In areas without water borne sewerage, grey water use improves the performance of septic tanks and reduces fresh water use;
- **Load on Sewage Treatment Plants.** Grey water use reduces the hydraulic, biological and nutrient load on the wastewater treatment plants which can have several additional benefits such as deferring new capital works etc.;
- **Reliable Irrigation Supply**. Grey water use provides a relatively constant supply of water for irrigation, which is not subject to restrictions during drought periods.

A possible configuration for re-use of water within a household is shown in **Figure 5.17**. While this figure represents the ultimate case of water re-use, various levels of implementation can be considered, and tailored, to suite the requirements of the water supplier and the consumer. It is unlikely that grey water will be appropriate or viable in the African context.

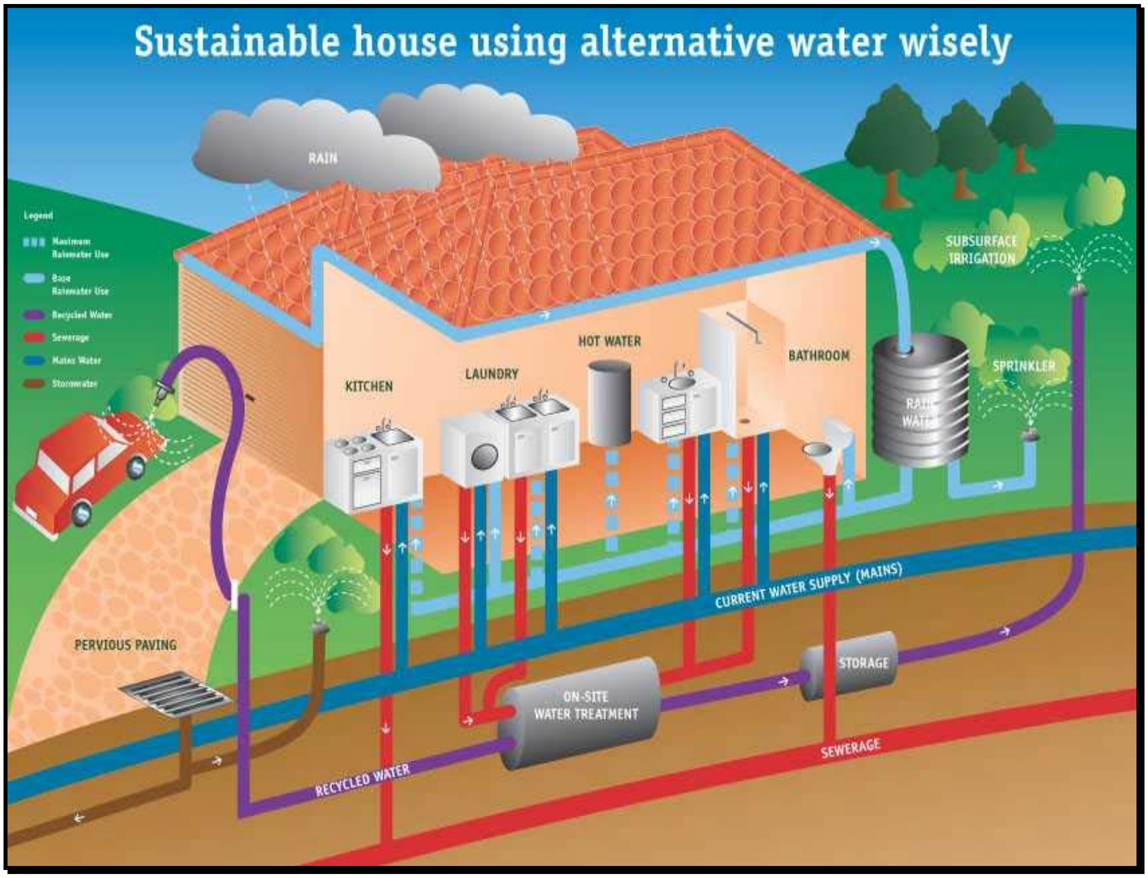


Figure 5.17: Possible configuration for Grey Water Use in a household.

(Diagram courtesy of Allan Mayne, Queensland Government Environment Protection Agency)

5.3 RAINWATER HARVESTING

Rainwater harvesting involves the capture and storage of rainwater from roofs, driveways, parking lots and patios (see also **Figure 5.17**). Rainwater is typically collected in cisterns, barrels or large storage tanks but can also be stored in basins and ponds. In addition to being used for irrigation and potable water, cisterns can also be used for fire fighting and in some areas, it is an important source of drinking water. The successful use of rainwater harvesting depends on various factors including:

- Size of the storage tank;
- Frequency and volume of rainfall as well as its seasonality.

In general, rainwater harvesting is less utilised in city areas with a full water reticulation systems and sufficient water to supply the full demands. In such areas the cost of the purchase and maintenance of the rainwater tank will often exceed the cost of water saved and the consumer may decide that it is not financially viable to collect rainwater. In other areas, however, many residents depend on the collection of rainwater for their main water supply and in such areas the cost of the tanks and associated maintenance costs are considered acceptable. In many areas, the rainwater tanks are equipped with a valve, which directs the first water of the season into the garden as it often contains dirt from the roof or driveway. After the first rains of the season have passed, the remaining water can then be stored, which is often sufficiently clean to use for various household and garden purposes.

Rainwater harvesting has certain benefits including;

- Providing a source of water in areas where alternative sources may not be available
- Reducing municipal water consumption;
- Reducing energy and chemical costs;
- Reducing storm water runoff.

5.4 WATER-WISE GARDENING

In some areas, the water used for domestic irrigation exceeds the water used for normal household use and is therefore the largest component of consumption in many households. If the garden water can be used more efficiently, significant savings can often be achieved without causing any inconvenience to the consumer. In some areas, residents use large quantities of potable water simply to keep their lawns green during dry periods, while in the same areas other residents must survive without water in their taps due to water shortages (see **Figure 5.18**).

Figure 5.18: Lawn being irrigated in an area experiencing water shortages

There are many issues related to proper Water-Wise gardening and the following items represent only a few of the most important and obvious considerations:

Watering Times: Watering should be restricted to the morning or evening. Evaporation is highest between the hours of 10:00 to 16:00 when watering should be avoided if possible. Watering on windy days should also be avoided, as evaporation rates are higher than on a calm day. Water pressure serving sprinkler systems should be sufficient to ensure that the water is applied in an efficient manner. If the pressure is too high, the water may be lost as a fine mist.

Use of water resistant lawn and plants. Many varieties of grass used in garden lawns are not drought resistant and require regular irrigation. Certain drought resistant plants and grasses are now available and these should be used whenever possible. The lawn area can also be designed in an oval form to match the spray pattern of the lawn sprinkler. By landscaping the lawn so that it has a saucer like shape, it can be used to harvest the rainwater from a heavy downpour.

Proper irrigation design. In areas where irrigation systems are used, care should be taken to ensure that the system is not over-designed.

Timing of automatic irrigation systems. In cases where automatic irrigation systems are utilised, there should be some facility to prevent the system being used during wet periods. It is a common sight in some areas to see irrigation systems operating at full capacity during a rainstorm. Tap timing devices for irrigation systems are available which are relatively inexpensive and will ensure that a garden is not being over-watered. At present, drip-irrigation systems, where pipes are laid underground and water is delivered to the root system of the plants, are available.

Use of soil moisture activated controller. In cases where expensive irrigation systems are used, they should be equipped with a soil moisture controller, which will only allow irrigation when required.

Grouping of plants. Plants with similar water needs should be grouped together so that they can be watered at the same time. Plants that thrive in the shade should be planted in the shady areas and vice versa for plants loving sun. These types have different water needs and if similar plants are planted together optimal use of water is achieved without the possibility of over of under watering.

Trenching. Small trenches should be used in gardens to direct any natural runoff and irrigation water to the areas where it is needed. Creating small mounds of earth around specific plants will enable them to be watered individually using a watering can if necessary.

Mulching. Spreading mulch on a garden reduces the water lost to evaporation by up to 70%. It also prevents excessive runoff from natural rainfall and inhibits weed growth as well as supplies nutrients to the soil. Mulch can be made from fallen leaves, wood chips, tree bark, composted straw/manure peat/moss and newspaper and is one of the most effective measures for reducing garden water requirements.

Trigger operated hose nozzle. If a hosepipe is used for garden watering it should be equipped with a trigger nozzle to minimise wastage.

Duration and frequency of watering. The duration and frequency of watering should be consistent with the needs of the plants. It has been shown that one single in depth application is more effective that several smaller applications since it encourages deep root growth.

Drip irrigation. Drip irrigation (above ground or underground network of irrigation pipes with drippers) uses significantly less water than a normal irrigation system and is equally effective. If possible, normal irrigation systems should be replaced with drip irrigation systems.

Some of the items mentioned in this section are completely irrelevant in many parts of Africa where consumers have insufficient funds to pay for water, let alone install automatic irrigation systems. The full range of issues has been provided to cover the full range of conditions experienced in Africa and the water supplier should only concentrate on the issues considered relevant to the system being considered.

6 PUBLIC AWARENESS AND EDUCATION

6.1 EDUCATION WITHIN THE SUPPLIER'S ORGANISATION

Education and awareness are key components of any successful WDM policy and before the consumers can be educated, it is necessary to ensure that the personnel working for the water supplier are fully aware of the need to manage water demand. It is therefore essential that training sessions be provided to introduce and explain in detail the various concepts of WDM throughout the water supplier's organisation. Normally such training sessions are developed at various levels of detail and are aimed to address the following levels of responsibility:

- Top management;
- Middle management and operational staff;
- Remainder of personnel.

Training of Top Management

From past experience it has been found that it is difficult to present training courses to top management over more than one day due to their time limitations and other important commitments. For this reason it is necessary to develop an intensive and high-level one-day training course that will address all key WDM issues without providing too much detail. Such a course would normally cover the following topics:

- General importance of WDM tailored to the specific conditions experienced by the particular water supplier;
- Development of a WDM strategy for a Water Supplier;
- Technical measures on WDM:
  - Introduction to Component Based Leakage Management Techniques;
  - Importance of sectorising and metering;
  - Importance of flow and pressure logging;
  - Leakage reduction measures;
- Education and public awareness;
  - Media marketing
  - Schools and community
  - Consumer advisory service

    - Community development
    - Customer care
- Financial management;
    - Economics of leakage management
    - Tariff setting
    - Good operational practices by Water Supply Authorities
        - Efficiency
        - Water meter management
        - User friendly water account
        - Reduction of water use in municipality
        - Reduction of unaccounted-for-water
    - Replacement policy on water meters and pipeline infrastructure
- Legislation and policy;
    - Undue water consumption
    - Water efficient appliances
    - Groundwater abstraction
    - Individual metering in accommodation units
    - Prevention of water pollution.

Training of Middle Management and Operational Staff

The training of the middle management and operational staff will often be undertaken over a period of several days. Some of the middle management may decide to pass on the "hands-on" training sessions, which are aimed specifically at the operational staff who must be able to undertake duties such as flow logging on their own. The middle management personnel are often enthusiastic about WDM and interested in gaining more than a superficial insight to the various aspects of WDM. The sessions would also have more of a technical nature. A normal training session for middle management and operational staff will involve the following:

- General importance of WDM tailored to the specific conditions experienced by the particular water supplier (as before);
- Introduction to Component Based Leakage Management Techniques (as before);

- Importance of sectorising and metering (as before);
- Practical implementation of sectorising (detailed – hands-on);
- Importance of flow and pressure logging;

- Practical flow and pressure logging (hands-on);
- Interpretation and analysis of minimum night flows;
- Interpretation and analysis of pressure logging results;
- Economics of leakage management (as before);
- Importance and analysis of burst data;
- Benchmarking of leakage throughout the supply system;
- Use and calculation of hour-day factors;
- Education and awareness;
- Retrofitting – pros and cons;
- Case studies.

Training of Remaining Personnel

The remaining personnel are usually neither at a level where they can make decisions regarding how WDM should be introduced, nor do they have an interest in how to implement any of the measures. It is therefore imperative to demonstrate the personal gains from WDM that can be achieved in the organisation as well as in the home.

Training of such personnel must therefore be short and to the point. They should be informed why WDM is an important issue and how each person can assist in the overall organisation to minimise wastage. Such training will be similar in some respects to the high level training in that no real detail will be provided. The exception is that practical examples must be given to illustrate concepts and WDM terms. In addition, however, some training on specific measures that should be adopted by the personnel will be included in the training session. Training of such personnel will normally take up a half-day session of 4 hours covering the following issues:

- General importance of WDM and water conservation tailored to the specific conditions experienced by the particular water supplier (as before);

- How each individual can contribute to WDM within the organisation;
- How each individual can promote the concepts of WDM to others outside the organisation.

It should be noted that materials covering each of the topics mentioned above already exist in various organisations and it is therefore not necessary to re-develop training material from scratch. In most cases, it is necessary to modify existing material in some way to create suitable training material for a specific organisation.

In order to reinforce the concepts and philosophy of WDM, water suppliers can carry out various initiatives, which may not save a large volume of water but the very implementation of such measures creates awareness amongst the personnel as well as any visitors to the organisation. Initiatives, which are often undertaken by water suppliers may include:

- **A water-wise garden** is one in which all the main water-wise principles are applied (mulching, grouping of plants with the same water needs and improvement of the soil amongst others). It is often appropriate to concentrate on plants that are adaptable to the site, rather than to change existing conditions in the garden to suit the plants. Local indigenous plants are preferable, as well as plants from similar climates throughout the world. Such a garden is of great marketing value to show personnel and visitors that an attractive garden can be developed with very little effort and without expensive irrigation systems.
- **An internal water audit** of the organisation's head office. This will demonstrate how such an audit can be undertaken, and provide personnel with some real figures of how much water is being used. This provides the base against which various WDM measures can be implemented to show how the demand can be managed over time;
- **Retrofitting of taps and toilets** throughout the organisation's head office and/or satellite offices. Retrofitting can involve a number of different options including the following:
    - Dual flush low volume toilets;

- Replacement of any automatic flushing urinals with user-activated or waterless urinals;
- Replacement of shower heads with low flow shower heads;
- Replacement of taps with spray nozzle low flow taps or taps with aerators.

It should be noted that the retrofitting can in some cases include infra-red activated taps and toilets as used in many international hotels and airports. In most African cities, however, such devices are unlikely to perform properly due to the range of problems experienced in many cities. This includes intermittent supply, the fact that such devices require individual power supplies and tend to be prohibitively expensive (being imported from Europe or the USA). It is also important to display signage in the restrooms to encourage the efficient use of water after retrofitting has taken place. Not everybody knows how a dual flush toilet works.

Action Plan for Water Efficient Premises

One of the key initiatives that all water suppliers should undertake is to ensure that their own offices use water efficiently. By implementing various WDM initiatives, the water supplier creates an awareness of water conservation to all employees as well as to any visitors to the organisation. In order to implement such measures, the water supplier should develop and implement an action plan, which should include some, or all of the actions indicated below:

- Ensure all water uses of the organisation is metered;
- Find out how much the organisation is paying for water and effluent charges. This can be obtained from the latest water bills which can then be expressed per person per day for the specific premises, or for that matter for the organisation;
- Carry out a night-flow analysis if you suspect that consumption and/or leakage is abnormally high. This will involve logging any supplies into the building;
- Check the size of water meter to ensure it is appropriate for the water usage and flow range;
- Carry out a water use survey for the buildings;
- Monitor water meter readings on a weekly basis. Act quickly if there is a sudden and unexplained increase;

- Develop an awareness campaign for all staff members;
- Estimate potential savings from reducing water use and effluent generation;
- Agree and publicise a target for water saving;
- Identify other benefits from managing demand – i.e. reduced energy use, CO_2 emissions, deferment of capital expenditure, etc.;
- Decide how much it is worth spending on water saving initiatives;
- Identify and evaluate appropriate water saving initiatives such as, low flush toilets, low flow showers, self closing taps, waterless urinals, repair of all leaks etc.;
- Implement the water saving initiatives;
- Introduce an internal written policy of specifying low consumption when purchasing any new water using devices;
- Promote successes visibly to encourage other organisations to reduce their water consumptions.

6.2 EDUCATION IN SCHOOLS

Schools education is probably one of the most important aspects of the education and awareness component of any WDM strategy. If the children can be convinced of the benefits to the community and specifically the environment, of WDM measures, they will convey the message to their parents. The latter may be fixed in their ways and otherwise very difficult to educate as far as WDM is concerned.

Schools education in WDM is a key issue in many parts of the world and an enormous amount of material is already available to assist water suppliers in setting up and implementing some form of schools education campaign in WDM. In some countries, the water suppliers and relevant government departments work together to create an education campaign that forms part of the Education Syllabus in the schools. In this regard, the example of the Queensland Government in Australia is considered one of the most comprehensive and effective schools education campaigns.

Any organisation wishing to establish a schools WDM campaign would be advised to contact them prior to developing a new set of training material from scratch. Many government bodies are happy to share their expertise and experience (including training materials) with any other official government bodies from other countries wishing to create a new schools training programme. Further details of the Australian Schools Training Program can be obtained from their website on www.env.qld.gov.au. No doubt there are many other organisations which will also be willing to share their experience and materials with African countries.

Considerable time and effort has already been spent, in many parts of Africa, in connection with schools training programs with regards to water conservation and WDM. In South Africa, the Department of Water Affairs and Forestry has developed useful materials, which can assist when setting up a training programme.

Rand Water has also developed considerable useful material and has set up education initiatives through various site visits (to sewage treatment and water purification works etc.), as well as initiated and supported numerous leakage reduction projects in various schools. Rand Water is also sponsoring a water classroom at Delta Park in Johannesburg where school children can experience hands-on processes in water treatment and environmental education.

When considering a schools training programme the following should be included:

- Setting up a site visit to a water treatment works and a sewage treatment works;
- Suitable educational material for the classroom, which can include projects such as undertaking a water audit in the school, painting competitions, essays on water conservation, etc;
- Development of water audit kits for use in schools;
- Posters, booklets and pamphlets on the various aspects of water conservation for free distribution to the schools;
- Schools retrofitting projects where the school ablution facilities are retrofitted with low flow showerheads, dual flush toilets, low flow taps. Such measures are normally implemented in parallel with a water-auditing project to monitor the savings achieved and to create awareness for water conservation throughout the school. It has been found that water consumption in most schools can be

reduced by more than 50% in cases where automatic flushing urinals are replaced by urinal with user-activated flushing mechanisms – see **Section 5.1.2**.

- Establishment of water education rooms or mobile education trailers.

Full details of several projects, where measures were taken to reduce the wastage in schools, are provided in the accompanying report on the numerous WDM Pilot Projects undertaken by Rand Water in its supply area.

6.3 EDUCATION AT HOME

Education at home can be achieved through a variety of measures and, as was the case with the schools education campaigns, considerable material is already available from many organisations both in Africa and overseas which can be used as a starting point for any new campaign. The materials required will vary from one area to another and from country to country, depending on the level of service and the availability of the specific media to the consumer. For example in many areas, where consumers do not have access to television, media campaigns must be tailored for the radio or through leaflets and newspaper articles. In other cases, where some of the consumers may be illiterate and have no access to radio, other approaches must be developed.

In summary, it is necessary to evaluate the consumer base thoroughly in order to establish the most appropriate means of spreading the water conservation message after which an appropriate strategy can be developed and implemented. One must not make the mistake of providing inappropriate and unnecessary information to consumers. First, ascertain the requirements of the consumers and then supply the correct level of information. As mentioned previously, one of the most successful approaches to educating the consumers at home is through the children and the schools education system.

6.4 AWARENESS CAMPAIGNS

Public awareness campaigns are very important in spreading the message of water efficiency to the consumers. Most water suppliers wishing to promote WDM organise various activities designed to create awareness in these issues such as:

- **National water weeks**, in which government officials and well known celebrities undertake activities which are much publicised to create awareness of water conservation issues;
- **Competitions**, in which the consumers are encouraged to participate in some activity which highlights the value of water conservation. For example, there may be a competition to develop a new water conservation slogan for the water supplier, or to demonstrate how much water can be saved in a household over a period of several months, etc;
- **Articles or advertisements** in newspapers and popular magazines, highlighting some aspect of water conservation;
- **Water-wise posters** displayed at all garden centres for effective garden watering and how to minimise irrigation requirements;
- **Pamphlets** and/or leaflets on how to save water to be sent to all consumers with their water and electricity bills where appropriate;
- **Stickers** on how to save water, which are displayed in all hotel bathrooms and any public toilets at airports, railway stations, government buildings, etc;
- **Sponsorship** of appropriate events where water conservation can be promoted. For example, the water supplier may sponsor various sporting events such as road races, golf tournaments, football events, etc.

These items represent only a few of the many approaches that can be adopted to promote water conservation to the public in general. In most cases, a water supplier will work closely with different government departments using a variety of the measures mentioned, as well as others, which it feels to be appropriate.

If an organisation does decide to undertake awareness campaigns on WDM, it must be realised that such intervention cannot be seen in isolation to other measures and must be of a permanent nature. Technical interventions into water losses are therefore of little value without spending a considerable funds and effort on social intervention – creating awareness of the issues.

7 DOCUMENTATION

7.1 USEFUL REFERENCES

There are numerous useful manuals and publications on the subject of WDM, many of which are available from the Internet while others must be purchased. In addition to several excellent and comprehensive books on the subject (e.g. Vickers, 2001, Thornton, 2002 and Farley, 2003) there are two sets of manuals which are considered by the authors of this cookbook to be of particular value to anyone wishing to become involved with WDM.

The first set is the "Managing Leakage" reports produced by the UK Water Industry in the early to mid 1990's. This set of manuals is clearly the starting point for what has become the standard methodology for addressing leakage and WDM in potable water distribution systems. The manuals provide the background and theory for the Burst and Background Estimate (BABE) methodology on which most current WDM developments are based. The manuals are now over 10 years old in some cases and although they are still very useful, the methodology has progressed significantly to such an extent that they do not cover the latest developments.

Fortunately a second set of 10 manuals titled "Managing and Reducing Losses from Water Distribution Systems" has recently (2003) been produced by the Environment Protection Agency in Queensland, Australia in association with Wide Bay Water, a small but highly progressive water utility on the Queensland coast. Further details and costs can be obtained from DavidW@herveybay.qld.gov.au The 10 manuals are written in plain English for water utility officers, managers, field staff and administrators. Each manual focuses on a key area of water loss management either through real, physical losses or apparent, 'paper' losses. In addition to a comprehensive presentation of theory, the manuals include detailed case studies and implementation action plans. Topics include water audits, pressure management, real loss management, managing apparent losses, sectorisation and the economics of water loss management. These manuals clearly supersede the UK "Managing Leakage" reports and are an essential addition to any Water Utility library.

Details of both sets of manuals as well as various other reports and books on the subject of

WDM are provided in **Table 7.1**.

Table 7.1: Some useful WDM references

Authors	Title	Publisher	Reference
Alegre, H., Hirner, W., Baptista, J. and Parena, R, 2000	Performance Indicators for Water Supply Services	IWA Publishing 'Manuals of Best Practice' Series, 2000	ISBN 1-900222- 272
American Water Works Association	Manual of Water Supply Practices: Water Audits and Leak Detection: AWWA M36	Available from the AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235, USA.	ISBN 1-58321-018-0
Farley, M & Trou, S, April 2003	Losses in Water Distribution Networks – A Practitioner's Guide to Assessment, Monitoring and Control	IWA Publications, Portland Customer Services. sales@portland-services.com	ISBN 1-900222-116
LAMBERT, A.O.,1997	Pressure Management/Leakage Relationships: Theory, Concepts and Practical Applications	Conference on Minimising Losses in Water Supply Systems, Apr. 1997. IQPC Ltd, London	
Lambert A., Brown T.G., Takizawa M., Weimer D, 1999	A Review of Performance Indicators for Real Losses from Water Supply Systems	AQUA, Dec 1999	ISSN 0003-7214
Lambert, A, Myers, S and Trow,S. , 1998	Managing Water Leakage: Economic and Technical Issues.	Financial Times Energy Publications, Maple House, 149 Tottenham Court Road, London W1P 9LL	ISBN 1-84083-011-5
May, J, 1994	Pressure Dependent Leakage	World Water and Environmental Engineering	
Mckenzie, R.S., 1999**.**	Development of a standardised approach to evaluate burst and background losses in potable water distribution systems: SANFLOW User Guide	South African Water Research Commission, Available from the internet on www.wrc.org.za.	Report TT 109/99, ISBN 1-86845-490-8.
Mckenzie, R.S., 2001	Development of a pragmatic approach to evaluate the potential savings from pressure management in potable water distribution systems - PRESMAC User Guide.	South African Water Research Commission, Report Number Available from the internet on www.wrc.org.za.	TT 152/01 ISBN 1-86845-772-2.
Mckenzie, R.S., and Lambert A.O., 2001.	Development of a simple and pragmatic approach to benchmark real losses in potable water distribution systems - BENCHLEAK User Guide.	South African Water Research Commission, Report Number Available from the internet on www.wrc.org.za.	TT 159/01 ISBN 1-86845-773-7
Mckenzie, RS, 2001	Greater Johannesburg Metropolitan Council Water Conservation and Demand Management Strategy	UN Habitat in association with Greater Johannesburg Metropolitan Council	
Mckenzie, R.S., Meyer, N and Lambert A.O., 2002.	Calculating Hour-Day factors in Potable Water Distribution Systems - HDF User Guide.	South African Water Research Commission, Report Number Available from the internet on www.wrc.org.za.	TT 184/02 ISBN 1-86845-879-2
Mckenzie, R.S., 2002	Development of a Windows based package for assessing appropriate levels of active leakage control in water distribution systems	South African Water Research Commission, Available from the internet on www.wrc.org.za.	Report TT 169/02, ISBN 1-86845-832-6.
Mckenzie, RS, Wegelin, W and Meyer, N. 2002	Leakage Reduction Projects Undertaken by Rand Water	Rand Water in association with UN Habitat	ISBN 0-620-29503-1
National Water Council Standing Technical Committee,1980	Report No. 26, Technical Working Group on Waste of Water. Leakage Control Policy and Practice.	UK Water Industry	ISBN 0 904561 95 X

Authors	Title	Publisher	Reference
Office of Water Services (UK), 1998	1997/98 Report on leakage and water efficiency	OFWAT	ISBN 1 874234 42 6
Queensland Environmental Protection Agency & Wide Bay Water, 2001	Managing and reducing losses from Water Distribution Systems : Manual 1 - Introduction	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9491 0
Queensland Environmental Protection Agency & Wide Bay Water, 2002	Managing and reducing losses from Water Distribution Systems : Manual 2 – Water Audits	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9492 9
Queensland Environmental Protection Agency & Wide Bay Water	Managing and reducing losses from Water Distribution Systems : Manual 3 – The Economics of Water Loss Management	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	To be published towards the end of 2003 or beginning of 2004
Queensland Environmental Protection Agency & Wide Bay Water, 2002	Managing and reducing losses from Water Distribution Systems : Manual 4 – Establishing Pressure Management Zones and District Metered Areas: The Toolkit	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9493 7
Queensland Environmental Protection Agency & Wide Bay Water	Managing and reducing losses from Water Distribution Systems : Manual 5 – Advanced Pressure Management and PRV Selection	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	To be published towards the end of 2003 or beginning of 2004
Queensland Environmental Protection Agency & Wide Bay Water, 2003	Managing and reducing losses from Water Distribution Systems : Manual 6 – Real Loss Management	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9494 5
Queensland Environmental Protection Agency & Wide Bay Water	Managing and reducing losses from Water Distribution Systems : Manual 7 – Managing Apparent Losses	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	To be published towards the end of 2003 or beginning of 2004
Queensland Environmental Protection Agency & Wide Bay Water, 2003	Managing and reducing losses from Water Distribution Systems : Manual 8 – Case Studies in Water Loss Management	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9490 2
Queensland Environmental Protection Agency & Wide Bay Water	Managing and reducing losses from Water Distribution Systems : Manual 9 – Rural Water Loss Management	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	To be published towards the end of 2003 or beginning of 2004
Queensland Environmental Protection Agency & Wide Bay Water	Managing and reducing losses from Water Distribution Systems : Manual 10 – Executive Summary	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	To be published towards the end of 2003 or beginning of 2004
South African Bureau of Standards, 1999	Code of Practice for the management of potable water in distribution systems. SABS 0306	SABS, Private Bag X191, Pretoria, South Africa.	ISBN 0-626-12046-2
Thornton, J, 2002	Water loss Control Manual	McGraw Hill or through the American Water Works Association. www.awwa.org.	ISBN 0 07 137434 5

Authors	Title	Publisher	Reference
UK Water Industry, 1994.	Managing Leakage, Report A: Summary Report	UK Water Industry	ISBN: 1 898920 06 0
UK Water Industry, 1994.	Managing Leakage, Report B: Reporting Comparative Leakage Performance	UK Water Industry	ISBN: 1 898920 07 9
UK Water Industry, 1994.	Managing Leakage, Report C: Setting Economic Leakage Targets	UK Water Industry	ISBN: 1 898920 08 7
UK Water Industry, 1994.	Managing Leakage, Report D: Estimating Unmeasured Water Delivered	UK Water Industry	ISBN: 1 898920 09 5
UK Water Industry, 1994.	Managing Leakage, Report E: Interpreting Measured Night Flows	UK Water Industry	ISBN: 1 898920 10 9
UK Water Industry, 1994.	Managing Leakage, Report F: Using Night Flow Data	UK Water Industry	ISBN: 1 898920 11 7
UK Water Industry, 1994.	Managing Leakage, Report G: Managing Water Pressure	UK Water Industry	ISBN: 1 898920 12 5
UK Water Industry, 1994.	Managing Leakage, Report H: Dealing with Customer's Leakage	UK Water Industry	ISBN: 1 898920 13 3
UK Water Industry, 1994.	Managing Leakage, Report J: Leakage management Techniques, Technology and Training	UK Water Industry	ISBN: 1 898920 14 1
Water Services Association of Australia	Water Reticulation Code of Australia: WSA 03-1999	Available from Water Services Association of Australia Inc, 469 Latrobe Street, Melbourne, Victoria 3000, Australia	ISBN 1 87060 8862 1
Wegelin, W and Mckenzie, R.S., 2002.	Leakage Reduction through Pressure Management in South Africa: Concepts and Case Studies.	South African Water Research Commission, Report Number Available from the internet on www.wrc.org.za.	TT 186/02 ISBN 1-86845-878-2
Vickers, A	Handbook of Water Use and Conservation	Available from WaterPlow Press, PO Box 2475, Amherst, MA 01004-2475, USA. www.waterplowpress.com	ISBN 1-931579-07-5

7.2 USEFUL WEBSITES

Contact details for some useful websites that provide information on WDM are provided in **Table 7.2**. In many instances, information and reports can be downloaded free of charge and in other cases there may be a cost involved. The inclusion or exclusion of any website in the list in no way not implies support or non-support for any of the organisations or companies listed.

Table 7.2: Some useful WDM Web Sites

Organisation or Company	Web Site	Details of Site
American Water Works Association	www.awwa.org	American based web site with details of useful publications and information on all aspects of water supply including considerable information and publications on water conservation.

Organisation or Company	Web Site	Details of Site
Aqualoc	www.aqualoc.net/mainframe.html	Australian based company providing flow restricting devices for taps.
Con-Serv	www.con-serv.com.au	Australian based company providing flow restricting devices for taps and low flow shower heads.
Caroma	www.caroma.com.au	Australian based company providing low flow showerheads and dual flush toilets.
Delrama Ltd	www.delrana.com.au	Australian based company providing low flow showerheads.
Department of Water Affairs and Forestry (South Africa)	www.dwaf.co.za	Useful site: can download the SA Water Services Act (No. 108 of 1997) and National Water Act (No. 36 of 1998).
Dorf Ltd	www.dorf.com.au	Australian based company providing low flow showerheads.
Dynamic Fluid Control	www.dfc.co.za	South African based company specialising in the supply of isolating valves, air valves and control valves.
Environment Agency (United Kingdom)	www.environment-agency.gov.uk/savewater	Very useful web site containing many articles and reports, many of which can be downloaded free of charge. Also provides access to the "Demand Management Bulletin" which is extremely useful and informative to anyone considering WDM initiatives.
Enviroloo Ltd	www.eloo.co.za	South African based company involved with the manufacture and distribution of waterless toilets.
Ecosan Pty Ltd	www.jojo.co.za	South African based company involved with the manufacture and distribution of waterless toilets.
Flexispray Ltd	www.flexispray.com	Australian based company providing low flow showerheads.
Gem Flow Ltd	www.jemaustralia.com.au/index.html	Australian based company providing flow restricting devices for taps.
Interbath Ltd	www.interbath.com	Australian based company providing low flow showerheads.
Pressure Management Services	www.dfc.co.za	South African based company specialising in the supply and commissioning of pressure management equipment.
Queensland Government Environmental Protection Agency	www.epa.qld.gov.au	Web site with large quantity of useful information on many aspects of the environment including considerable material on water conservation.
Radio Detection Pty Ltd	www.radiodetection.com	Details of Leak Detection Equipment (SA)
Rand Water	www.randwater.co.za	Largest supplier of potable water in Africa and joint sponsor of this manual
Rand Water	www.waterwise.co.za	Details of the Rand Water Water-Wise program and Water Cycle Management.
RST Water Saving Systems Pty Ltd	www.rst.co.za	Details of low flow shower heads

Organisation or Company	Web Site	Details of Site
Save-a-Flush Pty Ltd	www.save-a-flush.co.uk	UK based company specialising in the manufacture and distribution of toilet displacement devices.
Sentinel Systems Ltd	www.vader.nw.com.au	Australian based company specialising in infra-red tap and toilet sensors
South African Water Research Commission	www.wrc.org.za	Government research organisation responsible for the development and distribution of many products to assist water suppliers in all aspects of water resource management, WDM and water quality issues.
South African Department of Water Affairs and Forestry	www.dwaf.co.za	Web site containing information on many issues related to WDM including the governments policy document as well as various water acts etc.
Technolog Ltd.	www.technolog.co.uk	UK based company specialising in pressure management controllers, loggers and remote logging equipment.
United Nations Centre for Human Settlements	www.un-urbanwater.net www.unchs.org	
Waterless Advantage Pty Ltd	www.rotaloo.com	South African based company involved with the manufacture and distribution of waterless urinals
Water Services Association of Australia	www.wsaa.asn.au	Australian based web site providing information and publications on various water supply and WDM related issues.
	www.ratings.wsaa.asn.au	Australian based web site providing details of the Water Conservation 5A Rating and Labelling Scheme managed by the WSAA.
Wide Bay Water	www.wbw.co.au	Australian based water company specialising in provision of technical support on various aspects of water conservation as well as the production of the series of 10 reports on “Managing and Reducing Losses from Water Distribution Systems” in association with the Queensland Government.
WRP Pty Ltd	www.wrp.co.za	South African based consultant specialising in Water Conservation and WDM plus training in all aspects of WDM
Zip Industries Ltd	www.zipindustries.com.au	Australian based company providing flow restricting devices for taps and toilet flushing devices.

APPENDIX A

GLOSSARY OF WATER BALANCE TERMS

APPENDIX A: GLOSSARY OF WATER BALANCE TERMS

The basic standard terminology used to define the components in the water balance is depicted in **Figure A1**.

System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			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 A1: Main components of the water supply water balance

Descriptions of the various terms shown in **Figure A1** are provided below.

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 the 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 (or stand) connections, the number of erfs (not properties) can be used.

Real Losses

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

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

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

System Input

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

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

Total Consumption

Total consumption is the sum of the following three components:

- Billed authorised consumption
- Unbilled authorised consumption
- Apparent losses.

Target Annual Real Loss (TARL)

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

Total Losses

Total losses are the sum of the real and apparent losses

Unavoidable Annual Real Losses (UARL)

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

Unbilled Authorised Consumption

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

Water Losses

The same as Total Losses which represent the sum of the Real and Apparent losses.

APPENDIX B

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

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

B1: HISTORICAL BACKGROUND

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

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

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

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

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

Figure B1 shows the typical range of problems that can be successfully tackled with these concepts. The remainder of this Appendix explains the application of BABE and FAVAD concepts to the development of the International Performance Indicators for Real Losses.

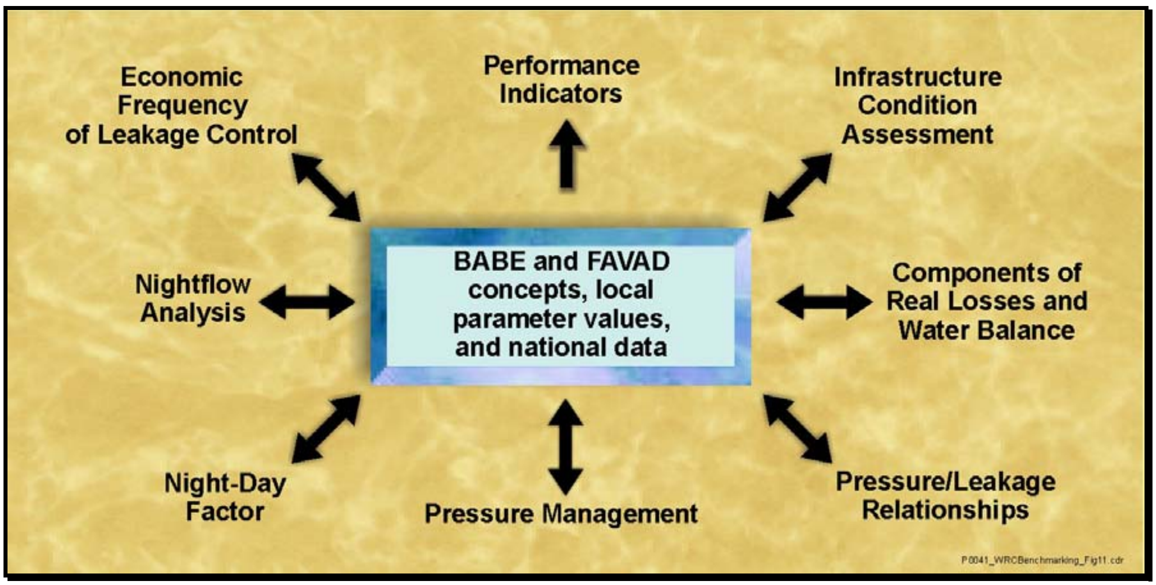


Figure B1: Problem-Solving using BABE and FAVAD concepts

B2: BURST AND BACKGROUND ESTIMATE (BABE) procedures

In order to address leakage it was considered necessary to first understand the various components making up the water balance for a typical water supply network. The previous approach as shown in **Figure B2** was to consider three main components: Authorised Metered, Authorised Unmetered and the remainder which represents all unaccounted-for water, and is often referred to as the real and apparent losses.

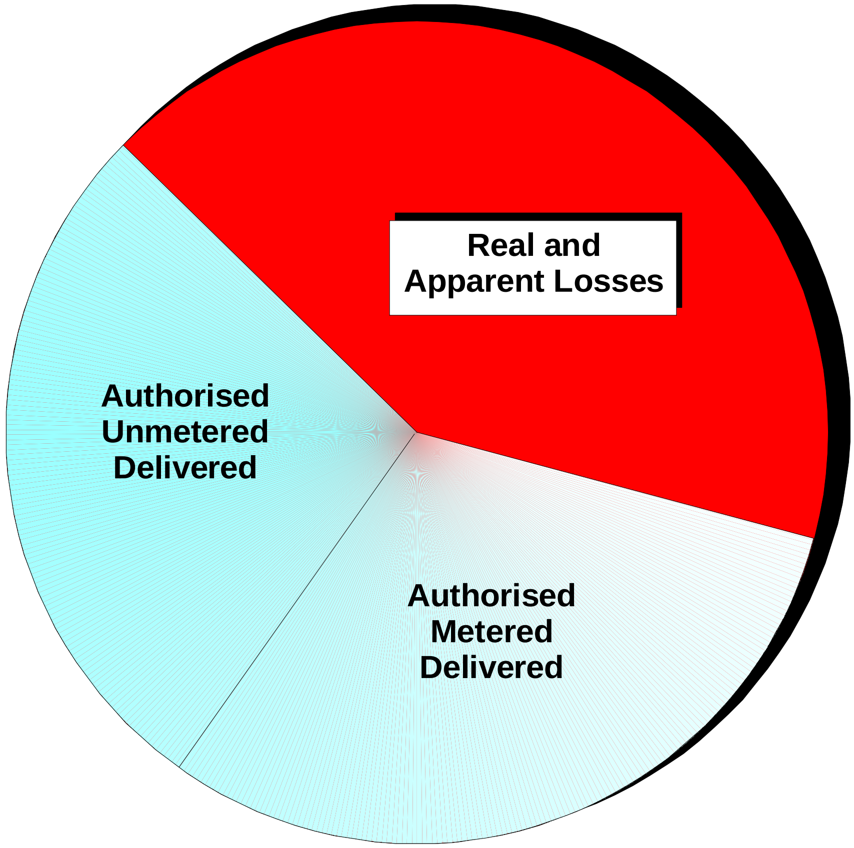


Figure B2: Traditional Water Balance.

In view of the large portion of the traditional water balance that was usually represented by the real and apparent losses, the whole water balance approach was revised by breaking the balance down into smaller components that could either be measured or estimated. In this manner, it was possible to gain a greater understanding of the different components and also of their significance to the overall water balance. A typical example of the BABE water balance is provided in **Figue B3**. It should be noted that the water balance need not be restricted to the components shown in this figure and, conversely, it can be split into a greater number of components or perhaps different components. Every system is different and it is the general approach that should be applied and not a specific and rigid framework.

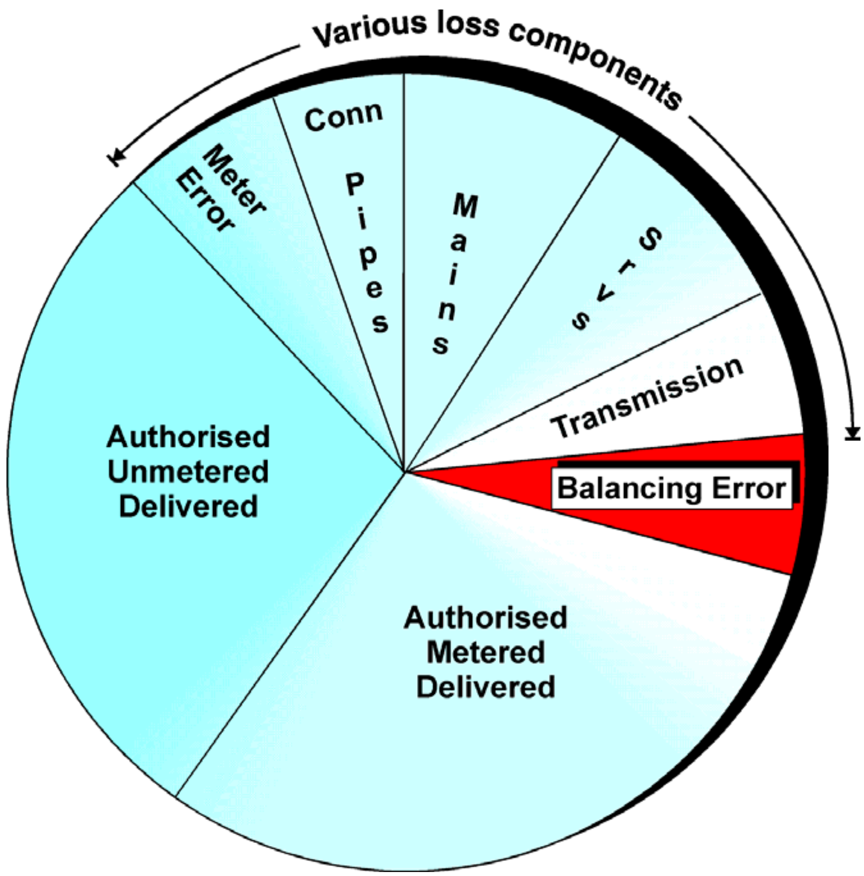


Figure B3: BABE Water Balance Approach.

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

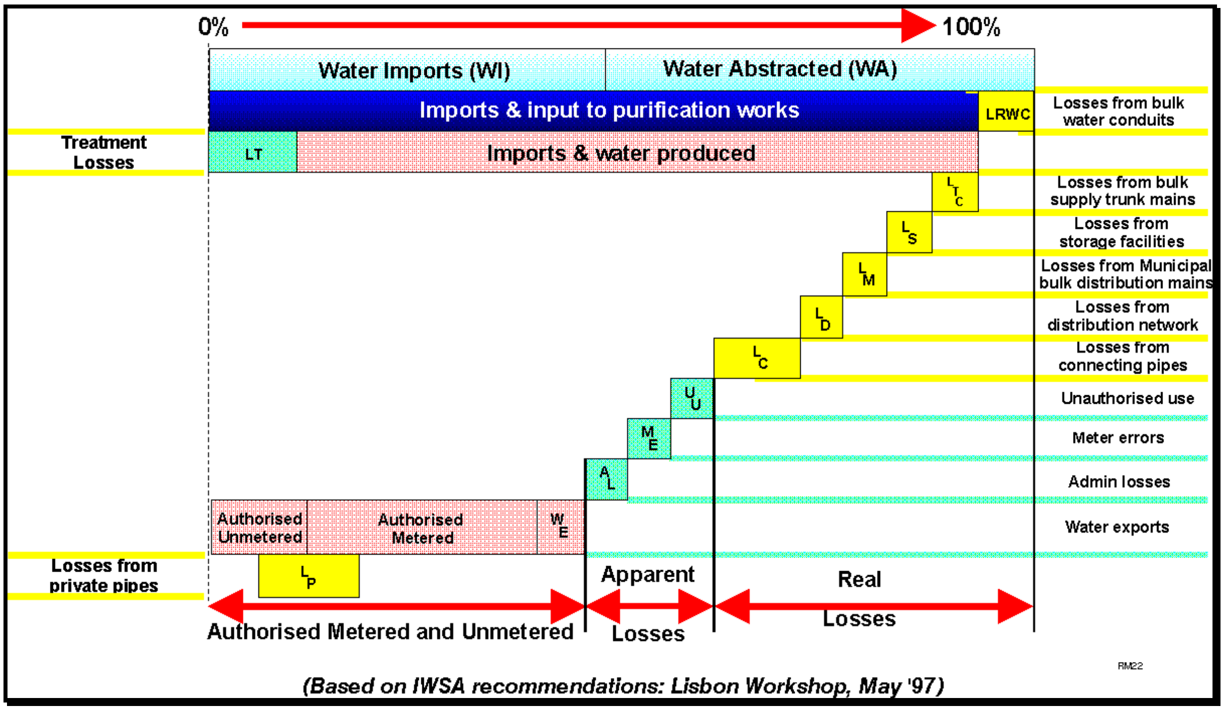


Figure B4: Recommended BABE Water Balance Components.

Figure B4 provides a breakdown of the most important components that can be included in a water balance for a specific water supplier. It is important to note that the losses have been broken down into real and apparent losses. Real losses are those where the water has left the system and has not been utilised in any way. If such losses can be reduced, the total water required by the supplier will also be reduced. Apparent losses, on the other hand, are simply “paper” losses that do not represent a loss from the system. They are usually due to illegal connections, and meter and billing errors. If such losses are eliminated, the total water required by the supplier may not change. However, the “unaccounted-for” component in the water balance will be reduced. In such, cases certain other components such as “Authorised Metered” or even “Authorised Unmetered” will increase as the apparent losses are reduced.

B3: WHAT ARE BURST AND BACKGROUND LEAKS ?

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

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

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

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

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

As discussed previously, the best of the traditional; basic (IWA Level 1)

Performance Indicator for Operational management of Real Losses is the following:

ℓ/conn/d (when the system is pressurised)

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

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

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

litres/conn/day/metre of pressure (when the system is pressurised)

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

L varies with P^{N1}

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

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

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

The 'Detailed' Operational Performance Indicators for Real Losses, deals with both these factors, and average operating pressure, by calculating a system-specific value for 'Unavoidable Annual Real Losses' (UARL). The ratio of the Current Annual Real Losses (CARL, calculated from the standard Water Balance) to the UARL, is the Infrastructure Leakage Index (ILI), i.e.

Infrastructure Leakage Index ILI = CARL/UARL

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

- Background leakage – small undetectable leaks at joints and fittings;
- Reported bursts – events with larger flows which cause problems and are reported to the water supplier;
- Unreported bursts – significant events that do not cause problems and can only be found by active leakage control.

B5: CALCULATION OF UNAVOIDABLE ANNUAL REAL LOSSES (UARL)

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

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

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

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

Table B1: Parameters required for the calculation of UARL

Component of Infrastructure	Background Losses	Reported Bursts	Unreported bursts
Mains	• Length • Pressure • Minimum loss rate/km*	• Number/year • Pressure • Average flow rate* • Average duration	• Number/year • Pressure • Average flow rate • Average duration
Service connections to street/property line	• Number • Pressure • Minimum loss rate/conn*	• Number/year • Pressure • Average flow rate* • Average duration	• Number/year • Pressure • Average flow rate • Average duration
Service connections after street/property line	• Length • Pressure • Minimum loss rate/km*	• Number/year • Pressure • Average flow rate* • Average duration	• Number/year • Pressure • Average flow rate • Average duration

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

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

Table B2: Parameter values used to calculate UARL

Component of Infrastructure	Background Losses	Reported Bursts	Unreported Bursts
Mains	20* 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	• 2.25/1000 connections/year at • 1.6 m^3/h per burst* • average duration of 8 d	• 0.75/1000 conn/yr at • 1.6 m^3/h per burst* • average duration of 100 d
Unmetered Service connections after street/property line	0.50* ℓ/conn/hr per 15m length	• 1.5/1000 connections/year at • 1.6 m^3/h per burst* • average duration of 9 d	• 0.50/1000 conn/yr at • 1.6 m^3/h per burst* • average duration of 101 d

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

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

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

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

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

Component of Infrastructure	Background Losses	Reported Bursts	Unreported Bursts	Total UARL	Units
Mains	9.6	5.8	2.6	18	litres/km mains/d per m of pressure
Service connections to street/property line	0.60	.04	0.16	0.8	litres /conn/d/ m of pressure
Unmetered Service connections after street/property line	16.0	1.9	7.1	25	litres /km underground. pipe/day/m of pressure

NOTE: the UARL from Unmetered Service Connections after the street/property line can be ignored in the South African context, as all customers are metered and these meters are located close to the street/property line. This component of UARL has not, therefore, been included in the BENCHLEAK software. The losses from the service connections (main to meter) tend to dominate the calculation of UARL in most parts of South Africa, except at low density of connections (less than 20 per km of mains).

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

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

Where:

UARL = Unavoidable annual real losses (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, 3920 service connections all located at the street property boundary edge and an average operating pressure of 50 m.

UARL = (18 * 114 + 0.80 * 3920 + 25 * 0) * 50 litres/d

= 102 600 + 156 800 litres/d

= 259 400 litres /d

= 259.4 m^3/d

= 94 681 m^3/year

= 66 litres/conn/d

B

APPENDIX C

Methods Of Calculating Average Pressure In Distribution Systems

APPENDIX C: METHODS OF CALCULATING AVERAGE PRESSURE IN DISTRIBUTION SYSTEMS

C1: A SYSTEMATIC APPROACH TO CALCULATING AVERAGE PRESSURE

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

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

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

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

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

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

If Network Analysis models are not available, the approach used in part B2 of this

Appendix should be followed. If Network Analysis models are available, follow the approach in **Section C3**.

C2. AVERAGE ZONE PRESSURES WHERE NO NETWORK MODELS EXIST

C2.1 Calculate Weighted Average Ground Level for Each Sector

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

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

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

Whichever infrastructure parameter is selected, the weighted average ground level can then be calculated as shown in **Table C1** below**.**

Table C1: Example calculation of weighted ground level

Contour Band (m)			Number of Service Connections	Contour Band Mid Point * Number of Connections
Lower Limit	Upper Limit	Mid-Band		
2.0	4.0	3.0	18	54
4.0	6.0	5.0	43	215
6.0	8.0	7.0	40	280
8.0	10.0	9.0	41	369
10.0	12.0	11.0	63	693
12.0	14.0	13.0	70	910
14.0	16.0	15.0	41	615
16.0	18.0	17.0	18	306
18.0	20.0	19.0	12	228
20.0	22.0	21.0	8	168
22.0	24.0	23.0	3	69
24.0	26.0	25.0	0	0
Totals			**357**	**3907**

Weighted Average Ground Level = 3907 / 357 = 10.9 m

C2.2 Measure or Calculate Average Zone Pressure

Obtain the average pressure at the Average Zone Point in the following manner:

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

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

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

C2.3 Calculate Weighted Average Pressure for Aggregation of Zones

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

Table C2: Example calculation of weighted ground level

Area Reference	Number of Service Connections	Average Zone Pressure	Number of service Connections * AZP
A	420	55.5	23 310
B	527	59.1	31 146
C	443	69.1	30 611
D	1352	73.3	99 102
E	225	64.1	14 423
F	837	42.0	35 154
G	1109	63.7	70 643

H	499	56.3	28 094
I	1520	57.0	86 640
	6932		**419 122**

Weighted average pressure for the whole area = 419,122/6932 = 60.5 m

C3. AVERAGE ZONE PRESSURES USING NETWORK MODELS

C3.1 Calculate Weighted Average Ground Level for Each Sector

Because each node of a Network Analysis Model will normally have a number of properties, a datum ground level, and an average pressure value, it is relatively easy to calculate the weighted average pressure for all the nodes in the model (or any defined part of it).

It is worthwhile, however, to ensure that a weighted average ground level, and an AZP point are defined for each zone/sector, as these will occasionally be required for test measurement.

APPENDIX D

Example of a High Level Water Audit

DATA ENTRY SHEET FOR LEAKAGE BENCHMARKING IN SOUTH AFRICA

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	Example Delivery Centre	
Name of Water Supply System	Example Delivery Centre	
Contact Details:	**Name**	Mr AN Other
	Address	Private Bag X111
		Town
		1111
	Telephone	012 345 6789
	Fax	012 345 6789
	E-mail	Another@email.co.za

D2. SYSTEM DATA

Input Description	Variable	Example Data	Actual Data	Units	
Length of Mains (Transmission + Distribution)	Lm	1500	1069	km	
Number of Service Connections	Ns	60000	60208	Number	See Notes 1 & 2
Density of Service Connections (per km of mains)	Ns/Lm	40	56	Per km	
Percentage of time system is pressurised during year	T	100	99	%	See Note 3
Average operating pressure when system pressurised	P	45	40	metres	See Note 4
Population served by the supply system	Pop	100000	663037	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

Insert your comments in this space.

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

Insert your comments in this space.

D3. UNAVOIDABLE ANNUAL REAL LOSSES (UARL)

Details	Calculation	Example Result	Actual Data	Units
On mains	$18 \times Lm \times P \times 365 \times T/10^8$	443	278	10^3 m^3/yr
On Service Connections	$0.8 \times Ns \times P \times 365 \times T/10^8$	788	696	10^3 m^3/yr
Total Volume of UARL		**1232**	**974**	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**	**45**	Litres/ conn./day

D4. ANNUAL WATER BALANCE DATA

D4a. Data Period

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

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**	**543**	Litres /conn./day
Consumption in litres/conn/day		**1610**	**436**	Litres

APPENDIX E

Summary of the various WDM Models Available through the Water Research Commission

E.1: *SANFLOW: Background Night Flow Analysis Model*

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

A typical normal inflow to a ZMA is shown in **Figure E1** from which the minimum night-flow can be identified as the lowest flow entering the zone at any time. In most zones, the minimum night flow occurs sometime between midnight and 4 am. In order to evaluate the level of leakage in a particular zone from the inflow as shown in **Figure E1**, the minimum night-flow is split into various components in accordance with the general BABE principals. **Figure E2** shows the different components making up the minimum night-flow and these are fully explained in the SANFLOW user guide (WRC, 1999).

The analysis of background night flows is a simple exercise and the SANFLOW model provides a quick and effective aid to water suppliers in this regard.

The model is based directly on the BABE principals and is written in DELPHI for the Windows operating system. It can be obtained directly from the internet (www.wrc.org.za) together with a full manual and user guide.

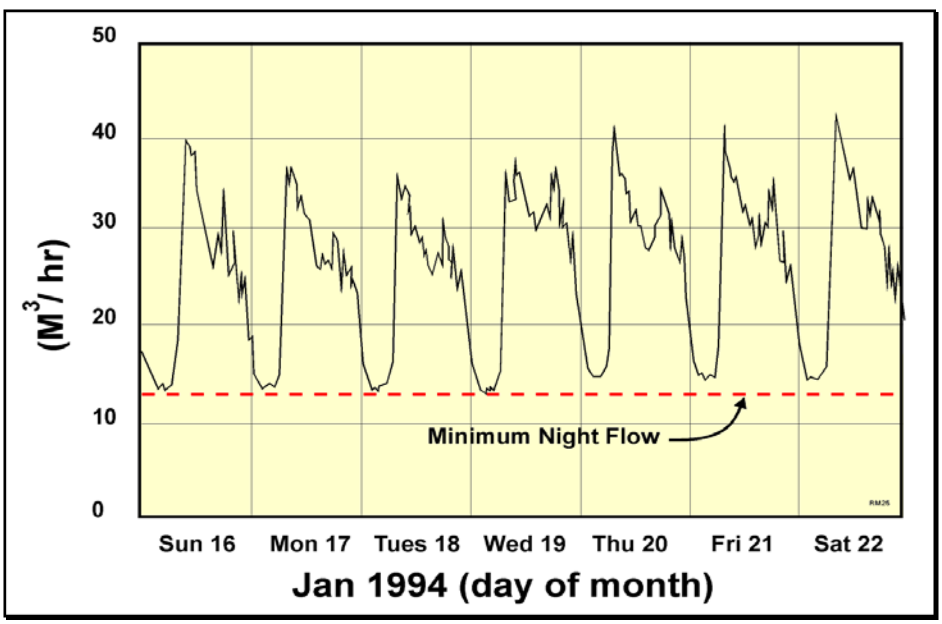


Figure E1: Example of inflow to a ZMA showing the minimum night flow

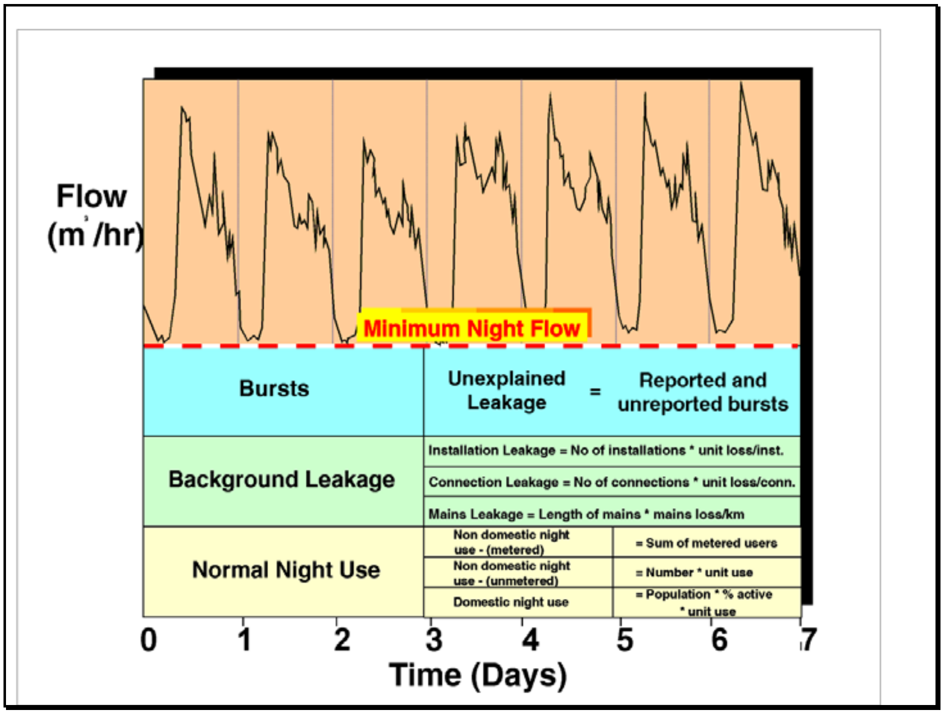


Figure E2: Components making up the minimum night-flow

The SANFLOW Model includes several additional features which are not currently available on any of the overseas versions. In particular, it includes the ability to undertake sensitivity analyses based on basic risk management principals in order to provide a likely distribution for the number of bursts in a zone (or district). This feature enables the user to set an upper and lower limit on each parameter used in the model. The selection of the parameter values has often been criticised as too subjective with the result that different users may obtain different results from the same initial data. By using the sensitivity analysis feature of the model, this potential problem can be addressed.

E.2: ECONOLEAK: Economics of Leakage Model

The economics of leakage control is becoming a very important issue since most water supply utilities in South Africa are operating on limited budgets. The water suppliers are often unable to provide proper motivation to carry out expensive rehabilitation or leak detection programmes.

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

In order to use the model, the water supplier should gather the information indicated in **Table E1**.

It should be noted, that if the information is not readily available from the water supplier's records, the default values can be used until more reliable information can be obtained.

Table E1: Basic information required to use the ECONOLEAK Model.

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

Power exponent for calculating number of mains leaks for different pressures (cubic relationship is normally adopted)	-	3
Cost of basic sounding per km of mains	Rand/km mains	700
Cost of leak noise correlator per km of mains	Rand/km mains	1400
% of mains requiring leak noise correlator to detect leaks	%	20

The ECONOLEAK model was designed to compliment the Background Night Flow Analysis Model and utilises much of the same information. It is, however, a stand-alone program operating in the Windows environment and written in Delphi.

The model uses the basic information described in **Table E1** to provide the water supplier with an indication of when they should intervene in a particular zone and also how much funding should be allocated to leakage detection and repair per annum. This information will assist the maintenance and technical staff to motivate for the appropriate funding from the finance department.

E.3: PRESMAC: Pressure Management Model

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

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

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

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

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

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

To overcome these problems the WRC commissioned the development of a pressure management model (PRESMAC). PRESMAC is based on the same BABE principles as the existing UK models and was modified to suit South African conditions where necessary. As opposed to the UK models which are based on the EXCEL spreadsheet architecture, the new South African model is written in DELPHI.

The model can be used to assess the likely savings (in monitory terms) of various pressure reduction options (fixed outlet and time–modulated PRV's) in a selected zone metered area. The analysis is undertaken in a relatively simple and pragmatic manner allowing the user to gauge the potential for pressure management very quickly and effectively without requiring a full detailed pipe network analysis. Although the methodology is based on a number of simplifications and assumptions, in practice the predicted savings are generally within 10% to 20% of those actually achieved (erring on the conservative side).

E.4: BENCHLEAK: Benchmarking of Leakage

One specific problem that surfaces regularly concerns the manner in which water suppliers express their levels of leakage. It is still common practice to express leakage as a percentage of the water supplied into a particular system or zone. Although this is possibly the most common manner of expressing leakage levels, it is also the most inaccurate and misleading.

To demonstrate the problems associated with percentage values a very simple example can be used . In this example a distribution system experiences leakage of 10 000 m^3/day. This system is analysed for a range of different consumers as shown in **Table E2**.

From **Table E2** it can be clearly seen that although the real losses are identical in all cases, the percentage losses vary considerably.

Table E2: Example to demonstrate problems with percentage losses

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

A project was initiated by the WRC to look into the problem of comparing leakage levels in the various supply systems throughout South Africa. A standardised approach to leakage benchmarking was developed through the project resulting in a new model called BENCHLEAK.

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

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

ILI = CARL / UARL

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

Another important issue addressed by the BENCHLEAK Model was the standardisation of the terminology used to describe the basic elements making up the water balance for a water supply system. In South Africa it was very difficult to compare results from one system with those from another system due to the fact that the Water Suppliers tended to use their own definitions of Real Losses and Unaccounted-for Water etc. By adopting a standard approach to the water balance, it will be possible to compare results from different systems in a meaningful manner and also compare the results from South African water suppliers with those from other water suppliers worldwide. The terminology adopted is fully in line with current International best-practice and full descriptions of all elements of the water balance are provided in the BENCHLEAK User Guide.

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

It is interesting to note that the ILI values for the South African systems range from 1.0 to approximately 20.0 with an average value in the order of 7.0. This can be compared to ILI values calculated for 27 supply systems in 19 countries which range from 1.0 to 10.0 with an average value of 4.2.

For most African supply systems it would be unusual to achieve an ILI value of below 2.0 and values in the order of 5.0 to 10.0 are relatively common and represent systems in a reasonable condition.

In summary, the BENCHLEAK methodology represents a significant development in the assessment of leakage and non-revenue water in water distribution systems. It provides water suppliers with a simple yet effective spreadsheet which they can use to assess the leakage and losses from their system. The model also provides an estimate of the minimum level of leakage which would be expected from the system under ideal conditions where all forms of leakage control are implemented. This feature adds considerable value to the benchmarking process and provides a lower limit which water suppliers can use as a future target. In most cases in Africa, the minimum level of leakage is well below the economic level of leakage and therefore most water suppliers will have to set a target which is considerably higher than the minimum possible leakage.

APPENDIX F

Details of the Khayelitsha Pressure Management project

KHAYELITSHA LEAKAGE REDUCTION THROUGH ADVANCED PRESSURE CONTROL

Ronnie Mckenzie: WRP Pty Ltd

OVERVIEW

The Khayelitsha Pressure Management Project includes the largest Advanced Pressure Control installation in the world and has been recognised as "World's Best Practice" by numerous respected international experts. The project has been hailed as a great success by the City of Cape Town and has been acknowledged not only for its Technical Excellence but also for its contribution to Environmental Sustainability and improving the level of service to the 450 000 inhabitants it serves. The project demonstrates the role of the Civil Engineer in serving the community and providing innovative solutions to a serious problem experienced throughout South Africa and in many other parts of the developing world. The project which cost R2.5 million to construct is already saving more than R18 million per year through reduced leakage and saves approximately 10% of the water to be supplied by the new Berg River Scheme (to cost R2 billion).

Through this project it is now possible to provide lower water pressures to the Khayelitsha residents thus reducing their monthly water consumptions to levels which they can afford to service.

F1: INTRODUCTION AND BACKGROUND

Khayelitsha is one of the largest townships in South Africa and is located approximately 20 km from Cape Town on the Cape Flats. The area covers 24 km^2 and provides housing to 450 000 people (see **Figure F1**). There are 43 000 serviced sites with both internal water supply and water borne sewage and a further 27 000 squatter shacks supplied from communal standpipes. The area has been expanding since the early 80's when the first settlements were established with the result that the basic water distribution infrastructure is relatively new and in good condition.

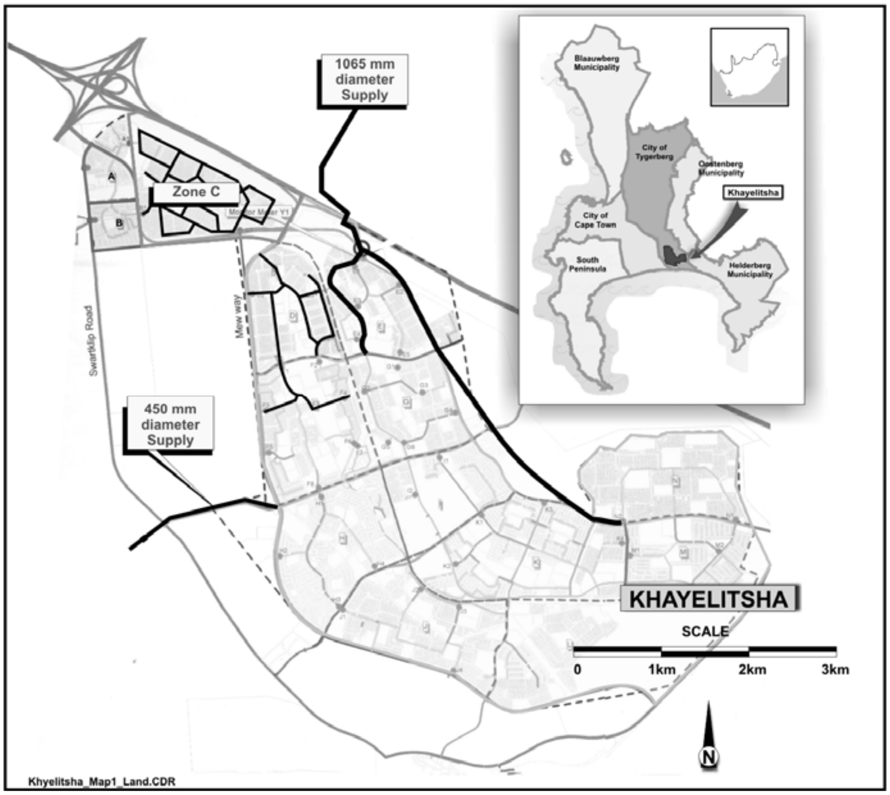


Figure F1: Location Map for Khayelitsha

Khayelitsha is supplied with potable water from Blackheath Reservoir situated at an elevation of 110 m through two large water mains of 450mm and 1065 mm diameter. The average pressure at the supply point is approximately 80m which is excessive and has caused considerable damage to the household plumbing fittings.

In April 2000 the water supplied to Khayelitsha was in excess of 21 million m^3/a with a Minimum Night Flow (MNF) of 1 600 m^3/hr (sufficient to fill an Olympic sized swimming pool every hour). From the analysis of the MNF as well as the night-time sewage flows, it was established that approximately 1 200 m^3/hr was leaking to the sewer system indicating that the key problem was household leakage and not burst pipes in the reticulation system.

The Khayelitsha Pressure Management Project was therefore initiated in June of 2001 by the City of Cape Town and the Project Team to improve the level of service to the Khayelitsha community by reducing the excessive water pressure in the reticulation system.

F2: SCOPE OF THE PROJECT

Following a preliminary investigation, the Project Team decided that the most practical approach would be to cut into the two water mains and commission two pressure management installations, each with several sections of small diameter pipe and the appropriate sized PRV's. In this regard it was decided to install three 300mm diameter sections in the 1065 mm diameter main (see **Figure F2**) and two 200 mm diameter sections in the 450 mm diameter main. It was also decided to introduce advanced pressure control which involves the commissioning of specially imported electronic controllers to manipulate the pressure into the area during off peak periods. Through the use of such controllers, it is possible to achieve larger savings than those obtained through the PRV's on their own.

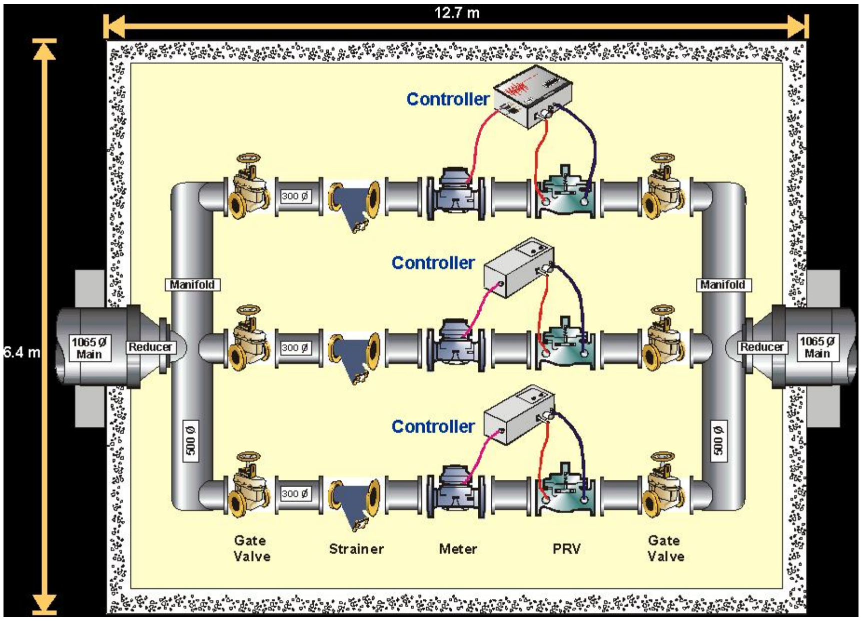


Figure F2: Schematic Layout of the 1065 mm diameter Installation

Having agreed on the approach and the conceptual design for the two PRV installations, the most difficult stage of the project was the construction of the chambers and the installation of the mechanical equipment. Most of the problems encountered were anticipated to a large degree but others could not have been predicted such as the floods of July and August 2001. Some details of the 1065 mm diameter installation are shown in **Figure F3.**

Figure F3: Internal View of a Portion of the 1065 mm diameter Chamber

F3: RESULTS FROM THE PROJECT

The average daily flow into the area was reduced from 2 500 m^3/hr (22 million m^3/a) to 1 800 m^3/hr (16 million m^3/a) through the used of "Fixed–Outlet" Pressure Control representing an annual saving of approximately 6 million m^3/year. The second phase of the pressure control involved using the electronic controllers (Advanced Pressure Control) to provide further pressure reduction during periods of low demand. The results from the "Time-Modulated" Pressure Control are depicted in **Figure F4** which highlights the additional savings that can be achieved through Advanced Pressure Control. The average daily flow into the area was reduced to 1 500 m^3/hr (13 million m^3/a) representing an annual saving of approximately 9 million m^3/year. The minimum night flow was reduced from 1 600 m^3/hr to 750 m^3/hr.

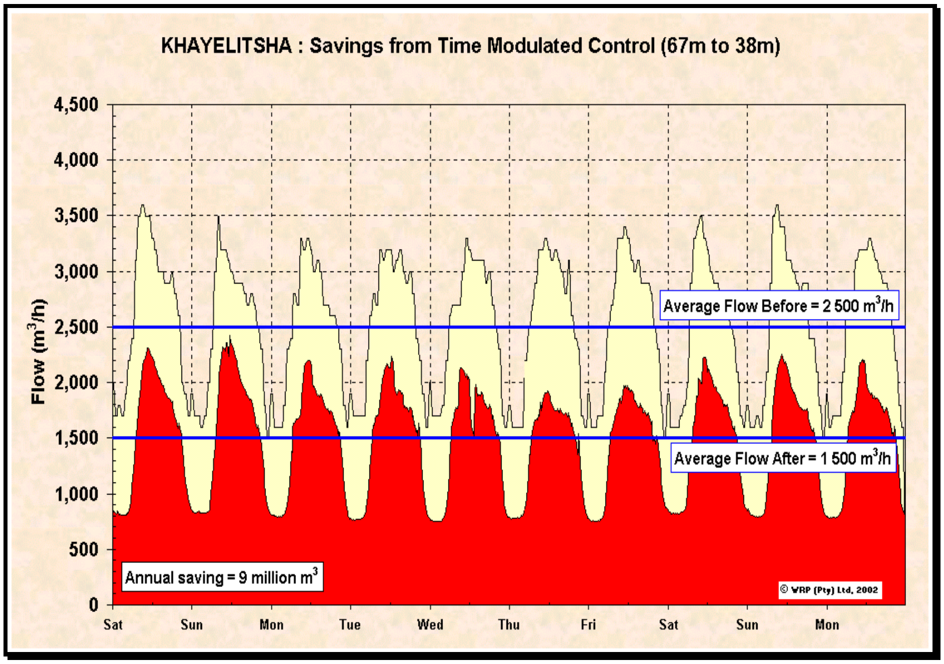


Figure F4: Inflow to Khayelitsha from Fixed Outlet Pressure Control

F4: SUMMARY AND CONCLUSIONS

The Khayelitsha Pressure Management project was initiated directly as a result of various submissions made to Council by the Project Team who provided sufficient motivation and evidence to support the investment of almost R3 million into the project.

Although there are already several advanced pressure control installations in South Africa, this project is by far the largest and most significant to be undertaken in the country. It is the first time in South Africa that an attempt has been made to reduce the pressure over such a large area from a single installation and the actual savings achieved are the highest in the world from such an installation.

The approach used in the Khayelitsha installation is simple and innovative. The savings achieved have exceeded both the Client's and the Project Teams' most optimistic expectations. The fact that the installation has been constructed and commissioned within such a short period of time and under such difficult and often dangerous conditions is of credit to both the Project Team and the Client's representatives working in Khayelitsha as well as the residents of Khayelitsha.

In conclusion, the Khayelitsha Pressure Management Project is not only one of the most important water conservation projects to have taken place in South Africa but is also one of the most significant projects of its nature worldwide. It has already attracted considerable attention from overseas specialists and is set to gain further prominence through various submissions and presentations at international conferences etc. It was completed to the full satisfaction of the Client within the available budget and time period allowed for the project and has paid for itself in the first two months of operation.