PRESMAC

Pressure Management Program

developed through

SOUTH AFRICAN WATER RESEARCH COMMISSION

By

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The publication of this report emanates from a project entitled: **Water Leakage: Pressure Management Model** (WRC Project Number **K5/997**)

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IMPORTANT

PREFACE

This document incorporates the user guide to the South African Pressure Management and Control (PRESMAC) model which has been developed through the Water Research Commission (WRC) funded project titled "The Water Leakage: Pressure Management Model".

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

DISCLAIMER

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

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TECHNICAL SUPPORT

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

Pressure Management Program (PRESMAC)

Executive Summary

The Problem

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 points. 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 dependent upon pressure, it is also clear that leakage rates will be highest during the periods when few, if any, consumers wish to use water.

Software Solutions

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.

In 1991, a National Leakage Initiative was established in the UK by the Water Services Association and the Water Companies Association to update and review the guidelines concerning leakage control that had been in use since 1980. It was agreed by all organisations involved in potable water supply that the guidelines required updating in view of the considerable progress that had been made over the previous ten-year period. As a result of new water legislation, it became necessary for all water suppliers to demonstrate to the regulators that they fully understood their position on leakage. This did not imply that all water suppliers had to demonstrate the lowest achievable leakage levels, but simply that they were applying correct and appropriate economic and resource principles. To this end, it was agreed that all water suppliers would adopt a straightforward and pragmatic approach to leakage levels. This was achieved through the development of various techniques that became known as the Burst and Background Estimate (BABE) procedures.

The BABE procedures were developed over a period of approximately 4 years by a group of specialists selected from several of the major water supply companies based in England and Wales. The group was instructed to develop a systematic and pragmatic approach to leakage management that could be applied equally well to all of the UK water supply utilities. The result of this initiative was a set of 9 reports published by the UK Water Industry (WRC) on the subject of managing leakage. The nine WRC reports cover the following topics :

The intention of the reports was not to be prescriptive, but to provide a "tool kit" to the water industry to enable the water supply managers to evaluate leakage levels and to manage the system.

Pressure management was identified as one of the key issues with the result that one full report was dedicated to the subject (Report G). The main problem was to develop a simple and pragmatic approach to predicting the reduction in leakage that can be achieved through a range of possible pressure management measures. Several of the UK water companies developed commercial software to address this problem.

Hardware Solutions

At the same time as the research into pressure management was being completed, several new pressure controllers were also being developed which were able to modulate *the pressure at a pressure reducing valve (PRV) situated at the inlet to a pressure zone. By using such controllers it became possible to reduce the pressure during periods of low demand and reduce leakage without adversely affecting the level of service to the consumers. For the first time ever, both software and hardware solutions could be used to tackle pressure in potable water distribution systems.*

In general, there are two types of Advanced Pressure Control: time-modulated control and flow-modulated control. The time-modulated controller offers the simplest and the least expensive form of Advanced Pressure Control. It is basically a timing device that 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 very simple and compact device that can accommodate up to four switching periods each day and two pressure levels: a high-pressure setting dictated by the PRV and a low-pressure setting as adjusted on the controller. The time-modulated controller is simple and easy to use and represents the least expensive form of advanced pressure control. It has certain limitations; one of which concerns the influence on fire-fighting flows. If fire-fighting flows present a problem, the time-modulated option may not be suitable; in which case the more advanced flow-modulated controller may be required.

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. 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 flow-modulated controller can 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. This will then provide the minimum leakage achievable. Although the flow-modulated controller is more expensive than the simpler time-modulated controller, it does offer greater flexibility which can be important in certain areas where fire-fighting requirements represent a potential problem.

The PRESMAC Model

Although the pressure management software developed in the UK is available commercially to companies or consultants throughout the world, it is not designed specifically for South African conditions. In addition, this software is relatively expensive in rand terms overseas. 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 and as part of a greater strategy by the South African Water Research Commission to promote water conservation, a project was initiated in 1999 to develop a South African pressure management model (PRESMAC). The new model is based on the same BABE principles but it 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 and was developed locally with support from Mr Allan Lambert.

The PRESMAC pressure management model is used to assess the likely savings (in monetary terms) of various pressure reduction options (fixed-outlet and time-modulated PRV's) in a selected zone metered area. The analysis is undertaken in a relatively simple and pragmatic manner based on the general BABE concepts. This approach allows the user of the program 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).

Data Requirements

To use the PRESMAC model the user must collect certain basic information for the zone metered area or pressure management area in question. The basic information required includes:

- *number of connections;*
- *length of mains;*
- *number of properties;*
- *population;*
- *expected leakage rates from connections, properties and mains;*
- *pressure exponent for the system as a whole;*
- *details of any commercial consumers.*

The information used in PRESMAC is basically the same information used in a normal minimum nightflow analysis. In addition to the basic information, however, the user must provide three 24-hour pressure profiles and also the 24-hour zone inflow. The average hourly values are required at the following points:

- *pressure at the inlet point;*
- *pressure at the average zone point;*
- *pressure at the critical point;*
- *inflow to the zone.*

These four sets of hourly values are usually measured using flow and pressure loggers which are attached to the flow meter at the zone inlet as well as at three other suitable points. The pressures can basically be logged at any suitable point such as a fire hydrant or a tap located in/on someone's property.

Using PRESMAC

The PRESMAC model allows the user to analyse the existing situation in any specific pressure management area. It then allows the user to assess the likely savings that can be achieved through the installation of a new PRV or by re-setting an existing PRV to a lower pressure. Finally, the model allows the user to assess the potential savings that can be achieved through the use of a time-modulated controller. The time-modulated controller is the simplest, least expensive and most widely used controller available. It is already in use in many parts of South Africa having been introduced to the country at the beginning of 1999.

It should be noted that the model in its current form does not accommodate the analysis of the more complicated and expensive flow-modulated controller, although this option may be added at some future date. In most cases, the analysis of the time-modulated controller will provide the required motivation for the purchase and installation of any form of advanced pressure control. If it is found that the time-modulated controller can be justified on sound financial grounds, then it is likely that the flow-modulated controller will provide even greater savings.

PRESMAC

Pressure Management Program

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1. PRESSURE MANAGEMENT MODEL

1.1. 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. This means that the minimum pressure (normally specified in the local by-laws) occurs at some critical point in the system which is often either the highest point in the system or the point furthest from the supply.

Most 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 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. As a result 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 burst pipes tend to occur during the late evening and early morning periods when system pressures are at their highest.

This concept is shown graphically in **Fig. 1.1** which represents a typical pressure situation for a zone at peak demand periods where the minimum pressure required is 20 m.

The same zone is shown again in **Fig. 1.2** 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).

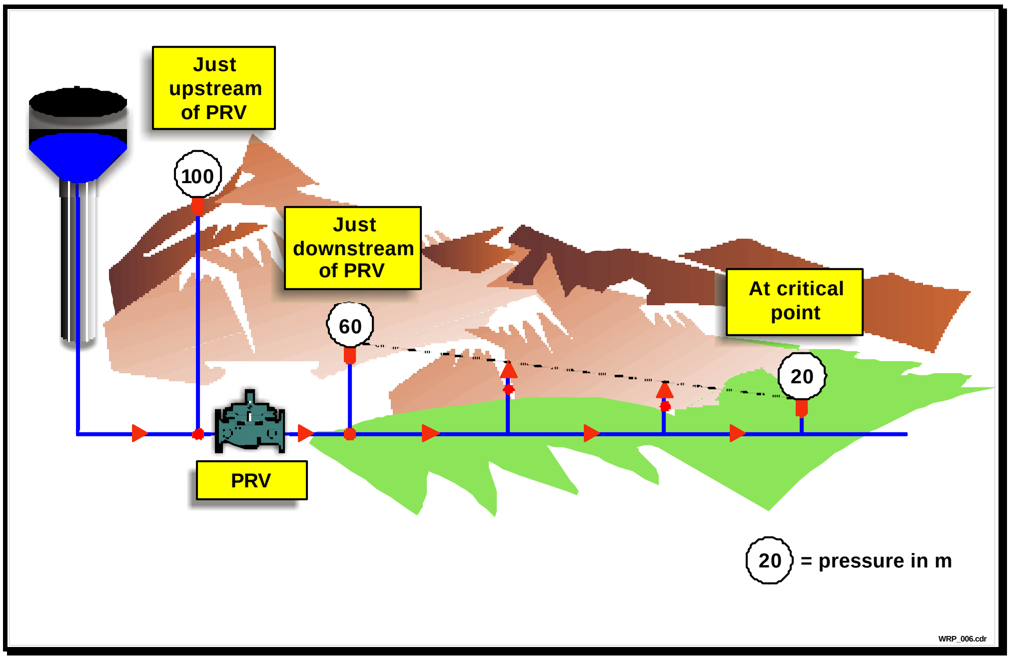


Figure 1.1: Typical zone pressure distribution during peak demand periods

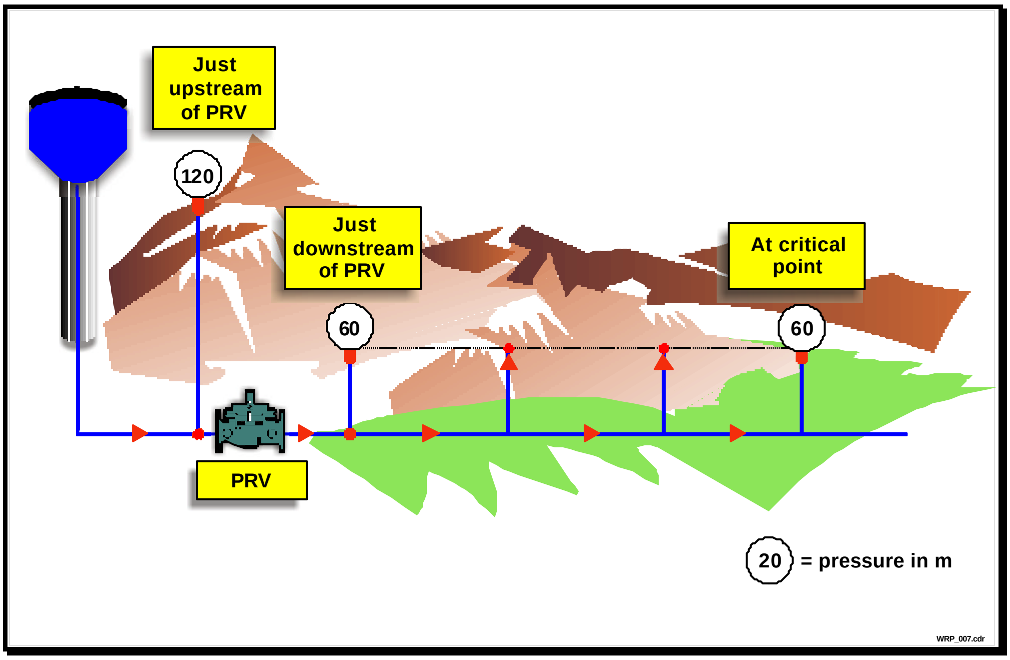


Figure 1.2: Typical zone pressure distribution during low demand periods

From **Figs. 1.1 and 1.2** 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, then it can be concluded that leakage levels in most systems are higher than they should be during most of the time.

It is clear that if the excess pressure in a system can be reduced, then so too can the leakage, which, in turn, will save money. This is the basic philosophy governing pressure management in potable water distribution systems and is often referred to as "Active Pressure Control" or "Advanced Pressure Control".

1.2. 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 (and now also in South Africa) where active pressure control has been 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 used to reduce customer demand, this is generally not the primary objective. 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.

In 1991 a National Leakage Initiative was established in the UK by the Water Services Association and the Water Companies Association to update and review the guidelines concerning leakage control that had been in use since 1980. It was agreed by all organisations involved in potable water supply that the guidelines required updating in view of the considerable progress that had been made over the previous ten-year period. To this end, it was agreed that all water suppliers would adopt a straightforward and pragmatic approach to leakage management. This was achieved through the development of various techniques that became known as the Burst and Background Estimate (BABE) procedures.

The BABE procedures were developed over a period of approximately 4 years by a group of specialists selected from several of the major water supply companies based in England and Wales. The group was instructed to develop a systematic and pragmatic approach to leakage management that could be applied equally well to all of the UK water supply utilities. The result of this initiative was a set of 9 reports published by the UK Water Industry (1994) on the subject of managing leakage.

The intention of the reports was not to be prescriptive, but to provide a "tool kit" to the water industry to enable the water supply managers to evaluate leakage levels and to manage the system. Pressure management was identified as one of the key issues with the result that one full report was dedicated to the subject (Report G). The main issue addressed in the report was the development of a simple but realistic approach to predicting the reduction in leakage that can be achieved through a range of possible pressure management measures. Several of the UK water companies subsequently developed commercial software to address this problem based on the methodology outlined in the report. This software has since been used in many parts of the world including several parts of Europe, Brazil, Ghana, South Africa and Malaysia.

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. It should be noted that 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. For the purpose of this project, however, only the electronic controllers are considered since they dominate the PRV control market and have been used successfully in many parts of South Africa.

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 the study, three possible forms of pressure control were considered of which the first two are incorporated into the PRESMAC Model.

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

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 **Fig. 1.3**.

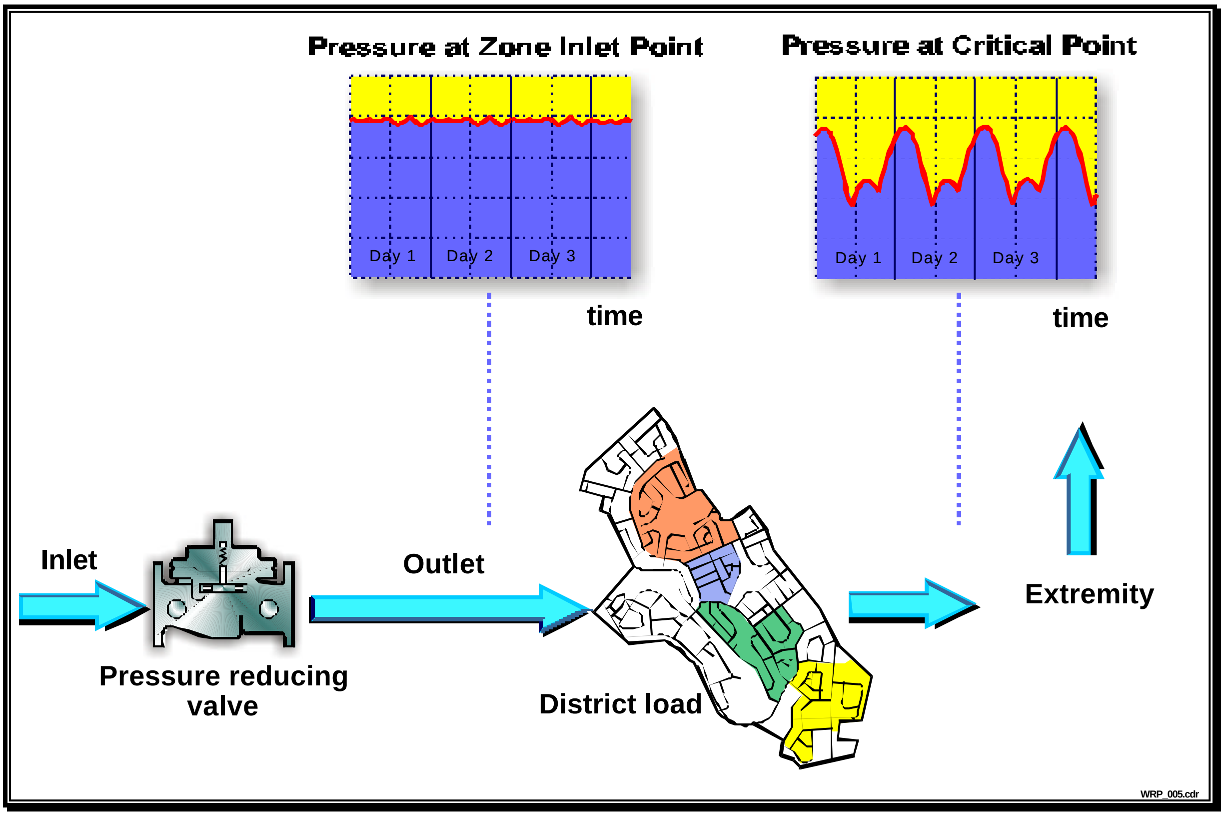


Figure 1.3: Pressure control using conventional PRV

Time-modulated controller

The time-modulated controller is the simplest form of Advanced Pressure Control and also the least expensive. It is a timing device that 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 very 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 **Fig. 1.4**) per day although, in most cases, only one is needed. A typical installation of a time-modulated controller is shown in **Fig. 1.5** and the general objectives are shown in **Fig. 1.6**.

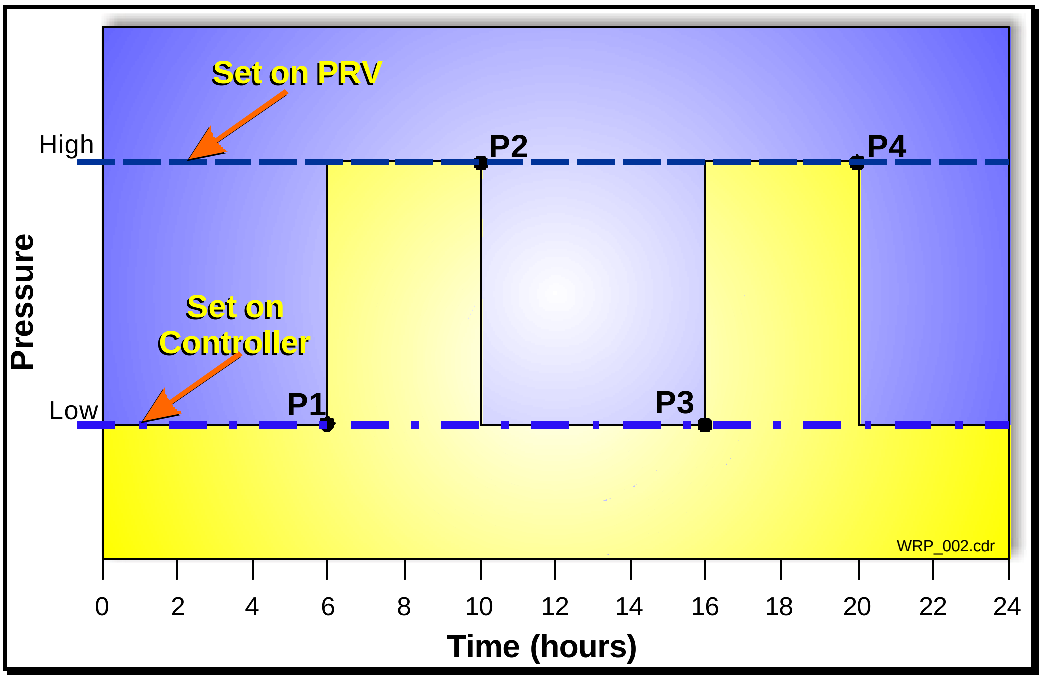


Figure 1.4: Typical 4-point time modulated pressure profile

Figure 1.5: Typical installation of a time-modulated PRV controller

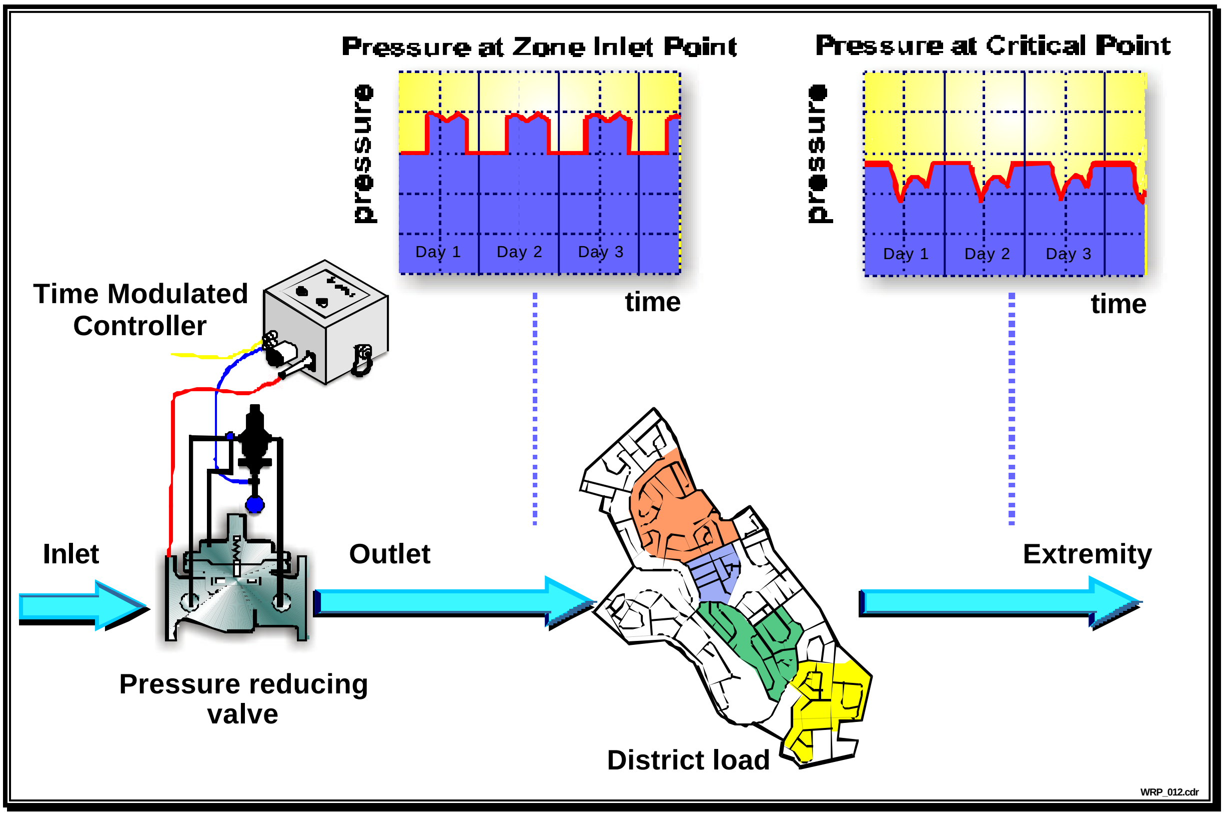


Figure 1.6: Pressure control using a time-modulated PRV controller

It should be noted that the time-modulated controller shown in **Fig. 1.5** (see arrow) is a simple and self-powered unit which can operate for approximately 5 years on a single battery. It is programmed through the use of 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. Through the use of such a controller, it is possible to cut out some of the high-pressure peaks especially during night-time periods.

The main 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 can 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 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 are shown in **Fig. 1.7**.

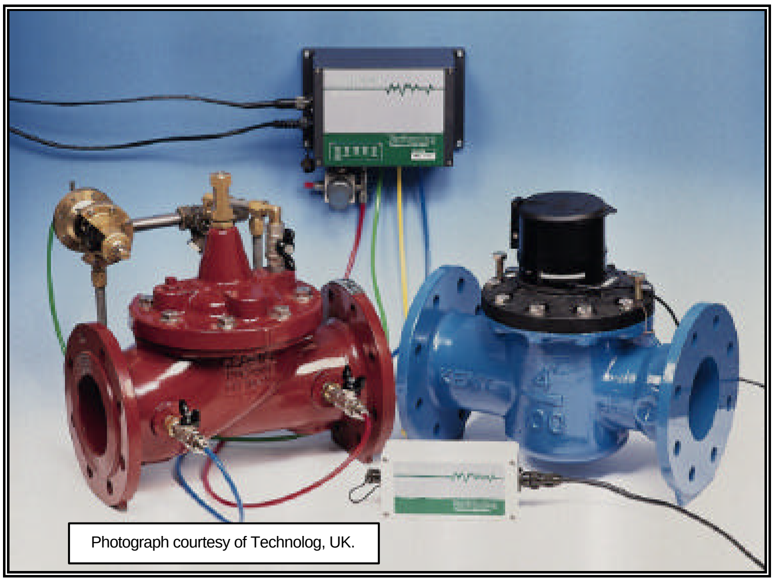


Figure 1.7 : Components required for a flow-modulated PRV installation

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 concepts of the flow-modulated controller are shown in **Fig. 1.8**.

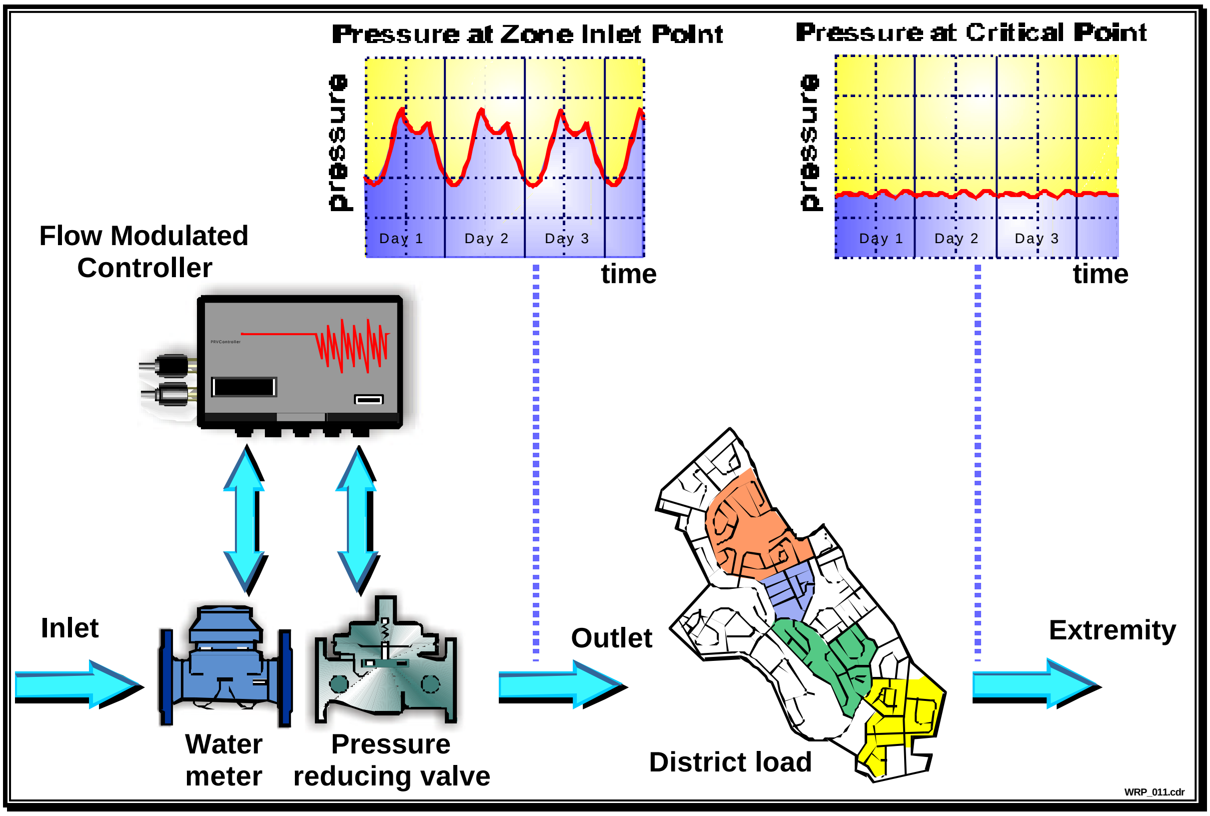


Figure 1.8: Pressure control using a flow-modulated PRV controller

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 **Fig. 1.9**

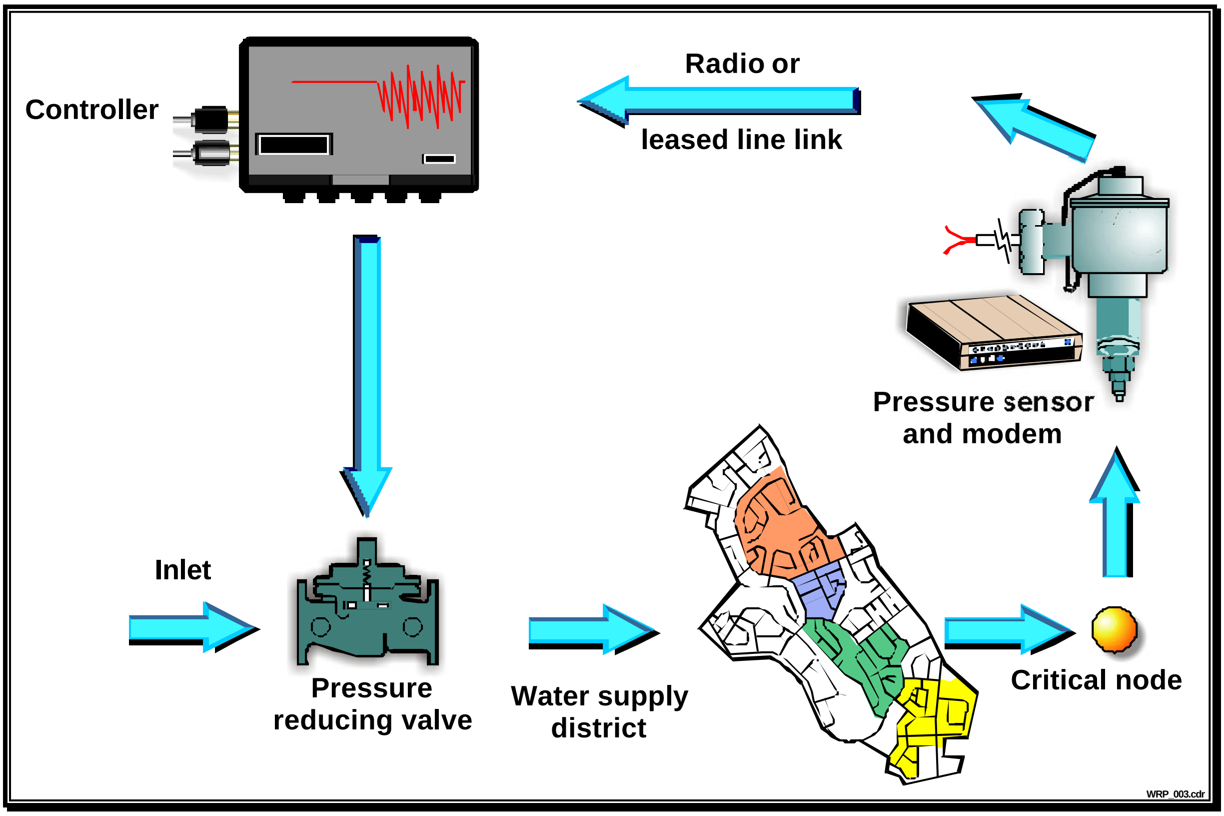


Figure 1.9: Pressure control using a telemetry linked flow-modulated PRV controller

1.3. THE PRESMAC MODEL

1.3.1. General

Although the pressure management software developed in the UK is commercially available to 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. Although the potential savings can be very significant, many of the smaller water suppliers in South Africa are unable to budget for such software without demonstrating the savings in advance – clearly a cart and horse situation.

To overcome these problems and as part of a greater strategy by the South African Water Research Commission to promote water conservation, a project was initiated in 1999 to develop a South African pressure management model (PRESMAC). The model is based on the same BABE principles as the existing UK models and modified to suit South

African conditions where necessary. As opposed to the UK models which were based on the EXCEL spreadsheet architecture, the new South African model is written in DELPHI and was developed locally with support from Bristol Water Consultancy Services and Mr Allan Lambert who were both instrumental in the development and use of the UK models (Lambert et al, 1998).

The PRESMAC pressure management model is used to assess the likely savings (in monetary terms) of various pressure reduction options in a selected zone metered area. This approach allows the user of the program to gauge the potential for pressure management very quickly and effectively without undertaking 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).

1.3.2. Data Requirements

To use the PRESMAC model the user must collect certain basic information for the zone metered area or pressure management area in question. The basic information required includes:

- number of connections;
- length of mains;
- number of properties;
- population;
- expected leakage rates from connections, properties and mains;
- pressure exponent for the system as a whole;
- details of any commercial consumers.

The information used in PRESMAC is basically the same information used in a normal minimum nightflow analysis and all of the items mentioned above are explained fully in the SANFLOW user guide (WRC, 1999). In addition to the basic information, however, the user must provide three 24-hour pressure profiles and also the 24-hour zone inflow. The average hourly values are therefore required at the following points:

- pressure at the inlet point,
- pressure at the average zone point,
- pressure at the critical point,
- inflow to the zone.

These four sets of hourly values are usually measured using flow and pressure loggers which are attached to the flow meter at the zone inlet as well as at three other suitable points such as a fire hydrant or a tap located on someone's property. The information required to run the PRESMAC Model is shown in the data input form in **Appendix B**.

1.3.3. Analysis Approach

The analysis approach involves investigating each area carefully before any new equipment is installed. Each zone should be checked for integrity since any results obtained from a non-discrete zone will be questionable. It should be noted that, although preferable, it is not always necessary to have a single supply point to a particular zone. In cases where there are two or even three supply points, it is still possible to carry out a meaningful analysis as long as all of the supply points are monitored simultaneously.

After logging the zone inflows and pressures at the various key points, the pressure analysis program (PRESMAC) can be used to assess the scope (if any) for reducing leakage through pressure control. From the results, the appropriate equipment can then be selected and installed after which follow-up loggings should be undertaken to verify the results. It should be noted that it is usually necessary to allow for some additional time to "calibrate" the controller after it has been installed. Although the PRESMAC Model will provide an indication of the pressure control limits based on the 24-hour pressure profiles supplied from the logging exercise, these limits often have to be adjusted in some way since most systems do not follow the exact profile provided each day of the week. As a result, there is always some fine tuning and manual adjustment required to obtain the best results without any consumer complaints.

Fig. 1.10 shows a typical situation encountered in a relatively small and well-managed supply zone. The figure shows the inlet pressure, the zone inflow and the pressure at the critical point during a 24-hour period.

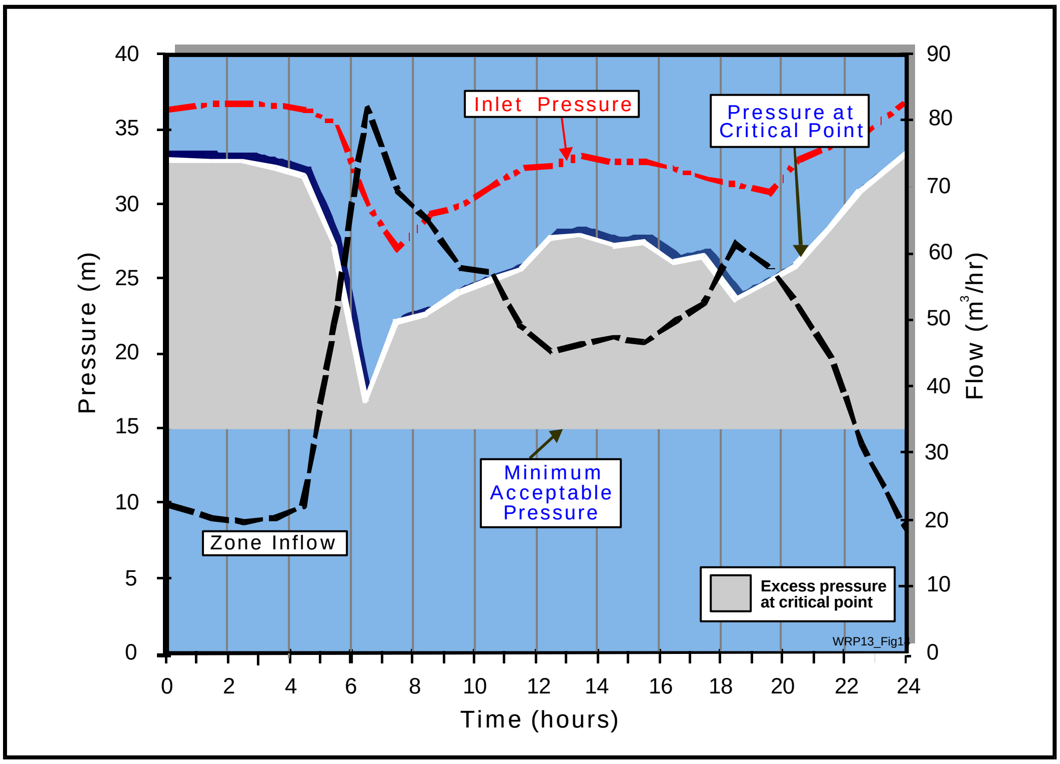


Figure 1.10: Typical zone with no pressure control

As can be seen, the inlet pressure is not particularly high, although there is some scope for improvement. It can also be seen from the figure that the zone inflow exhibits the typical daily peak demand pattern found throughout South Africa with high demand periods in the morning and early evening. Virtually all of the consumers are supplied directly from the water mains and there are few, if any, storage tanks in the area.

For the purpose of this example, it has been decided that the minimum acceptable pressure throughout the day is 15 m. This minimum pressure has been selected for illustrative purposes and does not indicate that 15 m should be accepted as the minimum pressure in all zones. In some zones, the fire-fighting requirements may be 30 m, in which case there would be virtually no scope for further pressure management. In the example, however, it can be seen from the pressure at the critical point that there is considerable excess pressure in the system as indicated by the shaded portion in the figure.

From **Fig. 1.10** it can also be seen that neither the pressures nor the minimum night flow are unusually high. There is obviously some room for improvement. However, the example is typical of a normal zone that may be found in many parts of the world. The savings in such a zone are unlikely to be as spectacular as other examples often quoted from various parts of Africa, Brazil and Malaysia etc. As a general rule of thumb, it is usually possible to reduce the minimum night flow by around 50% in cases where it is already high due mainly to background leakage and/or internal plumbing leakage. If the minimum night flow is less than 20 m^3/hr, it is unlikely that the savings achieved will be sufficient to pay for the installation in less than one or two years. Ideally, pressure management should be considered as an option in zones where the minimum night flow is above 20 m^3/h and preferably above 50 m^3/h.

As can be seen from the zone inlet pressure in **Fig. 1.10**, the zone considered in the example has no form of pressure control and, therefore, the first option to be analysed is a standard fixed outlet PRV.

The PRESMAC Model is used to analyse the situation when a standard PRV is installed and set to an inlet pressure that will just provide 15 m of pressure at the critical point during the peak demand period. The corresponding figure is shown in **Fig. 1.11** from which it can be seen that a fixed outlet PRV can be used to ensure that the pressure at the critical point is limited to the minimum required pressure (15 m in this example) at the period of maximum demand. It can also be seen from the figure, however, that there remains considerable excess pressure in the system during most of the day.

To reduce the excess pressure it is necessary to use a more sophisticated form of pressure control than simply a standard PRV. As mentioned previously, there are many types of PRV controllers available and most large valve manufacturers have several products which can be used to reduce excess pressure in a system. One such product is a simple yet effective time-modulated controller which has been used with great success in many parts of the world including South Africa. Typical results from the model for the time-modulated option are shown in **Fig. 1.12.**

From **Fig. 1.12** it can be seen that the use of the time-modulated controller results in a significant reduction in the excess system pressure as indicated by the smaller shaded portion in the figure.

If further improvement is still required, the more sophisticated flow-modulated controller can be considered. The results from the flow-modulated controller are shown in **Fig. 1.13** from which it can be seen that there is some improvement on the results depicted in **Fig. 1.12**. It should be noted that the PRESMAC Model does not offer the option of analysing the flow-modulated controller. Details of the flow-modulated controller have been included for completeness and to demonstrate that further improvements can often be achieved over those produced by a time-modulated controller. For analysis purposes, it is usually sufficient to model the time-modulated controller to determine if there is scope for pressure control after which the controller can be selected based on the local conditions and requirements.

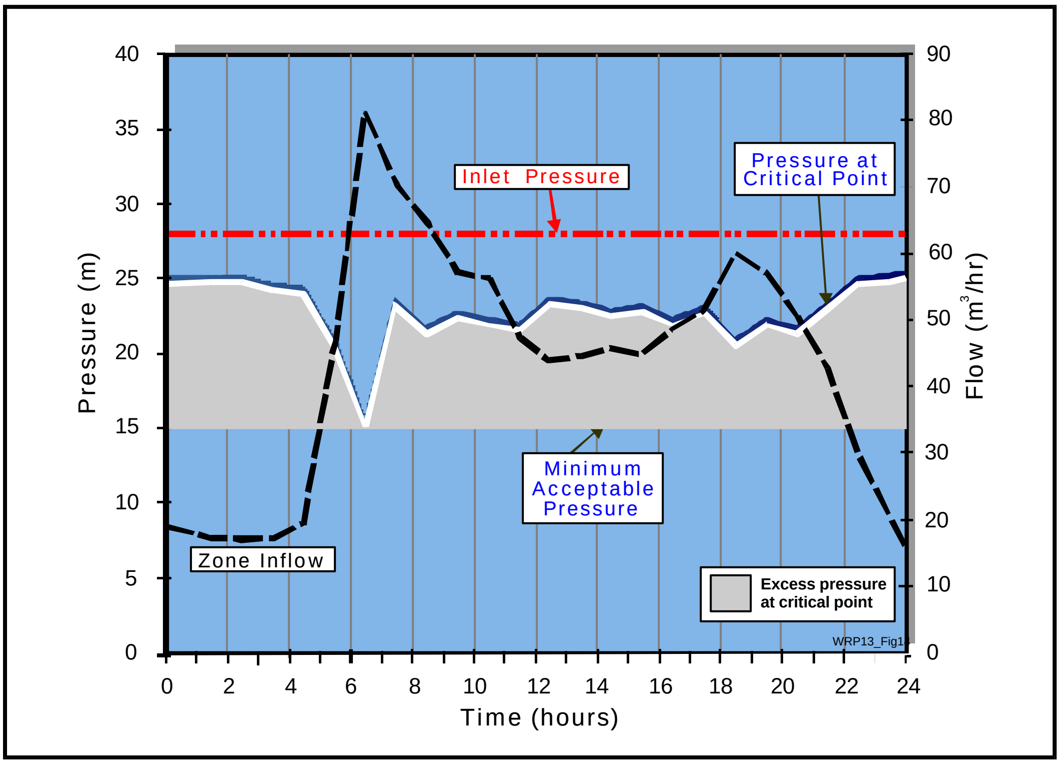


Figure 1.11: Typical zone with fixed-outlet pressure control

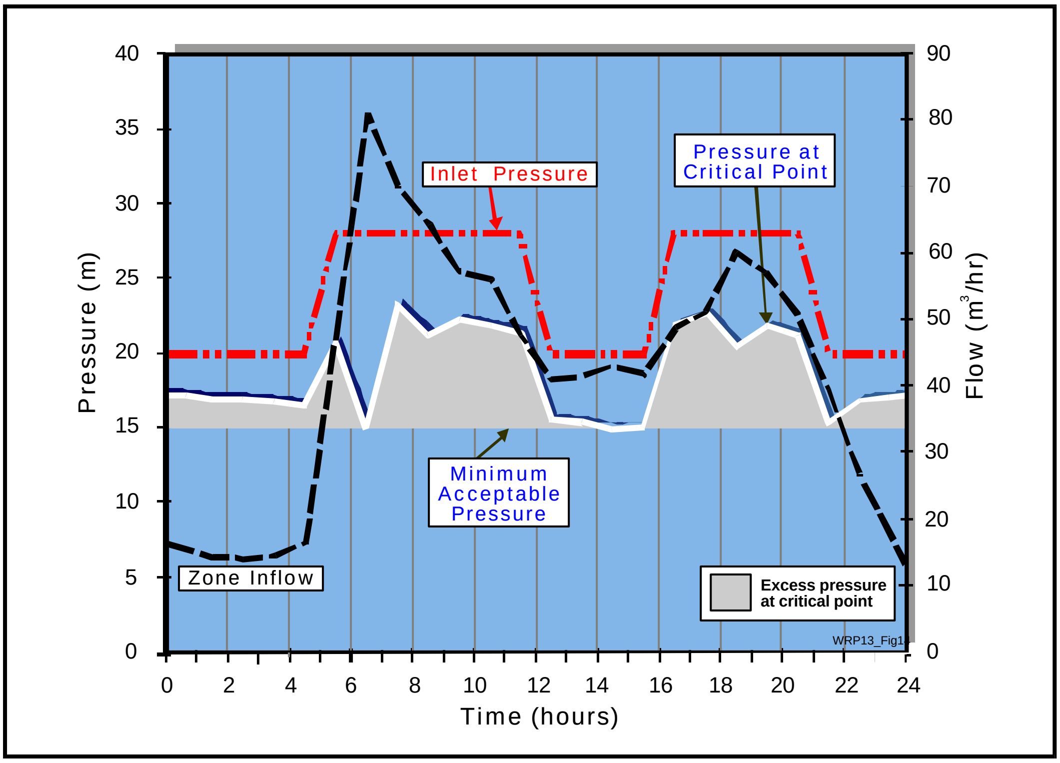


Figure 1.12: Typical zone with time-modulated pressure control

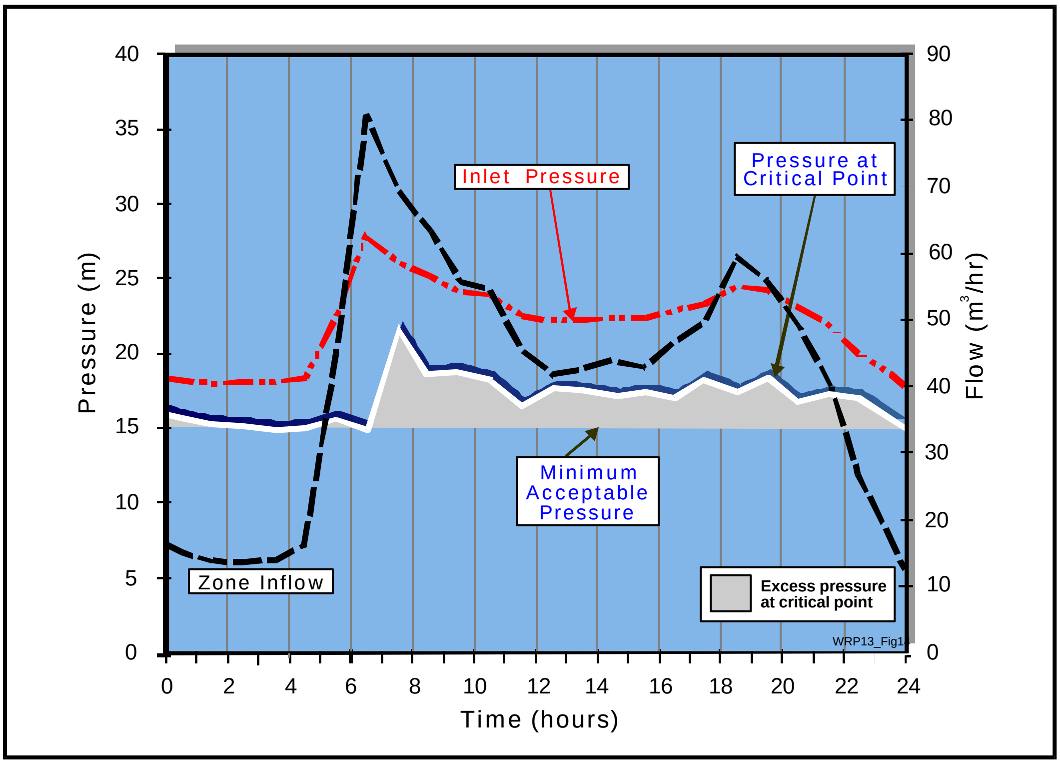


Figure 1.13: Typical zone with flow-modulated pressure control

In this particular example, there is little additional financial benefit to be gained from the use of the flow-modulated controller over the cheaper and less sophisticated flow-modulated controller. If the fire-fighting requirement is a potential problem, then selection of the controller may be dictated by functionality rather than economy. In some cases there is little benefit to be gained from even the time-modulated controller and a standard PRV without advanced pressure control may then be the most appropriate measure.

The decision regarding which form of PRV controller to use (if any) in a particular system is generally based on sound financial considerations with the proviso that the equipment selected also satisfies local fire-fighting regulations. By using the computer model to predict the savings through reduced leakage associated with the various pressure management options, it is possible to estimate the payback periods for each option. This information can then be used to select the most appropriate option. It should be noted that the option with the shortest pay-back period is not always selected since there are often external considerations which dictate the final choice as previously mentioned.

1.4. METHODOLOGY

To carry out the analysis using the Pressure Management Model (PRESMAC) two basic equations are used.

Equation 1: Pressure/Loss Equation

$$L_0/L_1 = (P_0/P_1)^N \qquad \text{Eq. 1(a)}$$

or

$$L_1 = L_0 * (P_1/P_0)^N \qquad \text{Eq. 1(b)}$$

where

L_0	=	initial leakage loss in m^3/h
L_1	=	new leakage loss in m^3/h
P_0	=	initial pressure (m)
P_1	=	new pressure (m)
N	=	pressure exponent (non-dimensional) – see **Section 2.2**

The above equation can also be solved for N to give

$$N = \log (L_0 / L_1) / \log (P_0 / P_1) \qquad \text{Eq. 1(c)}$$

Equation 2: Head Loss/Flow equation

The second equation used in the PRESMAC Model is basically a head loss equation used to estimate the head loss between the inlet point and both the AZP and critical points for any particular flow. It is a simplification of the normal friction factor equations in which all of the terms excluding the flow are lumped into a single coefficient K. The equation used is shown in **Equation 2.**

$$H_L = K * Q^2 \qquad \text{Eq. 2}$$

where

H_L = head loss in m

K = head loss coefficient ($m^{-5}.h^2$)

Q = flow in (m^3/h)

Using the two equations and the BABE methodology, the PRESMAC model can be used to analyse and test the various pressure management options.

1.5. PURPOSE AND LAYOUT OF THIS REPORT

The purpose of this report is to explain the methodology behind the new PRESMAC Model and to provide a simple and clear user manual to the model. The report is set out in 5 sections, details of which are provided below.

Section 1: Introduction and General

This section provides a general introduction to the concepts of Active Pressure Control and explains the need for and use of the new PRESMAC Model. Some details explaining the basic concepts upon which the PRESMAC Model is based are also provided, although no in-depth theory is given.

Section 2: Details of the PRESMAC Model

This section provides details of all variables used in the PRESMAC Model as well as the various items of information that are generated by the model. It effectively explains how the model functions and provides more detailed information on certain key issues that must be clearly understood when using the model. This section should be consulted by all users.

Section 3: Using the PRESMAC Model

This section is effectively the "User Guide" to the PRESMAC Model and is possibly one of the most important sections in this report. Hardware and software requirements are discussed as well as the installation and running procedures for the model. The user is guided step-by-step through the installation and startup procedures while all windows and associated forms are explained in detail.

Section 4 : References

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

Appendix A : Introduction to BABE and FIVAD Concepts

This Appendix provides details of the basic concepts of the BABE procedures which are a key element to all of the water demand management programs being developed through the Water Research Commission (WRC). This section is repeated in the reports for each of the four models developed for the WRC and need not be consulted if the user has already studied the concepts in a previous report. In order to use the PRESMAC Model properly it is important that the user has a firm understanding of the BABE procedures and all new users should familiarise themselves with **Appendix A** before proceeding. This appendix provides details of the basic Burst and Background Estimate concepts as well as details of the Fixed and Variable Area Discharge concepts upon which the PRESMAC Model is based.

Appendix B: Data entry forms and Sample Data Set

Appendix B contains an example of a data entry form which can be used to capture the basic information required to run the PRESMAC Model. A blank form as well as a typical completed form are provided for reference. A sample data file is also included in **Appendix B** for reference.

2. DETAILS OF THE PRESMAC MODEL

2.1. HOW THE MODEL WORKS

Before explaining the operation of the PRESMAC Model it is important to appreciate that no two water supply systems are identical and that the water lost through leakage in a particular system is dependent upon many factors including:

- The length of mains
- The number of service connections;
- The average operating pressure;
- The pipe material and ground conditions;
- The quality of workmanship when the system was installed;
- The levels of cathodic protection in the case of iron and steel pipes;
- Various other factors.

Obviously it is not possible to take everything into account and in most cases it is difficult to obtain even the most basic information concerning the pipe network. It is also known that the leakage from any system is a combination of burst leakage and background leakage, both of which react differently to changes in pressure. For the purpose of the PRESMAC Model, various simplifications are adopted which are considered to be realistic in view of the many unknown factors that influence the leakage predictions. The most important assumptions and issues are discussed separately in the remainder of **Section 2** of this report.

In order to assess the leakage occurring in a particular water distribution system, the PRESMAC Model undertakes a series of calculations in a step-wise manner:

Step 1: The measured zone inflow is first split into pressure-dependent and pressure-independent components that will naturally react differently to changes in pressure.

Step 2: Calculate the K factors (as mentioned in **Eq. 2**) for the head losses between the inlet point and the Average Zone Point (AZP) as well as between the inlet point and the critical point for each hour in the 24-hour analysis period.

Step 3: Carry out various basic checks on the initial flow conditions to ensure that the figures are realistic.

Step 4: Select a new fixed outlet pressure and recalculate the pressure-dependent flows. The pressure-independent flows are assumed to remain unchanged and it is only necessary to recalculate the portion of the zone inflow that is influenced by the change in pressure.

Step 5: Select a suitable time-modulated pressure distribution and repeat the details outlined in **Step 4**. The selected pressure distribution should bring the minimum pressure at the critical point down to the minimum acceptable pressure defined for the system. The minimum acceptable pressure may be different from one zone to another and will depend upon several factors including the presence of multi-storey buildings, industrial users, fire-fighting requirements and payment levels etc.

Step 6: Select a flow-modulated pressure distribution and repeat the various steps outlined in **Step 4**.

Step 7: Summarise the results and present them in a simple and easily digestible format from which the water supplier can make an informed decision regarding which form of pressure control (if any) is appropriate for the system being investigated.

- Before proceeding to explain the various steps in more detail, it is necessary to discuss two of the key parameters (the pressure exponent and the hour-day factor) that must be clearly understood before proceeding.

2.2. PRESSURE EXPONENT (N1)

The N1 value used in **Equation 1** (i.e. $L_1 = L_0 * (P_1/P_0)^{N1}$) represents the power exponent for all distribution losses in the system which is influenced by pressure. This may appear rather confusing to those who have used the night-flow analysis model (SANFLOW) where the burst and background leakage are dealt with separately throughout the analysis process, with the result that there are two pressure exponents, one for burst leakage and the other for background leakage. In the case of the pressure analysis this is not the case and all leakage in a particular system is lumped together. The pressure exponent used in the calculations represents a “lumped” parameter for both burst and background losses. The value for N1 used in the PRESMAC Model will, therefore, normally vary between 0.5 (default value for bursts) and 2.5 (highest value for background leakage) with an average or default value of 1.0. Systems with a high percentage of background leakage will tend to have N1 values in excess of 1.0 while systems where the leakage is predominantly burst leakage on iron or steel pipes will have N1 values of less than 1.0.

If possible, the value of N1 for a system should be calculated directly using measured information obtained from a “pressure step-test” analysis undertaken during the period of minimum night flow. The pressure step-test analysis may take between two and three hours during which the minimum night flow would normally remain relatively constant. It should be noted that the minimum night flow normally comprises three components: normal night customer use, background leakage and burst leakage. Full details of the split between the various components is provided in the SANFLOW User Guide (WRC, 1999).

The calculation of N1 is undertaken by measuring the pressure and inflow at the inlet point and simultaneously measuring the pressure at the average zone point and critical point. The pressure at the inlet point is then reduced in stages, allowing for the system to stabilise before proceeding with the next pressure reduction. Normally two or three pressure reductions can be achieved during the two- to three-hour period of constant minimum night flow. After the consumption starts to rise due to the consumer demand, it is not possible to continue with the pressure step-test since it is not possible to predict accurately the influence of pressure on the consumer demand. The value of N1 is estimated directly from the change in minimum night flow and the head losses between the inlet and average zone points, as well as between the inlet and critical points and, finally, between the average zone point and critical points. A typical pressure step-test calculation is shown in **Table 2.1**.

Table 2.1 Calculation of N1 from pressure step-test analysis

Description	Start time	End time	Pressure			System Inflow (m^3/h)	Night Use	Distribution losses	Estimate of N1 Value		
			Inlet (m)	AZP (m)	Critical (m)				Initial	Stage 1	Stage 2
Initial Conditions	01:30		64	52.0	36.0	72.0	8	64.0			
Stage 1	02:00	02:30	51	42.6	31.0	61.2	8	53.2	0.93		
Stage 2	03:00	03:30	45	38	29.0	56.2	8	48.2	0.90	0.86	
Stage 3	04:00	04:30	40	34	26.0	51.5	8	43.5	0.91	0.89	0.92

The example shown in **Table 2.1** involves a 3-step pressure test from which 6 individual estimates of the N1 value can be derived. The calculations of the N1 values are presented individually for each of the six estimates as shown in **Table 2.2**.
The N1 values are calculated using **Equation 1c** as given in **Section 1.2**.

$$N = \log(L_0 / L_1) / \log(P_0 / P_1) \qquad \textbf{Eq. 1(c)}$$

Table 2.2: Calculation of the N1 values for example shown in Table 2.1

Stage	Basic Head Loss Equation	Estimation of N1	N 1
For stage 1	$(64.0 / 53.2) = (52.0/42.6)^{N1}$	N1 = log(1.2030) / log(1.2207)	0.93
For stage 2	$(64.0 / 48.2) = (52.0/38.0)^{N1}$	N1 = log(1.3278) / log(1.3684)	0.90
For stage 3	$(64.0 / 43.5) = (52.0/34.0)^{N1}$	N1 = log(1.4713) / log(1.5294)	0.91
Between stages 1 and 2	$(53.2 / 48.2) = (42.6/38.0)^{N1}$	N1 = log(1.1037) / log(1.1211)	0.86
Between stages 1 and 3	$(53.2 / 43.5) = (42.6/34.0)^{N1}$	N1 = log(1.2230) / log(1.2529)	0.89
Between stages 2 and 3	$(48.2 / 43.5) = (38.0/34.0)^{N1}$	N1 = log(1.1080) / log(1.1176)	0.92

From the above analysis it is clear that an appropriate value of N1 is between 0.86 and 0.92. In this case a value of 0.9 or even 1.0 would most likely be used.

2.3. CALCULATION OF THE HOUR-DAY FACTOR

As mentioned previously, the maximum benefit to be gained from pressure reduction is at night when the demand for water is at its lowest and system pressures are usually high. One question asked frequently is how much water will be saved at night and how much during the day. Obviously, the savings will depend to a large degree upon the split in water demand between the pressure-dependent component (mainly leakage) and the pressure-independent component (mainly consumption).

In order to provide a meaningful indication of how much water can be saved throughout the day, a "hour-day factor" (HDF) can be used. The HDF is basically the multiplier by which the saving during the hour of minimum night flow is multiplied to give the savings during the full 24-hour period. If, for example, the savings are distributed evenly throughout the day, then the HDF will be 24. In practice, however, the savings are not usually distributed evenly, with the result that the HDF value is not 24. Values of between 10 and 40 are possible, although they normally range from a low of approximately 16 to a high of approximately 30. A low value of 16 indicates that there is a significant difference between the losses during the hour of MNF and the remainder of the day.

Example of hour-day factor calculation

In a specific zone metered area, the pressure dependant losses for the full 24-hour period were estimated to be 1438 m^3. If the pressure-dependent losses during the hour of minimum night flow were estimated to be 64 m^3 ,then the hour-day factor would be 22.47 (i.e. 1438/64).

If, however, the pressure dependent losses during the period of minimum night flow are reduced to perhaps 30 m^3 through some form of advanced pressure control, then the hour-day factor would increase to 47.9 (i.e. 1438/30).

The hour-day factor provides a useful indication of whether or not the estimated pressure-dependent flows estimated in the model are realistic.

2.4. PRESSURE-DEPENDENT AND PRESSURE-INDEPENDENT FLOWS

In order to assess the impacts of pressure reduction in a zone, it is first necessary to split the total flow entering the zone into the following two components.

- Distribution losses - influenced by pressure
- General consumption - not influenced by pressure.

How this split is achieved can be viewed as a rather subjective approach requiring some basic assumptions. Certain variables are provided to allow the user some flexibility in this regard and, in general, a somewhat conservative approach is usually adopted.

In summary, the various burst and background losses are assumed to be pressure-dependent while consumption is assumed to be pressure–independent. This implies that the three components of background leakage (connections, properties, and mains) as well as all burst leakage are pressure-dependent while the three components of consumption (population use, small-unmetered users and larger metered users) are all pressure-independent.

The above assumptions are not strictly correct in that there are usually some connection and property losses which are pressure-independent. A leaking toilet cistern for example, which is dependent upon the water level in the cistern and not the mains pressure would represent pressure-independent leakage. On the other hand, some of the legitimate use which is assumed to be pressure-independent can, in fact, be pressure-dependent. Water used for washing hands and brushing teeth, for example, is dependent upon pressure to some extent since many people simply turn on a tap and leave it running during such activities. Garden irrigation from a municipal supply is another example where domestic consumption can be influenced by pressure since many irrigators leave a sprinkler on for a certain duration irrespective of the quantity of water applied. As a result of such factors domestic consumption is known to decrease to some degree as the pressure drops. In view of these considerations and to err on the conservative side, the flow which is assumed to be independent of pressure is considered to be the following:

Components of flow independent of pressure

Consumption

- Normal domestic use
- Small non-domestic users
- Large-metered users

The component influenced by pressure is NOT taken into account at this stage to provide a conservative estimate of the potential savings

Background Losses

- A portion of the connection losses
  (default value 0.5 ℓ/conn.h = ± 15% of 3 ℓ/conn.h)

- A portion of the property losses
  (default value 0.5 ℓ/prop.h = ± 50% of 1.0 ℓ/prop.h)

In order to split the total flow into the pressure-dependent and pressure-independent components for each hour of the day, the following approach is adopted.

- Estimate the pressure-independent component during the hour of minimum night flow based on the BABE methodology.
- From the above, estimate the pressure-dependant component at the same hour from the MNF
- Having established the pressure-dependent losses during the hour of MNF for which the average zone pressure is known, the pressure-dependent component for each of the other 23 hours can be estimated using **Equation 1** as discussed in **Section X.X**.
- Having established the pressure-dependent losses, the pressure independent component can be estimated by simply subtracting the pressure-dependent losses from the total zone inflow for each hour of the day.

The process of splitting the total flow into the two components may initially seem confusing. It is important to note that it is only at the point of minimum night flow that the consumptive use can be estimated from first principles. At the point of minimum night flow the consumptive use can be estimated from the population and average use per person per hour (usually 6% of population times 10 litres per hour). The water used by other small consumers such as garages, etc as well as large consumers is also taken into account in order to estimate the actual consumption. Having established the consumption, the difference between it and the minimum night flow then provides an indication of the quantity of water lost through burst and background leakage. It is important to note that for the purpose of the PRESMAC Model, the burst and background leakage are treated as one component and that the N1 pressure exponent used in the model is a “lumped parameter”. This is a subtle difference from the SANFLOW night-flow analysis model where burst and background leakage are treated separately with the result that two N1 exponents are used.

The outputs from this stage of the analysis are two sets of 24-hour values representing the pressure-dependent and pressure independent flows.

To explain the calculation, a simple example is provided in **Table 2.4** using an initial pressure-independent flow of 8m^3/h (as estimated below in **Table 2.3**). The calculations are carried out as follows:

Table 2.3: Estimation of pressure-independent flow at MNF (Item 1 in Table 2.6)

Description	Basis of calculation	Calculated flow
Losses per connection	641 connections * 0.5 ℓ/con.h	= 0.32 m^3/h
Losses per property	2210 properties * 0.5 ℓ/property.h	= 1.11 m^3/h
Residential night use	9945 people * 6% * 10 ℓ/h	= 5.97 m^3/h
Non-residential (unmetered)	7 café’s @ 50 ℓ/h	= 0.35 m^3/h
Non-residential (metered)		= 0.26 m^3/h
Total pressure independent flow at MNF		**8.00 m^3/h**

The pressure dependent flow can now be estimated as shown in **Table 2.4** for the hour of MNF.

Table 2.4: Estimation of pressure-dependent flow at MNF (item 2 in Table 2.6)

Description	Basis of calculation	Calculated flow
Total metered flow – pressure-independent flow	72.00 m^3/h – 8 m^3/h	64 m^3/h

Having established both the pressure-dependent and pressure-independent flows during the hour of MNF, it is then possible to estimate the pressure-dependent losses for all other hours. An example of the calculation for the first hour (0 to 1) is provided in **Table 2.5**.

Table 2.5: Estimation of pressure-dependent flow at hour 0 – 1(item 3 in Table 2.6)

Description	Basis of calculation	Calculated flow
Use **equation 1b** where $L_1 = L_0 * (P_1/P_0)^{N1}$	L_1 = 64 m^3/h x (61 m / 64 m)$^{1.0}$	61.53 m^3 / h

The calculation of the pressure-dependent flow is repeated for each remaining hour until the pressure-dependant losses have been calculated for the full 24-hour period (calculations 5 to 25 in **Table 2.6**)

Table 2.6 Example to demonstrate the calculation of pressure-dependent and pressure-independent flow

Hour	Inlet Pressure (m)	Total Inflow (m^3/h)	Pressure-Dependent Flow (m^3/h)	Order of Calculation	Pressure-Independent Flow (m^3/h)	Order of Calculation
0 – 1	61	82.80	61.53	3	21.27	26
1 – 2	63	75.60	62.76	4	12.84	27
2 – 3	64	72.00	64.00	5	8.00	28
3 – 4*	64	72.00	64.00	2	**8.00**	**1**
4 – 5	64	72.00	64.00	6	8.00	29
5 – 6	64	75.60	64.00	7	11.60	30
6 – 7	61	93.60	62.76	8	30.84	31
7 – 8	60	108.00	61.53	9	46.47	32
8 – 9	57	111.60	57.84	10	53.76	33
9 – 10	57	115.20	57.84	11	57.36	34
10 – 11	57	118.80	57.84	12	60.96	35
11 – 12	57	115.20	57.84	13	57.36	36
12 – 13	57	111.60	57.84	14	53.76	37
13 – 14	56	115.20	56.61	15	58.59	38
14 – 15	56	111.60	56.61	16	54.99	39
15 – 16	57	111.60	57.84	17	53.76	40
16 – 17	56	104.40	56.61	18	47.79	41
17 – 18	57	104.40	57.84	19	46.56	42
18 – 19	57	108.00	57.84	20	50.16	43
19 – 20	58	108.00	59.07	21	48.93	44
20 – 21	58	104.40	59.07	22	45.33	45
21 – 22	59	100.80	60.30	23	40.50	46
22 – 23	60	100.80	61.53	21	39.27	47
23 – 24	60	97.20	61.53	25	35.67	48

* hour of minimum night flow

Having established the pressure-dependent flows for each hour of the 24-hour period, it is a very simple calculation to estimate the remaining pressure-independent flows for each hour by simply subtracting the pressure-dependent flows from the zone inflow. The results are indicated in **Table 2.6** (calculations 26 to 48)

The breakdown between pressure-dependent and pressure-independent flows for each hour in the 24-hour period has now been established as shown in **Table 2.6**.

2.5. ESTIMATION OF NETWORK FRICTION ("K") FACTORS

Having established the split between pressure-dependent and pressure-independent flows, the next step is to estimate the friction factors (K factors) for each hour of the day. The hourly "K" factors effectively represent the friction loss for the whole distribution system for a specific hour of the day. Two sets of "K" factors are used throughout the analyses, namely, those representing the friction losses from the inlet to the Avarage Zone Point (AZP) and, secondly, those representing the losses from the inlet to the critical point. The underlying assumption is that, for each hour, it is a "lumped" factor for the system as a whole and that although the factors will vary from hour to hour, they will remain approximately the same for each day. In other words, the same "K" factor will be used for hour 12 to 13 on day 1 as for hour 12 to 13 on day 2, day 3, day 4, etc.

This is a rather brood assumption and can best be understood by using an analogy of a road traffic system. If the water distribution system is compared to the traffic flow pattern of a similar sized town, the use of the "K" factor can be conceptualised. In a traffic system, the traffic flow patterns tend to be similar from day-to-day although they may vary considerably from hour-to-hour throughout the day depending upon when the peak hour traffic into and out of the main centre occurs. The pattern of water flow is assumed to vary much in the same manner, hence, the use of a separate K factor for each hour of the day. This simplistic approach has been found to provide realistic results in most instances, particularly at the critical point. The "K" values at the AZP often appear to fluctuate considerably. However, this is not considered to be a problem since the end results are considered within the acceptable tolerances for this basic approach.

The "K" factors are calculated in the following manner:

From **equation 2**

$$H_L = K \times Q^2 \qquad \text{or} \qquad K = H_L/Q^2$$

Where H_L = head loss (m)

Q = flow (m^3/h)

K = friction factor/coefficient ($m^{-5}h^2$)

Two "K" factors for each hour of the day are calculated using the above equation where the H_L term is the difference in pressure between the inlet point and the AZP as well as between the inlet point and the critical point. Details of the calculation of the "K" factors for the target and critical points are given in **Table 2.7**.

The calculation of the "K" factors for hour 0 – 1 is provided in **Table 2.7**.

Table 3.7: K factors for AZP and critical points (items 2 and 3 in Table 2.8)

Description	Basis of calculation	K factor
K factor at the AZP where : ΔH = 11m and Q = 82.8 m^3/h	K = 11 / $(82.8)^2$	0.00160 4
K factor at the critical point where : ΔH = 31 m and Q = 82.8 m^3/h	K = 31 / $(82.8)^2$	0.00452 2

The full set of K-factors is provided in **Table 2.8** for a specific data set.

As can be seen in **Table 2.8**, the "K" factors for the critical point appear reasonably consistent as would be expected. The "K" factors for the AZP, however, seem to vary considerably and tend to look unrealistic in some cases. This is not a problem and should also be expected, due to the fact that the position of the AZP is often not known and has been approximated.

Having established the split in the pressure-dependent and pressure-independent flows as well as the K-factors for each hour of the 24-hour period, it is now possible to test the impact of various possible pressure management options on the leakage from the zone. The first option to be considered is the installation of a standard pressure-reducing valve (PRV). In cases where a PRV is already in operation, it is possible to test the influence of changing the fixed pressure level.

Table 2.8: Estimation of K-values at AZP and critical point

Hour	Pressure (m)			ΔH Between inlet		Flow m^3/h	K factors for	
	Inlet (m)	AZP (m)	Critical (m)	AZP	Critical		AZP	Critical
0 – 1	61	50	30	11	31	82.8	0.001604	0.004522
1 – 2	63	51	34	12	29	75.6	0.00210	0.005074
2 – 3	64	52	36	12	28	72.0	0.002315	0.005401
3 – 4*	64	52	36	12	28	72.0	0.002315	0.005401
4 – 5	64	52	36	12	28	72.0	0.002315	0.005401
5 – 6	64	52	36	12	28	75.6	0.002100	0.004899
6 – 7	61	51	25	10	36	93.6	0.001141	0.004109
7 – 8	60	50	18	10	42	108.0	0.000857	0.003601
8 – 9	57	47	17	10	40	111.6	0.000803	0.003212
9 – 10	57	47	17	10	40	115.2	0.000754	0.003014
10 – 11	57	47	17	10	40	118.8	0.000709	0.002834
11 – 12	57	47	17	10	40	115.2	0.000754	0.003014
12 – 13	57	47	17	10	40	111.6	0.000803	0.003212
13 – 14	56	46	16	10	40	115.2	0.000754	0.003014
14 – 15	56	46	16	10	40	111.6	0.000803	0.003212
15 – 16	57	47	17	10	40	111.6	0.000803	0.003212
16 – 17	56	46	19	10	37	104.4	0.000917	0.003395
17 – 18	57	47	19	10	38	104.4	0.000917	0.003486
18 – 19	57	47	20	10	37	108.0	0.000857	0.003172
19 – 20	58	48	20	10	38	108.0	0.000857	0.003258
20 – 21	58	48	22	10	36	104.4	0.000917	0.003303
21 – 22	59	49	25	10	34	100.8	0.000984	0.003346
22 – 23	60	50	26	10	34	100.8	0.000984.	0.003346
23 – 24	60	50	28	10	32	97.2	0.001058	0.003387

2.6. ANALYSIS OF FIXED-OUTLET PRV

The fixed- outlet PRV option is the simplest and most basic of the various pressure management options that can be considered. It involves installing a PRV at the inlet to a zone which will ensure that the pressure entering the zone remains at a constant level throughout the day. (refer to **Fig. 1.1** in **Section 1.1**)

The objective of installing a PRV at the inlet point is to lower the pressure at the target or critical point until it meets the minimum level of service.

If leakage and head losses were uniform and linear in nature it would be a very simple operation to estimate how much the inlet pressure should be reduced in order to provide exactly the minimum pressure allowed at the critical point during the period of peak demand. Unfortunately, life is not quite as simple and a pressure drop of 10 m or more at the inlet point is often required to achieve a drop in pressure of only 5 m at the critical point. This is an important point that is often overlooked when considering the possibility of pressure reduction in a zone. The distribution engineer often indicates that the excess pressure at the critical point is perhaps only 3 or 4 m and, as such, he/she is of the opinion that there is little, if anything, to be gained from pressure reduction. If it is shown , however, that the inlet pressure can be dropped by more than 10 m to achieve the drop of only 3m at the critical point, then there are significant gains to be made.

In order to model this process in the PRESMAC Model, a very simple iterative approach is adopted in which the following methodology is employed.

Step 1

- An initial estimate is made of the fixed outlet pressure that will yield the minimum acceptable pressure at the critical point during the hour of minimum pressure (i.e. peak demand period). For example, if the minimum pressure at the critical point is 25 m and the minimum level of service is 20 m, then the inlet pressure can be reduced by at least 5 m. This estimate of 5m is then subtracted from the actual pressure at the inlet point during the critical hour and then applied for the full 24-hour period representing a static outlet pressure from the PRV.

Step 2

- Having set a constant pressure for the full 24-hour period, it is then necessary to re-calculate the new pressures at the AZP and critical point. This is an iterative procedure and will be described in detail later in this section.

Step 3

- The new pressure at the critical point is checked against the minimum pressure requirement and, if possible, the inlet pressure is reduced further. This procedure is repeated until the pressure at the critical point is in line with the desired minimum pressure.

The above procedure is best explained through the use of a simple example.

Example

In this example, the minimum pressure at the critical point is measured to be 16 m between hours 13 and 15 during which the inlet pressure is measured to be 56 m. In this case the minimum level of service is only 10m and the inlet pressure can be reduced by at least 6 m.

Step 1: Initial estimate of new fixed-outlet pressure

The initial estimate for the fixed outlet pressure will therefore be set at 50 m (59 m – 6 m). In practice we would probably start with a reduction of 10 m or 12 m. However, to demonstrate the procedures, an initial reduction of 6m will be used in the knowledge that the exercise will have to be repeated several times until a pressure of 10 m is obtained at the critical point.

The new inlet pressure to 50 m is now used for each hour as indicated in **Table 3.9**.

Step 2: Calculate the resulting pressures at the AZP and critical point

Using the new fixed-outlet pressure, the resulting pressures at both the AZP and critical point are for the first hour and then for each of the 23 remaining hours. At this iterative stage in the analysis, it is only necessary to analyse the hour of peak demand when the pressure at the critical point will be at its minimum. Since the whole procedure is undertaken almost instantly within the PRESMAC Model, the calculation is carried out for all 24 hours.

The calculation is undertaken in an iterative manner in which the "K" values calculated earlier are used. The procedure for the first hour at the AZP is as follows:

Step 2a

- For the first hour the initial pressure-dependent losses were estimated to be 61.53 m^3 for an inlet pressure of 61 m. The inlet pressure has been reduced to 50 m (i.e. a drop of 11 m) and so an 11m drop at the AZP to 39 m (i.e. 50 m – 11 m) is used as the first estimate.

Step 2b

- The pressure-dependent losses are re-calculated for the new pressure at the AZP from **Equation 1.** i.e.

$$\mathbf{L_1 = L_0 \times (P_1/P_0)^{N1}}$$

where **N1** in this example is assumed to be **1.0** which produces a new estimate of the pressure-dependent losses as **48 m^3/h** (i.e. 61.53 * (39/50)). This calculation indicates that the pressure-dependent losses will reduce from **61.53 m^3/h** to **48 m^3/h** during the first hour if the inlet pressure is reduced from **61 m** to **50 m**. This clearly demonstrates how important pressure can be with regard to system leakage.

Step 2c

- Using the new estimate of pressure-dependent losses of **48 m^3/h**, the previously calculated pressure-independent losses of **21.27 m^3/h** are added to give a new estimate of the total system inflow. It should be remembered that the pressure independent losses/use do not change with the decrease in the zone inlet pressure since they are theoretically independent of pressure. The new zone inflow is estimated to be **69.27 m^3/h** (i.e. 48 + 21.27) compared to the original value of **82.8 m^3/h**.

Step 2d

- Using the new estimate of the total zone inflow of **69.27 m^3/h,** the appropriate K value from **Table 3.3** (i.e. 0.001604) is used together with **equation 2** to re-estimate the head loss between the inlet point and the AZP.

i.e. new head loss = 0.001604 * 69.27^2 = 7.7 m

Step 2e

- The revised head loss of 7.7 m is now compared to the initial estimate of 11 m if the difference between the two estimates is significant. The inlet pressure is altered accordingly and the whole calculation is repeated. In this example it is clear that the head loss (11 m) has been overestimated and the new lower value is now used in the second iteration. As a result, a new estimate of the pressure at the AZP is made, using 7.7 m and not the previous estimate of 11 m. It should be remembered that the purpose of this calculation is to establish the new pressure at the AZP for the new inlet pressure of 50 m (previously 61.3 m).

The iterative procedure is shown in **Table 2.9.**

Table 2.9: Iterative approach used to calculate the new pressure at the AZP

	1	2	3	4	5	6
Iteration No.	**Estimate Pressure at AZP (m)**	**Estimated Pressure-dependent losses (m^3/h)**	**Pressure-independent losses (m^3/h)**	**Total zone inflow (2 + 3) (m^3/h)**	**Calculate new head loss between inlet and AZP (m)**	**New estimate of AZP Pressure (m)**
1	39.0	48.0	21.27	69.27	7.7	42.3
2	42.3	52.0	21.27	73.32	8.6	41.3
3	41.3	50.9	21.27	72.19	8.36	41.6
4	41.6	51.2	21.27	72.57	8.43	41.6
				72.44		

From **Table 2.9** it can be seen that the pressure at the AZP stabilises at **41.6m** after 4 iterations.

The same calculation is then undertaken for the remaining 23 hours at the AZP.

Having calculated the new zone inflow for each hour as well as the pressure at the AZP, the next step is to estimate the new hourly pressures at the critical point. In this case it is not necessary to carry out an iterative approach, but instead, make use of the zone inflow and the previously calculated K values which are used in **Equation 2**.

i.e. $\mathbf{H_L = K \times Q^2}$

In hour 1 the new Q value has been calculated to be **72.44 $\mathbf{m^3/h}$** (see **Table 2.10**) and the K value **0.004522**. Using these values the new head loss is calculated from

$$\mathbf{H_L = 0.004522 \times 72.44^2 = 23.73\ m}$$

The new pressure at the critical point for hour 1 is estimated to be:

50 m – 23.73 m = 26.3 m

This simple calculation is repeated for each hour until all pressures have been estimated. The resultant pressures at both the AZP and critical points are provided in **Table 2.10**.

Step 3: Check new pressure at critical point and adjust if necessary

From **Table 2.10** it can be seen that the drop in pressure to 50 m has resulted in a drop in pressure at the critical point to a minimum value of 14.1 m. In other words, a 6 m drop in inlet pressure has resulted in only a 1.8 m drop in pressure at the critical point. From this result it is clear that the inlet pressure can be lowered significantly more than 6 m to obtain a minimum pressure of 10 m at the critical point.

The process is repeated several times until the desired minimum pressure of 10 m is obtained. The results from the iterative process are shown in **Table 2.11.**

Table 2.10 Revised pressures at AZP and critical points for fixed outlet PRV.

Hour	Pressure at AZP (m)		Pressure at Critical Point (m)	
	Original	If Inlet = 50 m	Original	If Inlet = 50 m
0 – 1	50	41.6	30	26.3
1 – 2	51	41.5	34	29.3
2 – 3	52	41.8	36	30.9
3 – 4	52	41.8	36	30.9
4 – 5	52	41.8	36	30.9
5 – 6	52	41.7	36	30.6
6 – 7	51	42.2	25	21.9
7 – 8	50	41.8	18	15.5
8 – 9	47	41.2	17	14.9
9 – 10	47	41.2	17	14.8
10 – 11	47	41.2	17	14.7
11 – 12	47	41.2	17	14.8
12 – 13	47	41.2	17	14.9
13 – 14	**46**	**41.0**	**16**	**14.1**
14 – 15	47	41.1	16	14.2
15 – 16	47	41.2	17	14.9
16 – 17	46	41.1	19	17.1
17 – 18	47	41.3	19	16.9
18 – 19	47	41.3	20	17.7
19 – 20	48	41.4	20	17.5
20 – 21	48	41.5	22	19.3
21 – 22	49	41.7	25	21.8
22 – 23	50	41.9	26	22.4
23 – 24	50	41.9	28	24.2

Table 2.11 Derivation of new inlet pressure to provide critical pressure of 10m

Iteration	PRV Pressure (m)	Minimum pressure at critical point (m)
Initial	n/a	16.0
1	50	14.1
2	46	12.8
3	43	11.7
4	39	10.2
5	38.5	10.0

From the results shown in **Table 2.11** it can be seen that a PRV pressure of 38.5 m can be used to produce a minimum pressure of ±10m at the critical point.

The results produced from the program are now used to estimate the total savings that will be achieved through the use of the new PRV set at 38.5 m. Details of the savings are provided in **Table 2.12**.

Table 2.12 Savings achieved through the use of PRV set at 38.5 m

Hour	Zone Inflow (m^3/h)		Saving achieved
	Initial	For PRV at 38.5 m	m^3/h
0 – 1	82.8	61.2	21.6
1 – 2	75.6	53.0	22.6
2 – 3	72.0	48.7	23.3
3 – 4	72.0	48.7	23.3
4 – 5	72.0	48.7	23.3
5 – 6	75.6	52.0	23.6
6 – 7	93.6	71.1	22.5
7 – 8	108.0	86.0	22.0
8 – 9	111.6	92.7	18.9
9 – 10	115.2	96.2	19.0
10 – 11	118.8	99.7	19.1
11 – 12	115.2	96.2	19.0
12 – 13	111.6	92.7	18.9
13 – 14	115.2	97.2	18.0
14 – 15	111.6	93.7	17.9
15 – 16	111.6	92.7	18.9
16 – 17	104.4	86.7	17.7
17 – 18	104.4	85.7	18.7
18 – 19	108.0	89.2	18.8
19 – 20	108.0	88.1	19.9
20 – 21	104.4	84.6	19.8
21 – 22	100.8	80.1	20.7
22 – 23	100.8	79.1	21.7
23 – 24	97.2	75.6	21.6
Daily Totals	**2390.4**	**1899.6**	**490.8**

It should be noted that the savings indicated in **Table 2.12** are conservative and, in reality, are likely to be higher since no allowance has been made for a reduction in consumptive use or the reduction in leakage due to the reduced number of burst pipes. Although the consumptive use is initially assumed to be independent of pressure, this is not strictly accurate since some of the consumptive flow will be influenced by pressure. Recent studies by John May (personal communication) indicate that toilet cisterns can use up to an additional 10% of normal flush volume if connected directly to mains pressure. This is due to the additional flow occurring as the cistern is emptying and the valve is fully open.

The results provided also exclude any savings from reduced bursts which are usually calculated separately. The savings indicated in the PRESMAC Model only refer to the direct savings from reduced system input for the system in its current condition.

2.7. ANALYSIS OF TIME-MODULATED CONTROLLER

By using a fixed-outlet PRV, it is possible to reduce the system pressure to a level whereby the critical point receives the minimum level of service (i.e. 10 m in the previous example) during the period of maximum demand.

This is normally the point at which the engineers and system designers feel satisfied that they have completed their duty. In reality, however, the pressure at the critical point will be considerably higher than the minimum level of service for most of the time when the system demand is lower. In some respects this may be acceptable since it implies that everyone in the system is receiving at least the minimum pressure throughout the day. From a leakage viewpoint, however, it also implies that the leakage rates are likely to be considerably higher than they need to be during all times, except the one or two hours when the critical point is receiving the minimum allowable pressure as discussed in **Section 1.2**.

A time-modulated PRV consists of an electronic timing device that will drop the inlet pressure to a lower setting during certain times of the day or night. It is the simplest and least expensive form of advanced pressure control and enables the engineer to drop the pressure during periods of low demand.

Various time-modulated controllers are currently available which allow the engineer to select two pressures (high and low) as well as four switching periods. This enables the pressure to be switched from high to low up to four times per day. In many instances, it is found that only two switching periods are required and not the maximum of four available through the controller. Normally it is only necessary to drop the pressure from perhaps 8pm to 6am and leave it at the higher setting for the rest of the day.

It should be noted that certain time-modulated controllers can also be used in association with a flow meter to offer a crude form of flow-modulated control. In the flow-modulating mode such controllers can switch from low to high pressure if the flow sensor indicates a flow higher than some pre-defined limit. The use of a time-modulated controller operating in flow mode is not accommodated in the PRESMAC Model.

The PRESMAC model allows the user to simulate a time-modulated controller in order to assess the potential savings that can be achieved through its use. Although this option may not provide the higher savings that can often be achieved through the use of a flow-modulated controller, it will provide a realistic estimate of the savings that can be achieved through the use of the simpler and less expensive controller.

In order to use the time-modulating option, the user of the program simply selects a period (or up to two periods) during which the pressure is lowered from the high value to a lower value. For example, the user may wish to consider reducing the pressure at a fixed outlet PRV from 50m to 30m during the low demand period from 10pm to 5am as shown in **Fig. 2.1**.

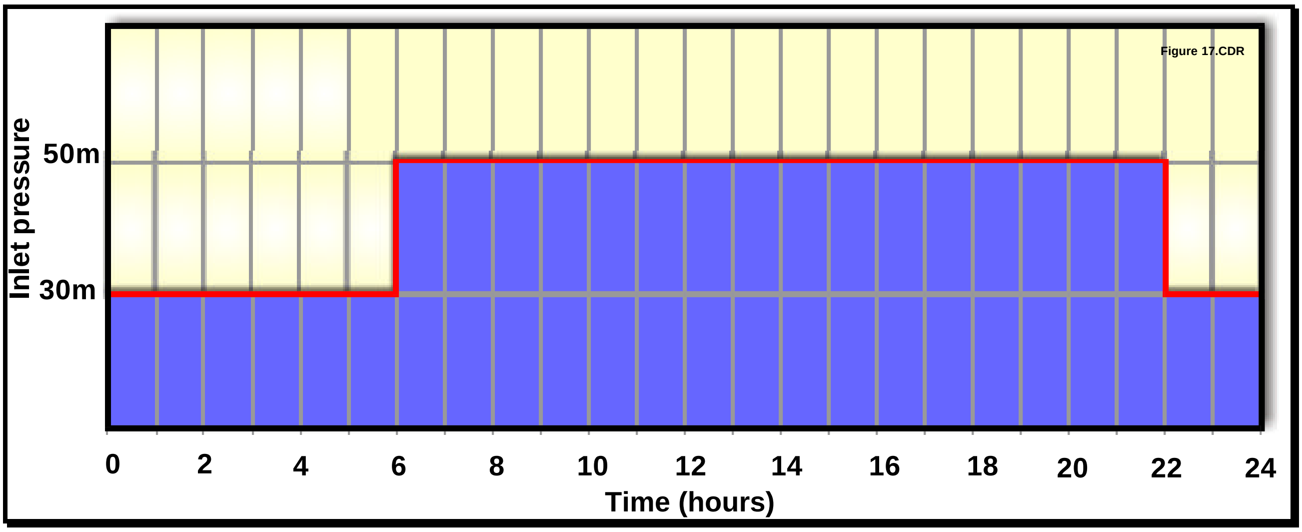


Figure 2.1 Example of a (two-point) time-modulated pressure profile

The time modulated option is analysed in exactly the same manner as the fixed-outlet PRV option, whereby the new pressures at the Average Zone Point (AZP) are first calculated in an iterative approach using the K factors. Having established the new pressures at the AZP and the corresponding zone inflows, the pressures at the critical point are estimated. The time-pressure profile can then be adjusted if required by either changing the times for switching from high to low pressure or by changing the pressure settings. As indicated previously, up to four switching levels can be used which will allow two blocks of low pressure to be modelled. It must be remembered that only two pressure settings are permitted – i.e. a high pressure and a low pressure.

3. USING PRESMAC

3.1. HARDWARE AND SOFTWARE REQUIREMENTS

In order to run the PRESMAC Model the user requires a standard personal computer with the Windows 98 (or above) operating system. The model has been developed for use on colour screens with a resolution of 800 by 600 or better.

3.2. INSTALLING PRESMAC

PRESMAC is supplied on a single disc which contains two files namely PRESMAC.EXE and PRESMAC.PRU. The PRESMAC.EXE file is the main executable which can be run by simply double clicking on the file from any standard file management program. The PRESMAC.PRU file is a sample data file providing the user with a data template from which other data files can be generated.

To load and run PRESMAC, the user should create a directory (called PRESMAC for example) and copy both files from the disc into the directory. The executable can then be run without any additional software. It should be noted that the model is not accompanied by an installation shield with the result that the user must create his/her own icons and items on the start-up menu if desired.

3.3. DATA REQUIREMENTS

In order to use PRESMAC the user must first obtain the relevant data for the area to be examined. Unfortunately, the data collection can often be time-consuming and problematic due to the fact that a certain amount of logging information is required. In general, the data required to operate the model are as follows:

General Zone Information

- Length of mains;
- Number of connections;
- Number of properties;
- Population;
- Condition of network (mains, connections, properties)
- Type of properties (informal, affluent etc)
- Estimate of illegal connections

Logged Flow and Pressure

- 24-hour profile of zone inflow;
- 24-hour profile of pressure at inlet point

- 24-hour profile of pressure at critical point;
- 24-hour profile of pressure at Average Zone Point.

In order to facilitate the data capture and reporting of data for each zone, a data input form has been prepared and is provided in **Appendix B**.

The logging information should ideally refer to a relatively extreme period when the system demands are at or near their highest. In some instances, it may be appropriate to consider two events, one during normal demand periods and the other during extreme demand periods. This is particularly relevant for areas experiencing large fluctuations in demand as is often the case in holiday locations or areas where garden irrigation during the hot summer periods is significant. Due to the flexibility of the advanced pressure control devices, it is relatively simple to define two (or more) operating procedures for the different periods of the year and the equipment can then be adjusted at the start of the winter and summer periods or as appropriate.

3.4. RUNNING PRESMAC

As mentioned previously, the PRESMAC Model is opened by double clicking on the PRESMAC.EXE file. This opens the PRESMAC Model which is a self-contained DELPHI Program requiring no additional software (e.g. EXCEL). After opening the model the user should see the standard front page as shown in **Fig. 3.1**. This page remains on the screen for several seconds to give the user sufficient time to read the version number, etc.

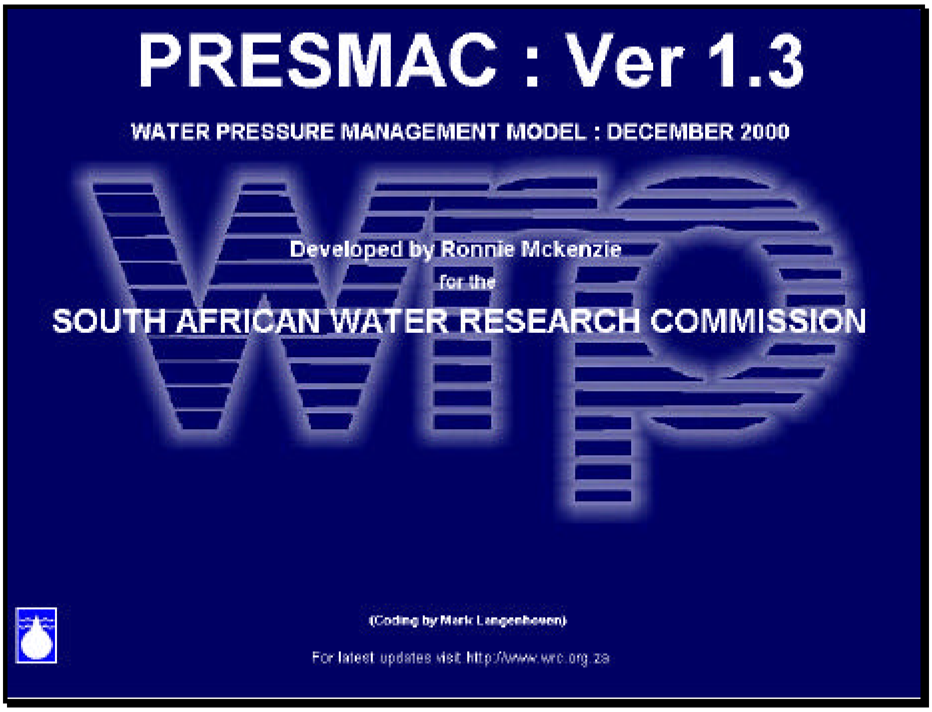


Figure 3.1: Opening banner from PRESMAC

After a few seconds, the main screen appears which allows the user to start running the model. Generally, the first action to be taken will be to open an existing data file. If the user has not created any data files previously, the sample data file PRESMAC.PRU should be opened. The main screen is shown in **Fig. 3.2**.

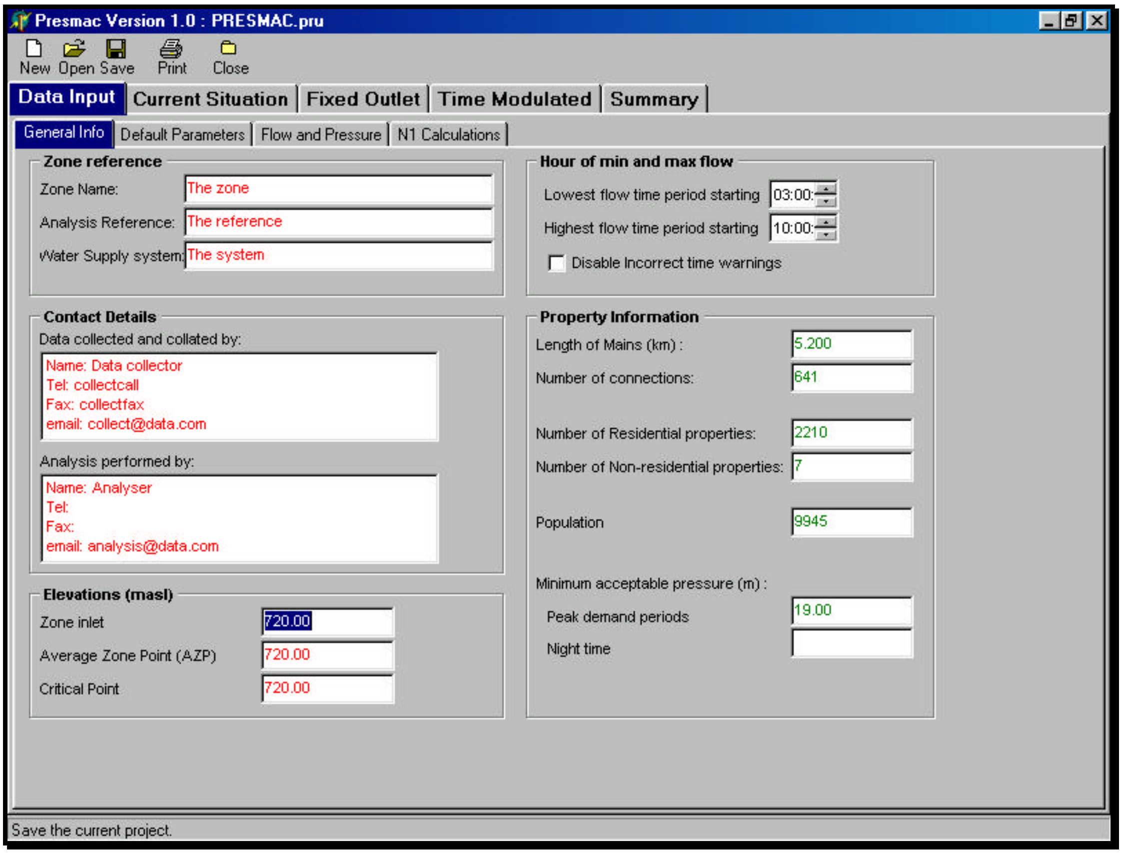


Figure 3.2 : Main menu in PRESMAC

As can be seen in **Fig. 3.2** there are five items on the main menu bar namely:

- Data Input
- Current Situation
- Fixed-Outlet PRV
- Time-Modulated PRV
- Summary

Each of the above items is discussed separately in the remainder of **Section 3**.

3.5. DATA INPUT

The Data_Input form provides various screens to allow the user to supply details of the system as well as the information required to analyse the potential for pressure management. The information required includes the items indicated in **Section 3.**3 plus other details such as the zone name and reference number, etc. When the Data_Input tab is selected, the user is provided with four sub-forms (see **Fig. 3.2**) to choose from namely:

- General_Info
- Default_Parameters
- Flow_and_Pressure
- N1_Calculations

3.5.1. General_Info

The General_Info form incorporates five blocks for data input namely:

- Zone Reference Information;
- Contact Details;
- Elevations of inlet, AZP and critical points;
- Hour number for minimum and maximum flow;
- Property information.

The items are self-explanatory and need no further description. The boxes are colour-coded, where red represents information that must be supplied by the user while the property information is given in green indicating that it is used elsewhere in the model. The hour number for minimum and maximum flow is shown in black which indicates that it is calculated directly from the data supplied by the user. It is possible to adjust the values calculated by the model in case there are several consecutive hours with the same minimum or maximum flow.

3.5.2. Default Parameters

If the Default_Parameters tab is selected, the form shown in **Fig. 3.3** will be displayed. This form allows the user to select and input various parameters that are used in the subsequent calculations. As before, the form is split into several blocks which contain related information. The following data blocks are included:

- System Leakage Parameters;
- Unit usage data during periods of Minimum Night Flow;
- Daily non-residential consumption**;**
- N1 Value;
- Night Consumption Calculations.

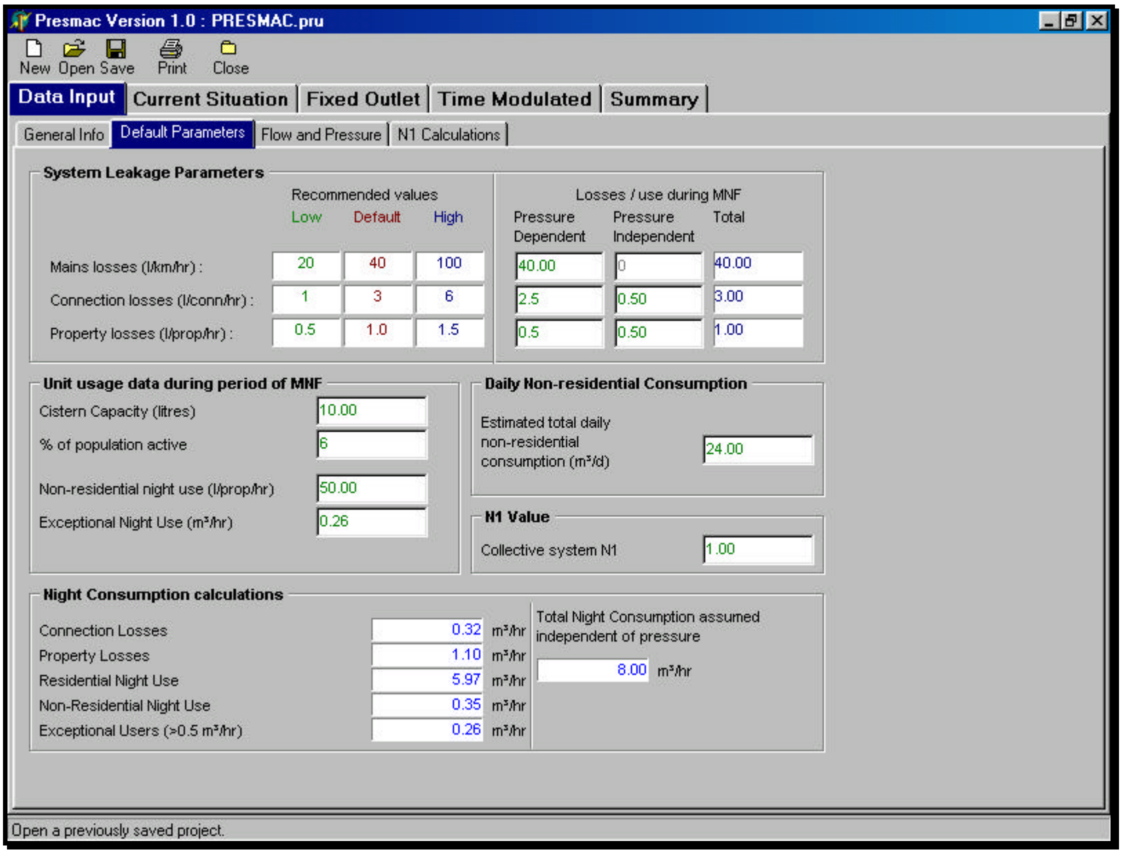


Figure 3.3: The Default_Parameters Form (from the Data_Input Form)

System Leakage Parameters

The user is required to supply information concerning the leakage parameters used to estimate the background leakage. Again it should be noted that all parameters are related to the standard pressure of 50 m. The information required is basically the same as used in the SANFLOW Model where the background leakage parameters are used to calculate the background leakage from the mains, connections and properties. In this case, however, the information is supplied in a slightly different form in that the parameters are split into pressure-dependent and pressure-independent components. The user is able to select a realistic parameter value and then indicate the split so that the background leakage can be analysed in a more realistic manner. It should be noted that all of the mains leakage is considered to be pressure-dependent, with the result that the user is not allowed to split the parameter value (40 ℓ/km.h in the example). With regard to the connection leakage, a small portion is usually assumed to be pressure-independent and in the example 0.5 ℓ/conn.h from the total of 3.0 ℓ/conn.h is considered to be pressure-independent. Similarly, with the property leakage, 50% of the leakage is assumed to be pressure-independent in **Fig. 3.3,** which could be used to take leakage from a toilet cistern into account for example.

Only the green figures can be changed by the user while the blue figures have been calculated and cannot be changed.

Unit Usage Data During Period of MNF

The information supplied by the user in this portion of the form is identical to that used in the SANFLOW Model and is relatively simple and straightforward.

- The **Cistern Capacity** is the capacity of the toilet cistern and is usually 10 litres or sometimes 6 litres.
- The **% of Population Active** represents the percentage of the population who will flush the toilet during the hour of minimum night flow. The standard percentage used in most cases is 6%, although this may vary from area to area. In areas serviced by standpipes the value will be zero.
- The **Non-Residential Night Use** is the unit use per hour for the non-residential units as input on the Data_Input form under the Property_Information block. Normally it will refer to a unit user for garages or all-night cafes, etc and a value of between 20 ℓ/prop/h to 50 ℓ/prop/h will be appropriate.
- The **Exceptional Night Use** refers to the water used by any large users where the actual meter readings are used to establish the water use during the period of minimum night flow.

Daily Non-Residential Consumption

The daily non-residential consumption is used in the model to estimate the average use per head of population per day and is not used in any other calculations. The user must try to estimate the total use per day by industry and commerce in order to estimate how much water is used for normal population consumption.

3.5.3. Flow and Pressure

The flow and pressure form is used to input the four 24-hour flow and pressure profiles which form the basis for the pressure management calculation. When this form is opened the user should see the details shown in **Fig. 3.4**.

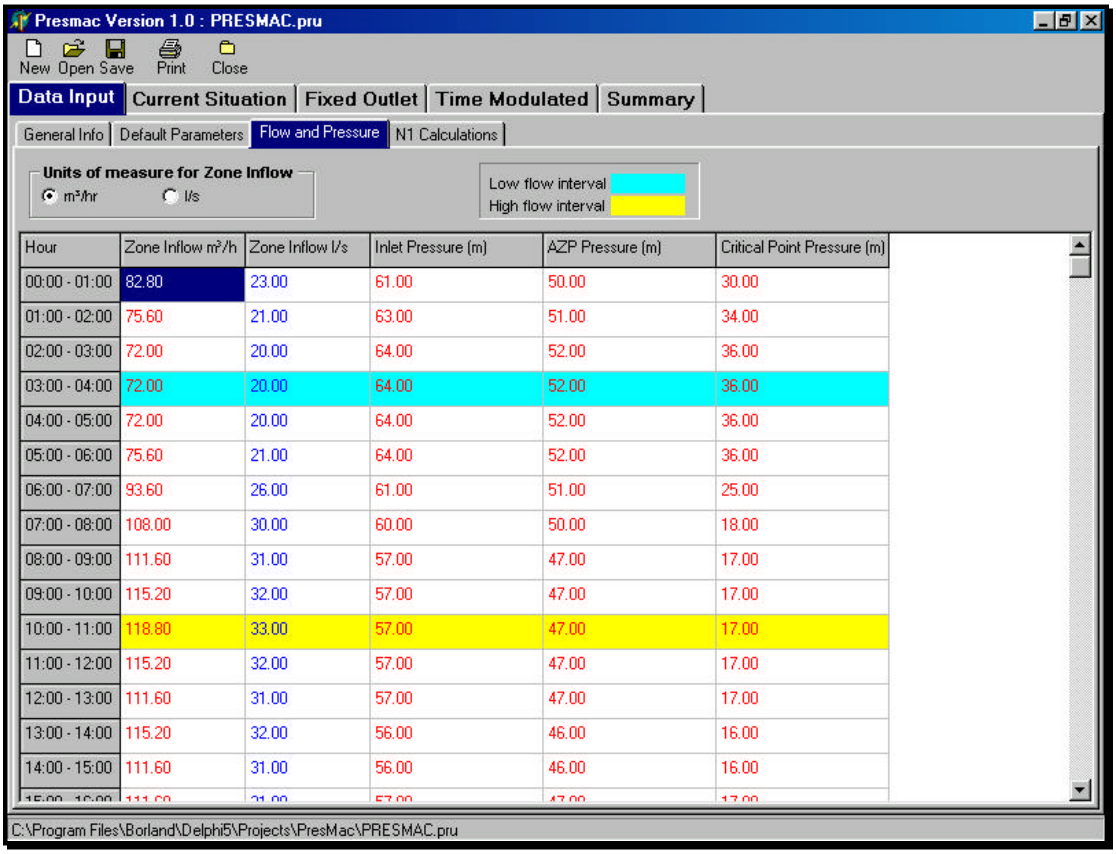


Figure 3.4 : Details of the Flow and Pressure Form

As can be seen from **Fig. 3.4**, five columns are given of which four are in red and one in blue. The blue column is a calculated column and depends upon the units selected for the zone inflow. If the user selects m^3/h as the unit for input, then the column for m^3/h will be in red indicating that the user must supply this data. The column in ℓ/second will then appear in blue since it is calculated directly from the figures given in m^3/h. The light blue and yellow shaded areas refer to the hours of minimum and maximum flow respectively.

3.5.4. N1 Calculations

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

It is generally accepted that flow from a hole in a pipe will react to pressure in accordance with normal hydraulic theory that indicates a square root power relationship between flow and pressure.

$$\mathbf{Flow_{P2} = Flow_{P1} \times (P1/P2)^{N1}}$$

where:

P1 = Pressure 1 (m)

P2 = Pressure 2 (m)

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

$Flow_{P2}$ = Flow at pressure P1 (m^3/h)

N1 = power exponent.

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

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

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

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. $2^{2.5}$).

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

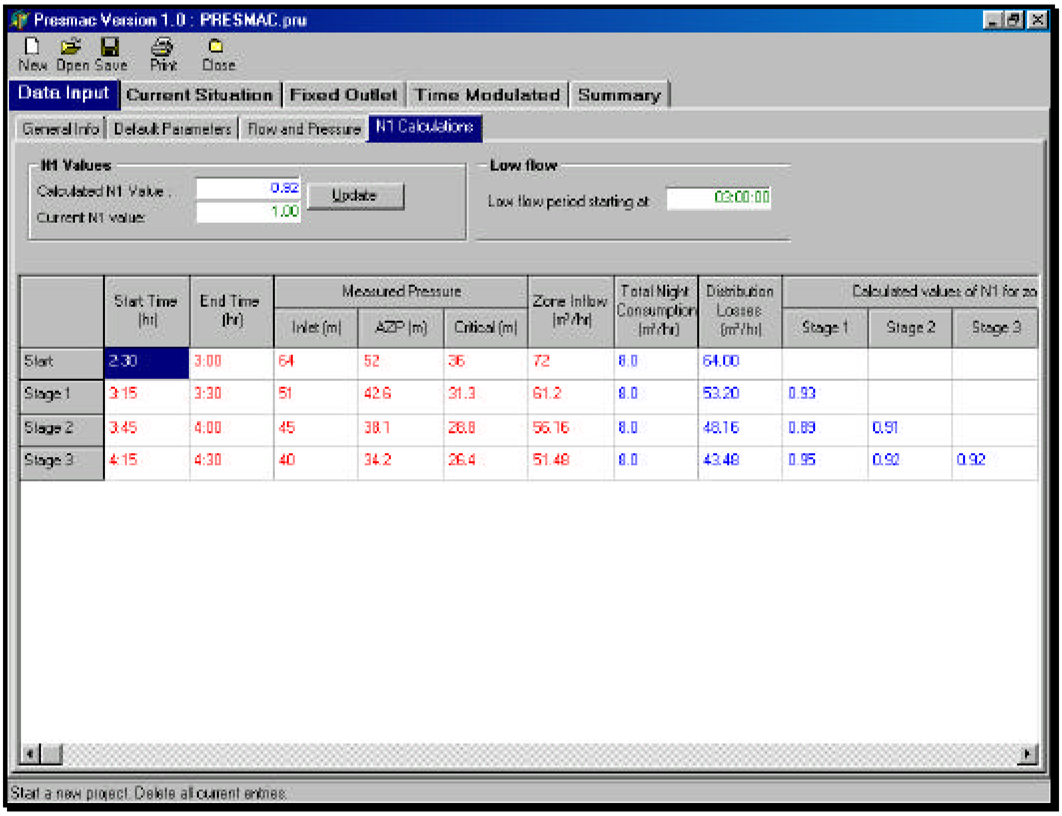
The N1 value used in PRESMAC is neither the burst or background N1 value as mentioned above. In this case, the N1 value is a lumped parameter representing the variation of leakage to pressure for the system as a whole where burst and background leakage is considered together. From various tests undertaken 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 the pressure management model, it is generally appropriate to adopt a conservative value of 1.0.

In some cases it is possible to establish the true N1 value for a system through a series of pressure "step-tests" which should 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, 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. A typical analysis is shown in **Fig. 3.5**, where it can be seen that an N1 value of 0.92 would be appropriate for the system being analysed. In this case, the user can manually type in the new value in the Default_Parameters form or click the "Update" button which will automatically copy the new value of N1 as calculated on the sheet to the correct location on the Default_Parameters form.

If there is no information on the N1 value and there is no time to carry out a pressure "step-test", then a value of 1.0 is normally accepted as realistic for a system. If it is known that the system is all metal pipes, a lower value may be used and if the pipes are all plastic, a higher value should be selected.

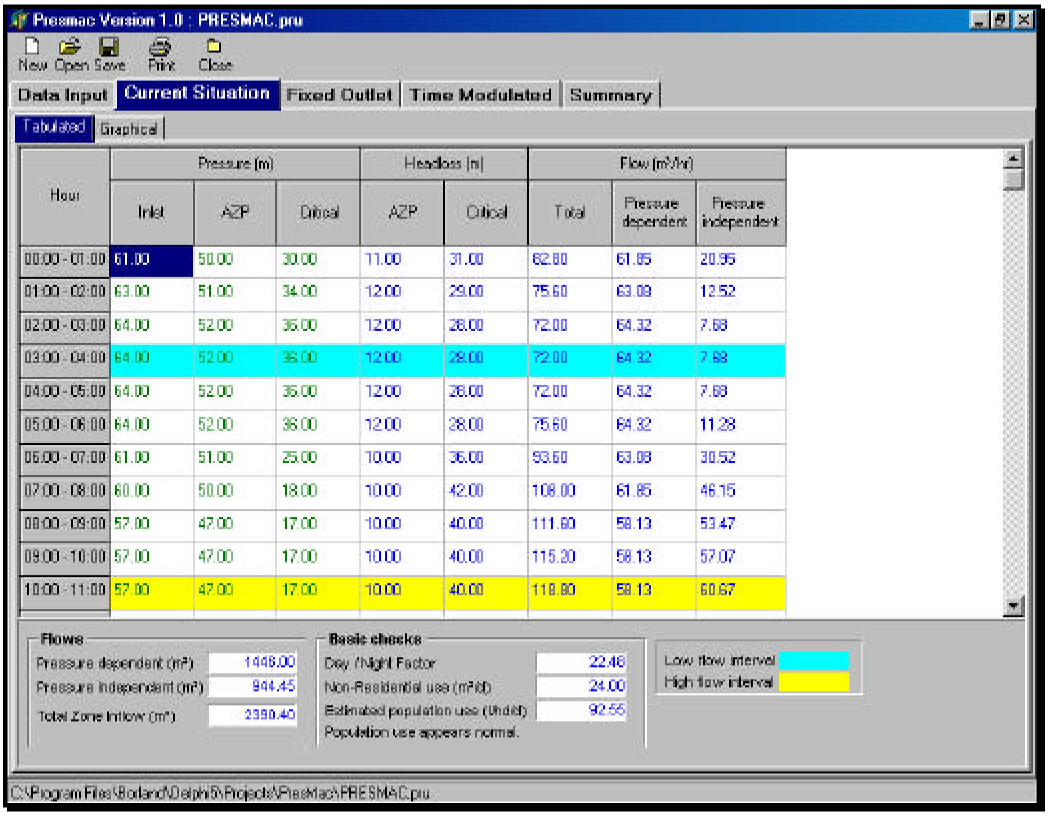
3.6. CURRENT SITUATION

The Current_Situation form effectively provides details for the zone before any form of pressure management is implemented. The form basically provides the data supplied by the user and, in addition, provides a split between pressure-dependent and pressure-independent flow. The information is available in tabular form as shown in **Fig. 3.6** and also in graphical form as shown in **Fig. 3.7**.



	Start Time (hr)	End Time (hr)	Measured Pressure Inlet (m)	Measured Pressure AZP (m)	Measured Pressure Critical (m)	Zone Inflow (m³/hr)	Total Night Consumption (m³/hr)	Distribution Losses (m³/hr)	Calculated values of N1 for zo Stage 1	Stage 2	Stage 3
Start	2:30	3:00	64	52	36	72	8.0	64.00			
Stage 1	3:15	3:30	51	42.6	31.3	61.2	8.0	53.20	0.93		
Stage 2	3:45	4:00	45	38.1	28.8	56.16	8.0	48.16	0.89	0.91	
Stage 3	4:15	4:30	40	34.2	26.4	51.48	8.0	43.48	0.95	0.92	0.92

Figure 3.5 : Example of a Pressure Step-Test Analysis



Hour	Pressure (m) Inlet	Pressure (m) AZP	Pressure (m) Critical	Headloss (m) AZP	Headloss (m) Critical	Flow (m³/hr) Total	Flow (m³/hr) Pressure dependent	Flow (m³/hr) Pressure independent
00:00 - 01:00	61.00	50.00	30.00	11.00	31.00	82.80	61.85	20.95
01:00 - 02:00	63.00	51.00	34.00	12.00	29.00	75.60	63.08	12.52
02:00 - 03:00	64.00	52.00	36.00	12.00	28.00	72.00	64.32	7.68
03:00 - 04:00	64.00	52.00	36.00	12.00	28.00	72.00	64.32	7.68
04:00 - 05:00	64.00	52.00	36.00	12.00	28.00	72.00	64.32	7.68
05:00 - 06:00	64.00	52.00	36.00	12.00	28.00	75.60	64.32	11.28
06:00 - 07:00	61.00	51.00	25.00	10.00	36.00	93.60	63.08	30.52
07:00 - 08:00	60.00	50.00	18.00	10.00	42.00	108.00	61.85	46.15
08:00 - 09:00	57.00	47.00	17.00	10.00	40.00	111.60	58.13	53.47
09:00 - 10:00	57.00	47.00	17.00	10.00	40.00	115.20	58.13	57.07
10:00 - 11:00	57.00	47.00	17.00	10.00	40.00	118.80	58.13	60.67

Figure 3.6: Tabulated Information from the Current_Situation Form

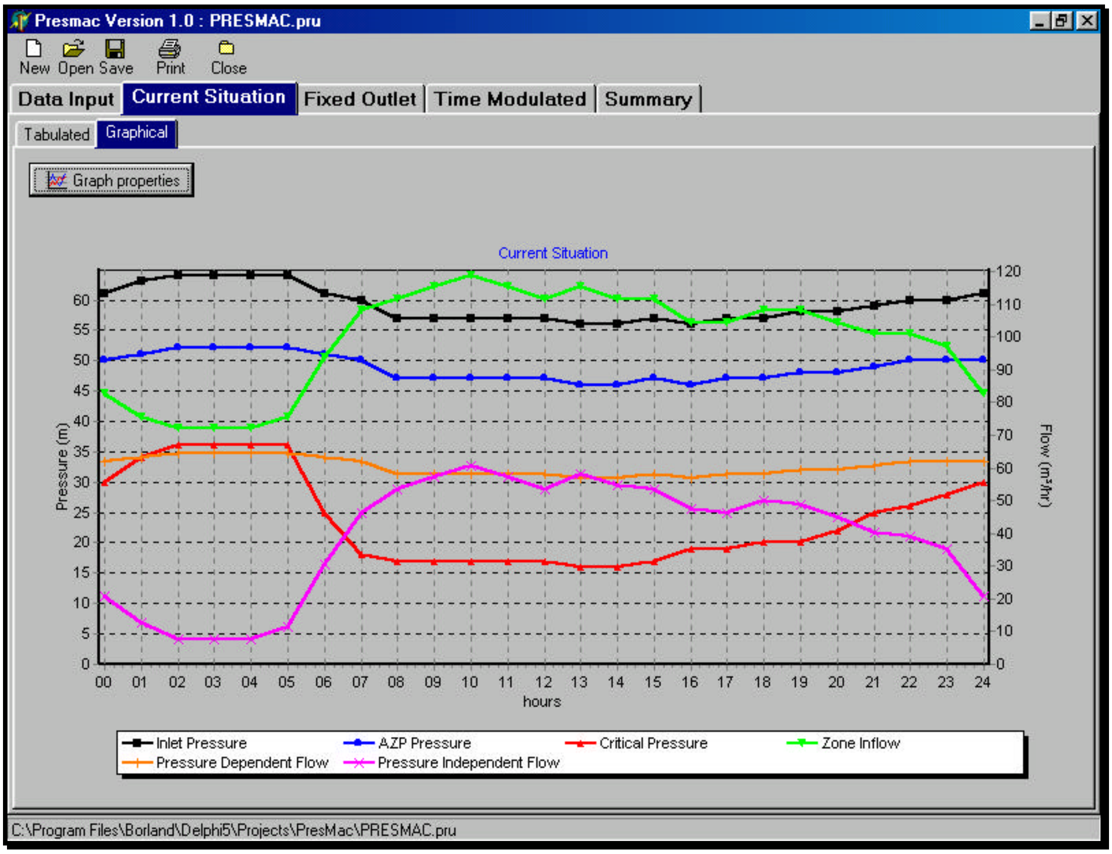


Figure 3.7: Graphical Output from the Current_Situation Form

It should be noted that the user can customise the graph to his/her own requirements by selecting the "Graph Properties" button. This, in turn, will provide a new form where the various lines shown on the graphs can be switched on or off. In addition, the scales for the pressure and flow can be defined which will then overwrite the default scales. This option is useful if the graphs from the different options are to be compared with each other. The graph options are indicated in **Fig. 3.8**.

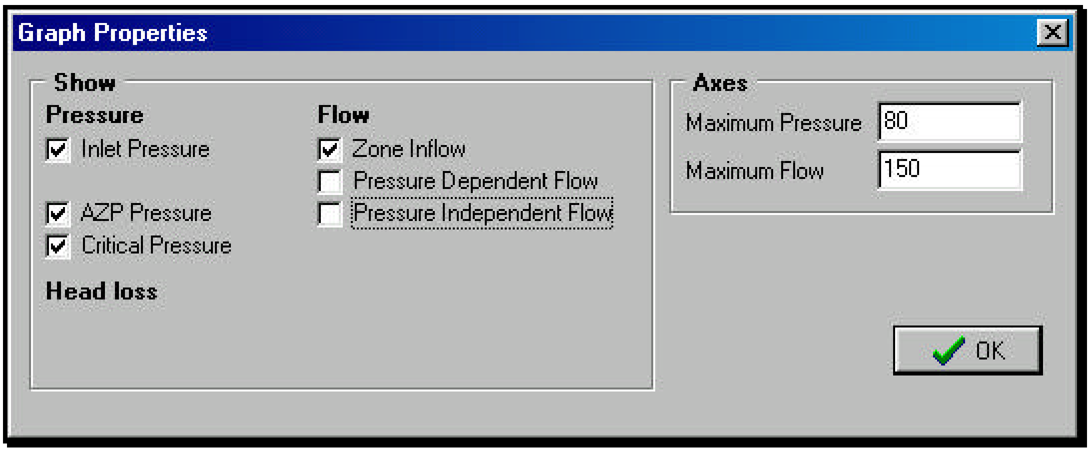


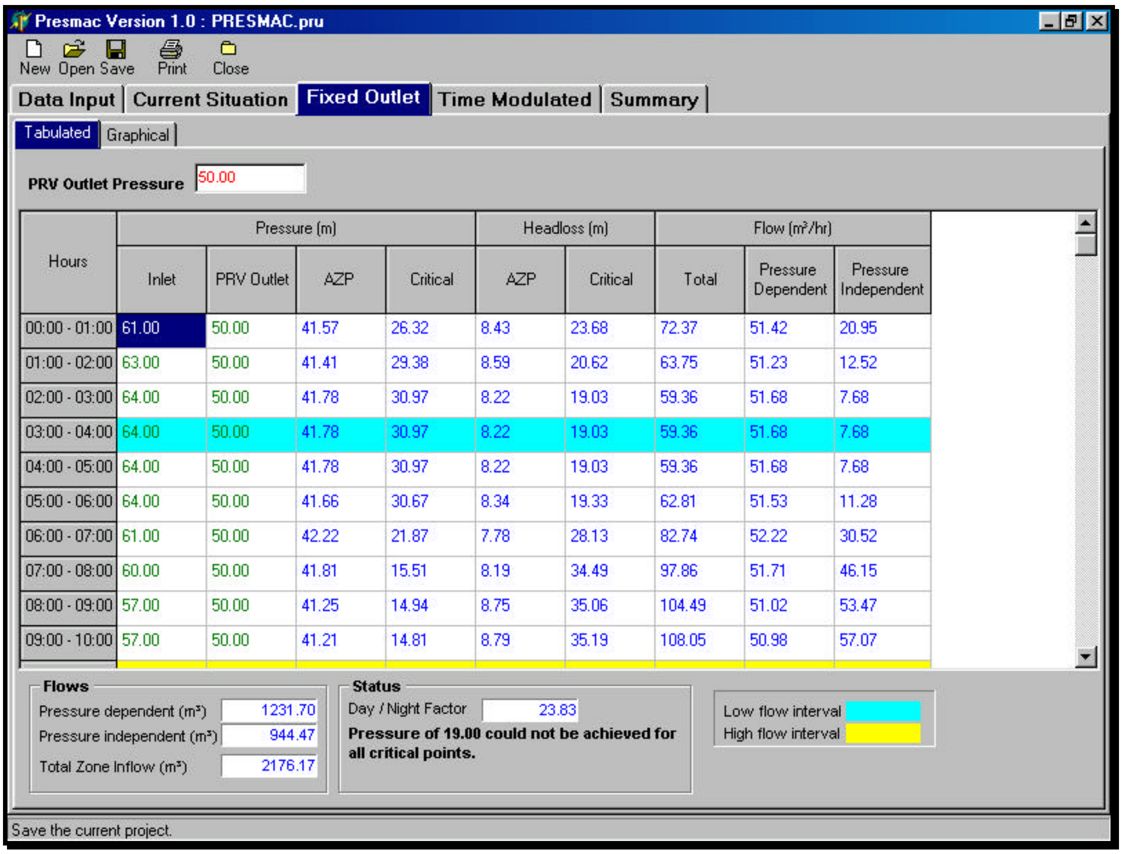
Figure 3.8: Graph options available

It should be noted that the graph options available for the “Current_Situation” exclude any head loss items although these are available on the “Fixed_Outlet” and “Time_Modulated” options.

3.7. FIXED-OUTLET PRV

The fixed outlet PRV option is usually the first option to be considered since it is the easiest option to implement and also the least expensive. The objective is to lower the zone inlet pressure in order to lower the pressure in the system to the level where the minimum acceptable pressure occurs during the period of maximum system demand. This option can only be considered in cases where the pressure during the period of maximum demand exceeds the minimum level of service. In many systems it is found that the pressure during the period of maximum demand is below the acceptable fire-fighting requirements or other minimum pressure as defined in the local by-laws. In such cases there is no scope for further pressure reduction using a fixed outlet PRV, although there may be some scope for improvement using the time-modulated option.

The data screen for the fixed-outlet PRV option is shown in **Fig. 3.9.**



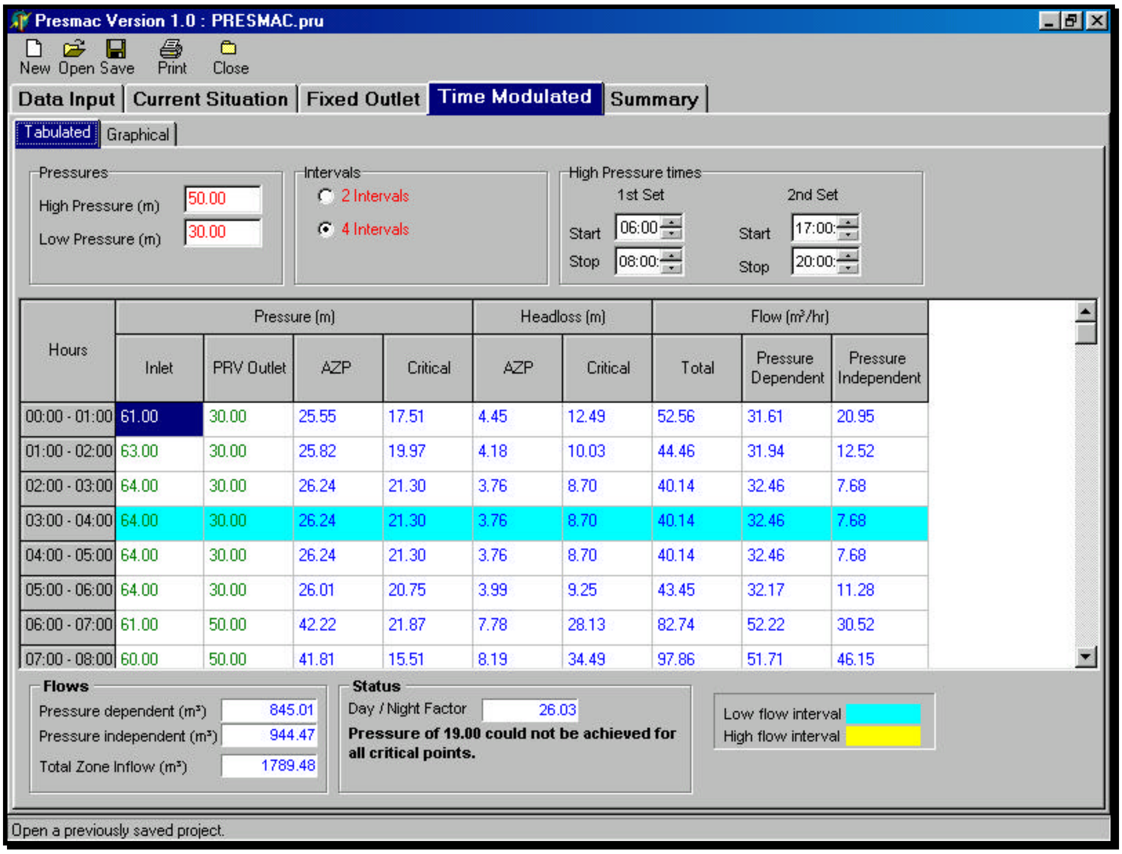
Hours	Pressure (m)				Headloss (m)		Flow (m³/hr)		
	Inlet	PRV Outlet	AZP	Critical	AZP	Critical	Total	Pressure Dependent	Pressure Independent
00:00 - 01:00	61.00	50.00	41.57	26.32	8.43	23.68	72.37	51.42	20.95
01:00 - 02:00	63.00	50.00	41.41	29.38	8.59	20.62	63.75	51.23	12.52
02:00 - 03:00	64.00	50.00	41.78	30.97	8.22	19.03	59.36	51.68	7.68
03:00 - 04:00	64.00	50.00	41.78	30.97	8.22	19.03	59.36	51.68	7.68
04:00 - 05:00	64.00	50.00	41.78	30.97	8.22	19.03	59.36	51.68	7.68
05:00 - 06:00	64.00	50.00	41.66	30.67	8.34	19.33	62.81	51.53	11.28
06:00 - 07:00	61.00	50.00	42.22	21.87	7.78	28.13	82.74	52.22	30.52
07:00 - 08:00	60.00	50.00	41.81	15.51	8.19	34.49	97.86	51.71	46.15
08:00 - 09:00	57.00	50.00	41.25	14.94	8.75	35.06	104.49	51.02	53.47
09:00 - 10:00	57.00	50.00	41.21	14.81	8.79	35.19	108.05	50.98	57.07

Figure 3.9: Typical data entry form for the Fixed-Outlet PRV Option

It should be noted that the only user input is the pressure setting for the proposed Fixed-Outlet PRV which is indicated by the red value of 50 m in **Fig. 3.9.**

3.8. TIME-MODULATED PRV

The time-modulated PRV option involves a standard fixed-outlet PRV which is equipped with a time-modulating controller. The maximum pressure setting is set on the main PRV while the low setting is set on the electronic controller. After the high and low pressure settings have been defined, the switching times must then also be derived. Either two intervals or four intervals can be selected and the model caters for both. The typical input form for the time-modulated PRV option is shown in **Fig. 3.10**.


Presmac Version 1.0 : PRESMAC.pru
New Open Save Print Close
Data Input | Current Situation | Fixed Outlet | Time Modulated | Summary
Tabulated | Graphical

Pressures
High Pressure (m) 50.00
Low Pressure (m) 30.00

Intervals
2 Intervals
4 Intervals

High Pressure times
1st Set: Start 06:00, Stop 08:00
2nd Set: Start 17:00, Stop 20:00

Hours	Pressure (m)				Headloss (m)		Flow (m³/hr)		
	Inlet	PRV Outlet	AZP	Critical	AZP	Critical	Total	Pressure Dependent	Pressure Independent
00:00 - 01:00	61.00	30.00	25.55	17.51	4.45	12.49	52.56	31.61	20.95
01:00 - 02:00	63.00	30.00	25.82	19.97	4.18	10.03	44.46	31.94	12.52
02:00 - 03:00	64.00	30.00	26.24	21.30	3.76	8.70	40.14	32.46	7.68
03:00 - 04:00	64.00	30.00	26.24	21.30	3.76	8.70	40.14	32.46	7.68
04:00 - 05:00	64.00	30.00	26.24	21.30	3.76	8.70	40.14	32.46	7.68
05:00 - 06:00	64.00	30.00	26.01	20.75	3.99	9.25	43.45	32.17	11.28
06:00 - 07:00	61.00	50.00	42.22	21.87	7.78	28.13	82.74	52.22	30.52
07:00 - 08:00	60.00	50.00	41.81	15.51	8.19	34.49	97.86	51.71	46.15

Flows
Pressure dependent (m³) 845.01
Pressure independent (m³) 944.47
Total Zone Inflow (m³) 1789.48

Status
Day / Night Factor 26.03
Pressure of 19.00 could not be achieved for all critical points.

Low flow interval
High flow interval

Open a previously saved project.

Fig. 3.10: Example of the Time-Modulated PRV Form

On **Fig. 3.10** it can be seen that the user has decided to try maximum and minimum pressures of 50 m and 30 m respectively and that two periods of high pressure have been selected: the first from 6 am to 8 am and the second from 5 pm to 8 pm. In addition, it can also be seen that in this case the minimum acceptable pressure of 19 m (defined in the data_input form under general_info) is not achieved during all 24 h in the simulation as noted in the "status" box. In a case like this the user would then adjust the pressures or the switching periods (or both) until the maximum savings are achieved without the pressure dropping below the minimum acceptable value.

3.9. SUMMARY

The summary form provides a very simple and concise table of the costs associated with the different options compared to the savings achieved for the different options considered. In order to obtain a sensible summary, the user must supply certain information including:

- The costs associated with the options considered;
- The cost of inflow (R/m^3);
- Consumption value (R/m^3);
- A multiplication factor (%);
- % of residential consumption judged to be pressure-dependent;
- % of non-residential consumption judged to be pressure-dependent;
- N1 value for correction to pressure-dependent consumption.

The layout of the summary form is shown in **Fig. 3.11.**

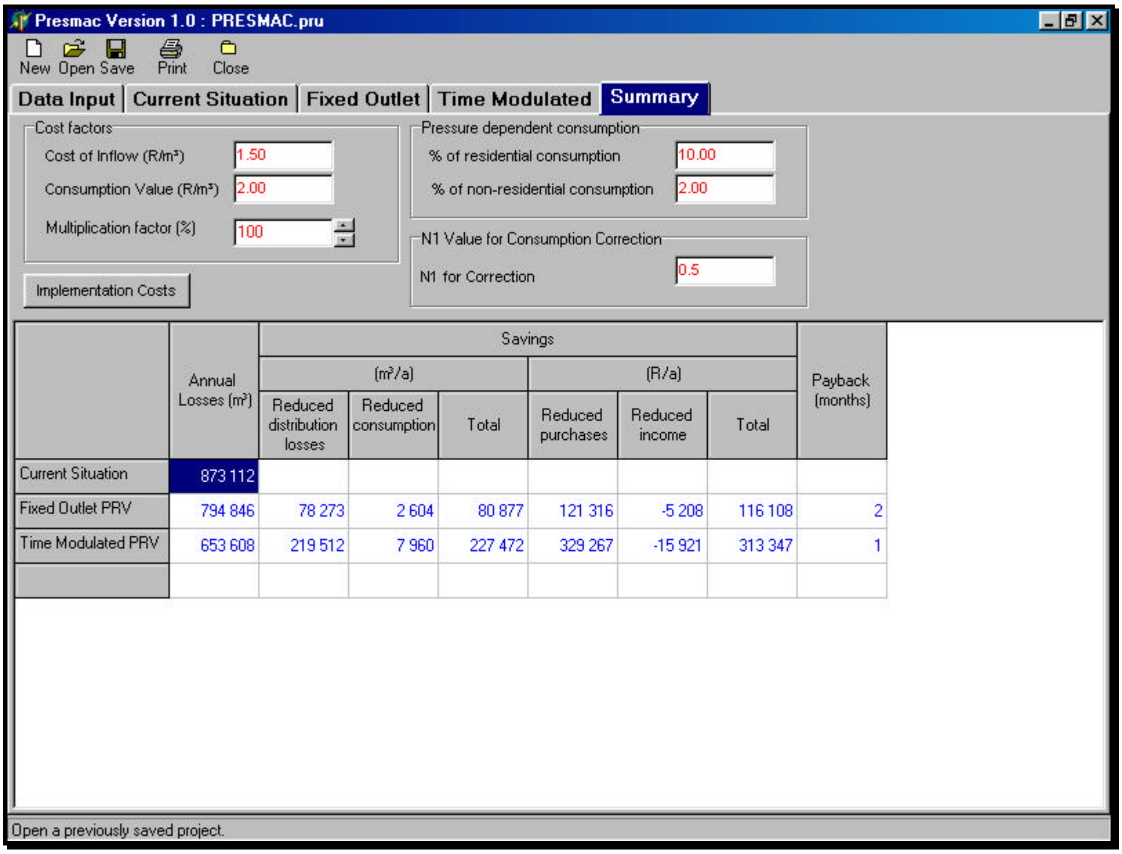


Figure 3.11: Example of the Summary Form

Costs associated with development options

The costs associated with the development options are supplied by the user on a separate form which is accessed by clicking on the “Implementation Costs” button which is on the main Summary form. This brings up a new form where the user can define the items to be used and the appropriate cost as shown in **Fig. 3.12.**

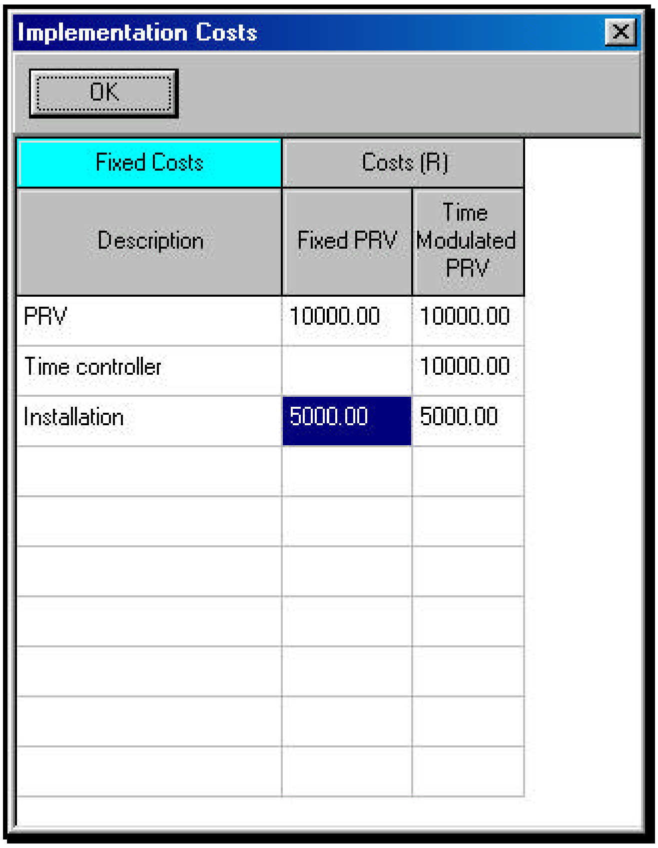


Figure 3.12: Example of “Implementation Costs” Form

The cost of inflow (R/m^3) and Consumption value (R/m^3)

The cost of inflow is the cost of the water entering the zone to the supplier. Any savings in leakage reduction **before the meter** will result in a saving to the supplier. Any reduction in water use by the consumer after the meter will represent a saving on water purchases but will also represent a loss of revenue to the water supplier at the average selling price. Any reductions in use or leakage after the meter will therefore represent a loss of revenue to the water supplier at a rate equal to the difference in the buying and selling price of the water.

Percentage of water use judged to be pressure-dependent and N1 value

As mentioned previously, if pressure is reduced there is normally some reduction in water use by the consumer. In order to take the potential loss of revenue into account, it is necessary to make some estimate of the percentage of use that is thought to be pressure-dependent. This is, unfortunately, rather difficult to establish and the user must make an estimate based on experience of the system in question. In the example shown in **Fig. 3.11**, values of 10% and 2% were selected for the pressure-dependent residential and non-residential use respectively. In addition, a separate N1 value is provided to assess the likely reduction in use due to the reduced pressure. The N1 value used for the overall system leakage is not appropriate since most of the reduction in consumer use will occur through a tap or other orifice where an N1 value of 0.5 is more likely to be appropriate.

Multiplication Factor (%)

A multiplication factor has been provided to allow the user to scale down the predicted savings to avoid over-optimistic predictions. In some cases it may be considered appropriate to leave this factor at 100% since the results are already conservative to some degree since they do not include the savings through reduced bursts and the associated repair costs etc. In some instances, however, the user may feel more comfortable which scaling down the predicted savings since the 24-hour period upon which the analysis is based is perhaps a particular sever period and not representative of the year as a whole. In such cases the user can change the factor in accordance with the particular circumstances of the zone in question to take account of seasonal demand patterns etc.

4. REFERENCES

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

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APPENDIX A

Introduction To Babe And Favad Concepts, And Calculation Of Unavoidable Annual Real Losses

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

A1: 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 (National Water Council, 1980) for leakage control that had been in use in the UK since 1980. Considerable progress 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' series of 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, as described by Lambert (1997).

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

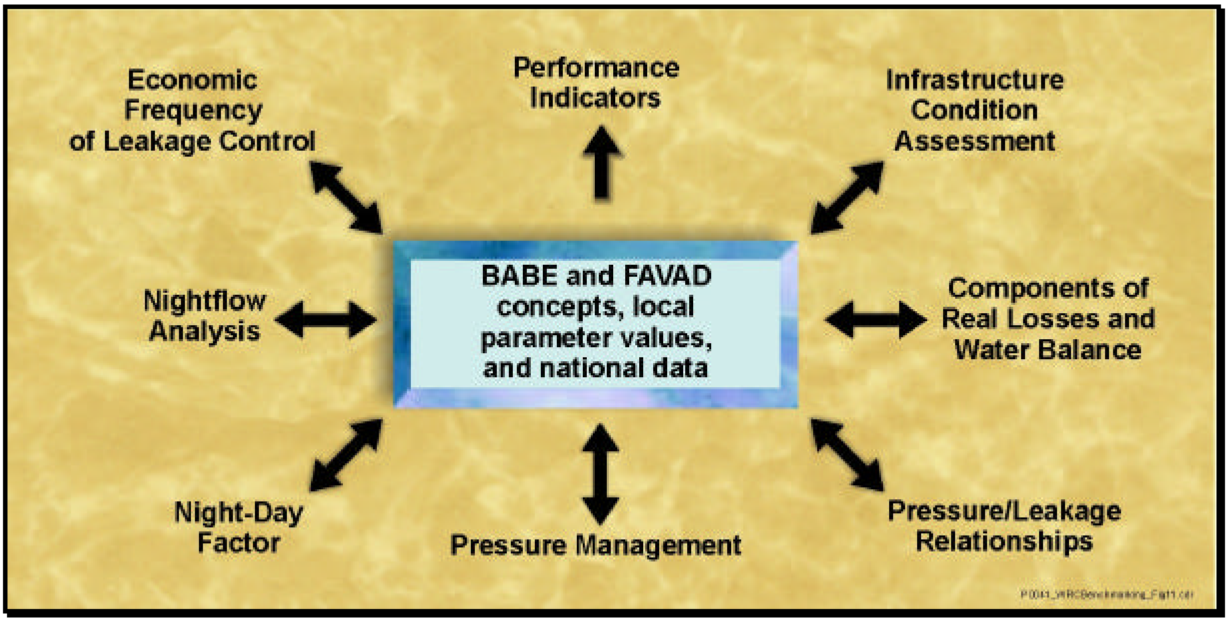


Figure A.1: Problem-Solving using BABE and FAVAD concepts

A2: BURST AND BACKGROUND ESTIMATE (BABE) procedures

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

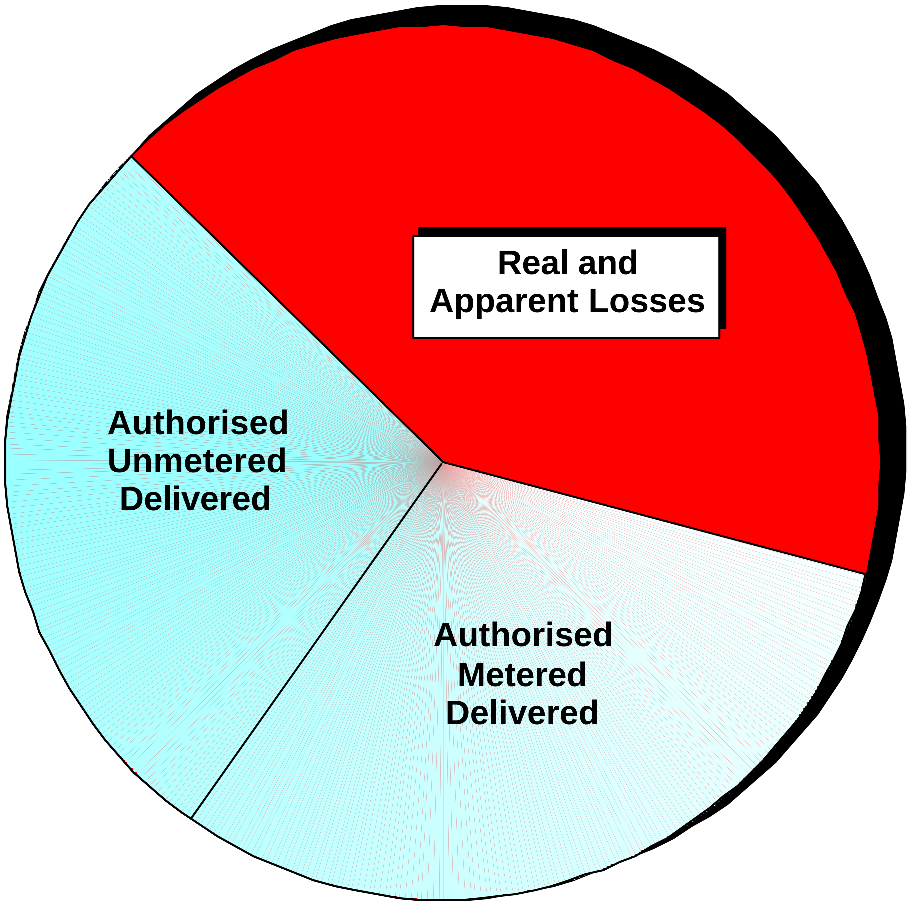


Figure A.2: Traditional Water Balance.

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

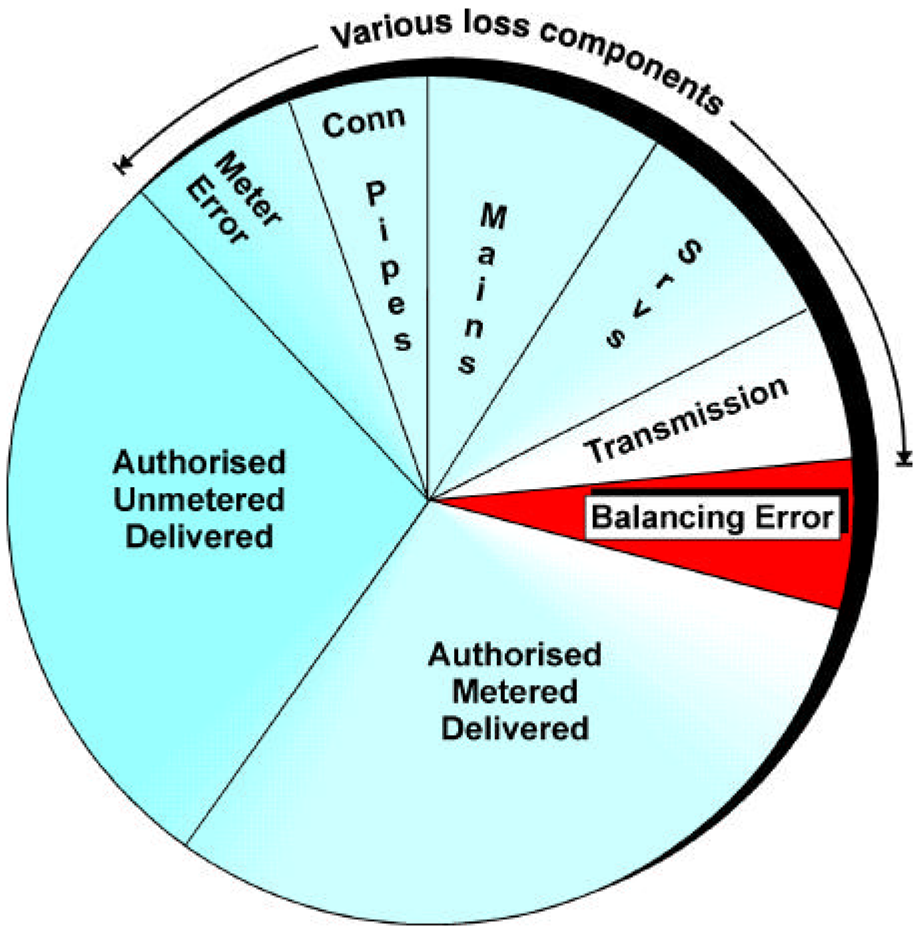
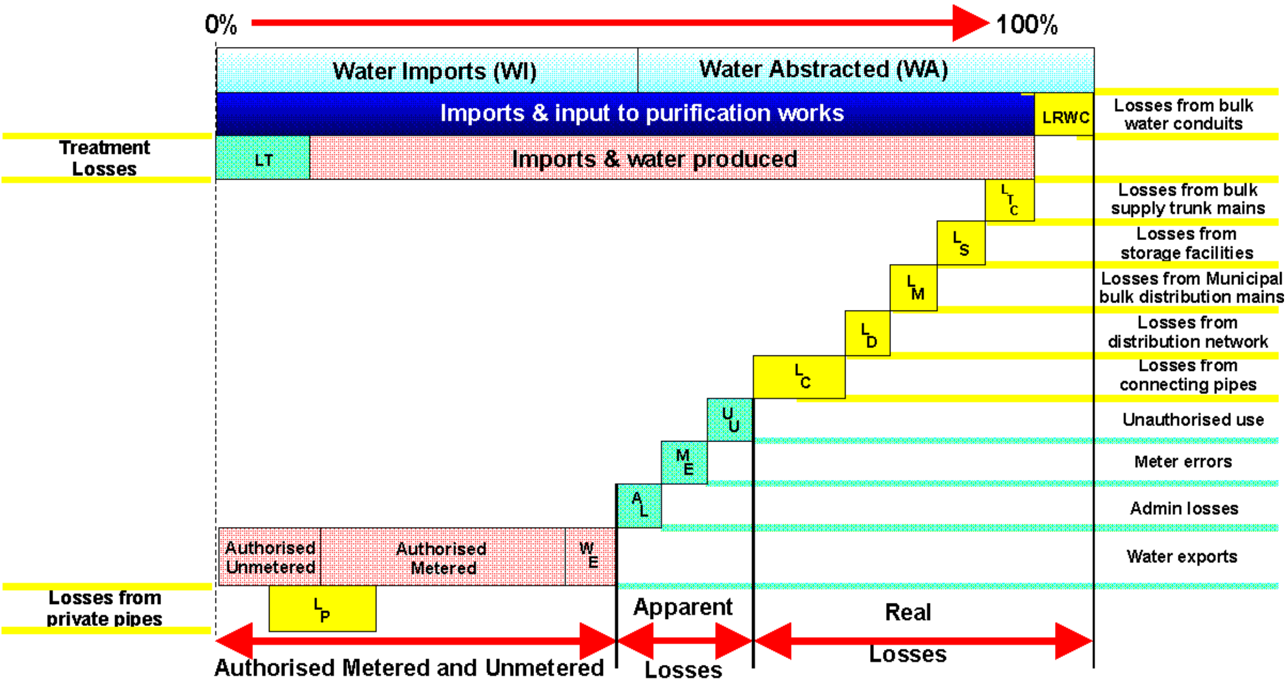


Figure A.3: BABE Water Balance Approach.

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



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

Figure A.4: Recommended BABE Water Balance Components.

Fig. A.4 provides a breakdown of the most important components that can be included in a water balance for a specific water supplier. It is important to note that the losses have been broken down into real and apparent losses. Real losses are those where the water has, in fact, 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.

A3: WHAT ARE BURST AND BACKGROUND LEAKS ?

The larger detectable events are referred to as bursts, while those that are too small to be located (if not visible) are referred to as background leaks. The threshold between bursts and background leaks can vary from country to country, depending upon factors such as minimum depth of pipes, type of ground and surface, etc. In the UK a threshold limit of 500 litres/hour was used in the 1994 Managing Leakage

Reports, but advances in technology and other factors suggest that a figure of around 250 litres/hour would be more appropriate in South Africa. In other words:

Events > 250 litres/hour = Bursts

Events < 250 litres/hour = Background Leaks

In 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 from leakage. However, using the BABE concepts, it is possible to calculate the unavoidable annual real losses on a system-specific basis.

A4: USE OF FAVAD AND BABE CONCEPTS IN DEVELOPMENT OF PERFORMANCE INDICATORS

The best of the traditional; basic (IWA Level 1) Performance Indicator for Operational management of real losses is the following:

Litres/service connection/day (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 '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/connection/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 (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 (Background and Bursts Estimates) concepts. With the 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.

A5: CALCULATION OF UNAVOIDABLE ANNUAL REAL LOSSES (UARL)

The procedure to estimate the unavoidable annual real losses (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 basically 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 A1**. From this table it can be seen that the one variable common to all elements is pressure. This is also the one variable that is normally excluded from most commonly used leakage performance indicators such as percentage, leakage per connection per year and leakage per km of mains per year, etc.

Each of the elements in **Table A1** 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 A2**.

The parameter values indicated in **Table A2** 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.

Table A1: Parameters required for calculation of UARL

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

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

Table A2: Parameter values used to calculate UARL

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

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

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 A3**. 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 A3**.

Table A3: Calculated Components of Unavoidable Annual Real Losses (UARL)

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

NOTE: the UARL losses from Unmetered Service Connections after the street/property line can be ignored in the South African context, as all customers are metered and these meters are located close to the street/property line. 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 A3**, the calculation of the UARL can be expressed as follows:

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

Where:

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

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

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

APPENDIX B

Data Capture Form for PRESMAC

Zone Pressure Analysis : Basic Information

General

Name of Water Undertaking:			
Name of Water Supply Zone			
Calculation by:		Telephone	
e-mail		Fax	

Condition of distribution network:

(tick appropriate box)

Mains Losses	V. High	High	Average	Low	V Low
	100 l/km/hr	80 l/km/hr	40 l/km/hr	20 l/km/hr	10 l/km/hr
Connection losses	V. High	High	Average	Low	V Low
	10 l/conn/hr	6 l/conn/hr	3 l/conn/hr	2 l/conn/hr	1 l/conn/hr
Property losses	V. High	High	Average	Low	V Low
(installations)	100 l/prop/hr	5 l/prop/hr	1 l/prop/hr	0.5 l/prop/hr	0.1 l/prop/hr
Illegal connections	V. High	High	Average	Low	V Low
Type of housing	Affluent	High Income	Med Income	Low Income	Informal

Basic information:

Length of mains(km)	
Number of connections	
Number of properties	
Estimated population	

Water use:

	%
Urban	
Industrial	
Commercial	
Other	

Elevation

	(m)
Inlet	
AZP	
Critital	

Pressure analysis:

Hour	Inlet Pressure (m)	Average Zone Pressure (m)	Critical Point Pressure (m)	Inflow to Zone (m3/hr)
0 - 1				
1 - 2				
2 - 3				
3 - 4				
4 - 5				
5 - 6				
6 - 7				
7 - 8				
8 - 9				
9 - 10				
10 - 11				
11 - 12				
12 - 13				
13 - 14				
14 - 15				
15 - 16				
16 - 17				
17 - 18				
18 - 19				
19 - 20				
20 - 21				
21 - 22				
22 - 23				
23 - 0				