Calculating Hour-Day Factors for Potable Water Distribution Systems in South Africa

by

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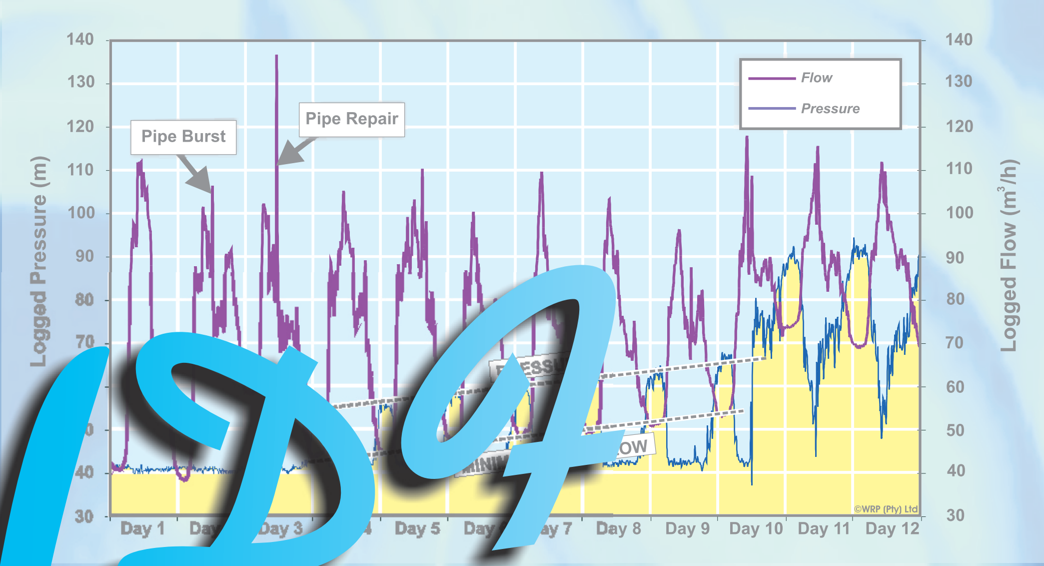

HDF MODEL USER GUIDE

TT 184/02
Water Research Commission

CALCULATING HOUR-DAY FACTORS FOR POTABLE WATER DISTRIBUTION SYSTEMS IN SOUTH AFRICA

User Guide

For the

HDF Model

developed through

SOUTH AFRICAN WATER RESEARCH COMMISSION

By

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Report TT 184/02

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IMPORTANT

PREFACE

This document is the User Manual for the Hour-Day Factor Model (HDF) which has been developed for the South African Water Research Commission. The objectives of the Software and the Manual are:

- to explain the importance of hour-day factors in potable water distribution systems;
- to present the methodology for calculating the hour-day factors in a system;
- to provide a simple and effective tool to assist water suppliers in calculating the hour-day factors in a particular zone or water supply area.

The methodologies used in the HDF Model are based on the latest International Water Association (IWA) procedures and terminology relating to component based leakage management formerly referred to as the Burst and Background Estimate procedures.

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

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TECHNICAL SUPPORT

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

ACKNOWLEDGEMENTS

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Hour-Day Factor : User Guide

Executive Summary

The HDF software and this User Manual are part of the ongoing process of refining and improving the methodologies for assessing and understanding leakage in water distribution systems throughout South Africa.

This manual contains full details of the Hour-Day Factor procedures as well as a simple User-Guide to the HDF Model. It also contains a few examples to demonstrate typical factors for a variety of situations likely to be encountered in the field.

The HDF is simply a factor that can be applied to a reduction (or increase) in the pressure dependent flow occurring at the hour of Minimum Night Flow to provide an indication of the total daily saving (or increase) in pressure dependent flow that can be expected over the whole 24-hour period. In most normal systems a value of between 18 and 22 can be expected while in areas which are already operating under some form of pressure control, values in excess of 24 can be expected.

The HDF allows water suppliers to make better estimates of the savings that can be expected from some form of WDM measure that has the effect of reducing pressure dependent leakage. Simply multiplying the reduction in Minimum Night Flow by 24 will normally yield over optimistic expectations and is a common error made in many WDM investigations.

The HDF Model also provides a very simple and useful procedure for estimating the Pressure Exponent (i.e. N1) for a particular water supply system. The correct selection of N1 for a system is important and the model therefore provides water suppliers with a very simple and easy to use approach to this issue.

This document provides details of how the Hour Day Factor can be used to assist water suppliers in addressing their leakage problems and how it can be calculated for a specific water management area. The manual also serves as the User Guide to the HDF model which is simply an Excel spreadsheet designed to calculate the HDF for an area given certain key input data. By using the model, the water supplier can gain a better understanding of how the leakage in an area will react to certain WDM measures that influence the Minimum Night Flow.

Although the HDF model is relatively simple and straightforward, it provides yet another useful tool to the water distribution manager in the fight against leakage and wastage of a valuable natural resource.

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

Model/Software	Supporting User Guide/Document	WRC Report Number
SANFLOW	Development of a standardised approach to evaluate bursts and background losses in water distribution systems in South Africa	TT 109/99
BENCHLEAK	Benchmarking of leakage for water suppliers in South Africa	TT 159/01
PRESMAC	Development of a pragmatic approach to evaluate the potential savings from pressure management in potable water distribution systems in South Africa	TT 152/01
ECONOLEAK	Economic model for leakage management for water suppliers in South Africa	TT 169/02
HDF	Model to estimate the Hour Day Factor for pressure dependent flow in a particular water management zone.	TT 184/02

HDF : USER GUIDE

South African Leakage Benchmarking Model

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1. INTRODUCTION

1.1. GENERAL

The Hour Day Factor (HDF) is simply a factor that can be applied to a reduction (or increase) in the pressure dependent flow occurring at the hour of Minimum Night Flow to provide an indication of the total daily saving (or increase) in pressure dependent flow that can be expected over the whole 24-hour period. In most normal systems a value of between 18 and 22 can be expected while in areas that are already operating under some form of pressure control, values in excess of 24 can be expected.

By understanding and using the HDF Model, water suppliers will be in a position to make better estimates of the savings that can be expected from various water demand management measures. The normal practice of simply multiplying the reduction in Minimum Night Flow by 24 is flawed and will normally yield over optimistic expectations in most WDM investigations.

The HDF Model is based on the standard Burst and Background Estimate (BABE) procedures which were developed initially in the UK for use in the UK Water Industry to provide a standardised and methodical approach to the understanding and management of leakage from potable water distribution systems. Since the BABE procedures were developed in the mid 1990’s, they have been improved, customised and used to great effect in many parts of the world including many third world areas. Full details of the BABE methodology can be found in the SANFLOW Model user Guide (WRC, 1999) while some of the key concepts are summarised in **Appendix B**.

In addition to the basic BABE methodology, the HDF Model makes use of the basic principles of the Fixed Area and Variable Area Discharges (FAVAD) as developed by May (1994) in the mid 1990’s. Full details of the pressure/leakage relationships including the FAVAD principles are provided in the PRESMAC Model User Guide (WRC, 2001). The key details are also summarised in **Appendix B** as part of the overall BABE methodology.

1.2. LAYOUT OF THIS USER MANUAL

The user manual contains 5 sections and 4 appendices, as described below.

Section 1: Introduction

This section explains the layout of the manual.

Section 2: Outline of the HDF Software

This section is essentially the “User Guide”, in which each component of the HDF software is explained and examples are provided to assist the new user to understand the concept of the Hour-Day Factor and how it can be used to assist water supply managers in assessing the potential for leakage reduction in a particular system or zone.

Section 3: Details of the HDF Model

This section explains how the model looks and operates including the technical details of the individual forms making up the model. It provides example calculations of both the power exponent (N1) as well as the HDF using example data taken from a real system.

Section 4: Using the HDF Model

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

Section 5: References

This section provides a few useful references for users wishing to gain more in-depth knowledge of the subject of component based leakage 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 the subject or the BABE procedures.

Appendix A: Glossary of Terms

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

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

Appendix B outlines the basic BABE (Bursts and Background Estimates) concepts of components of real losses, and the FAVAD (Fixed and Variable Area Discharges) concept of pressure:leakage relationships.

Appendix C: Methods of Calculating Average Pressure

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

Appendix D: Printout of the HDF Worksheets

The four sheets making up the HDF model are listed including the data capture sheet which can be used by water suppliers who are unable to run the model but would like their system to be analysed. The data capture sheet is included in the model but can also be photocopied from the manual in the event that the water supplier has no access to EXCEL.

2. INTRODUCTION

2.1. WHAT IS AN HOUR-DAY FACTOR

Most water suppliers throughout South Africa are now well acquainted with the concept on Minimum Night Flow and many are aware of the Burst and Background Estimate procedures which enable them to interpret the MNF in order to estimate the levels of unreported losses in their systems. In many instances, efforts taken to reduce leakage are documented in reports where the reduction in MNF is provided as the sole indicator of the level of success of leakage reduction. The reduction in MNF expressed in m^3/hr is then multiplied by a factor of 24 to provide an indication of the daily savings which in turn are multiplied by 365 to provide the annual savings. Such extrapolations are often erroneous and provide exaggerated savings leading to over-optimistic predictions of the levels of return and success of a particular intervention. The Hour-Day Factor (HDF) is simply a factor which represents the appropriate multiplier that can be used to scale up the savings estimated from the MNF so that the savings are applicable for the full day. This concept is best explained through the use of a simple example.

To explain the Hour-Day Factor concept we will consider a typical pressure management analysis in which the water supplier wishes to establish the reduction in leakage from a particular pressure management initiative such as installing a Pressure Reducing Valve with a fixed outlet pressure throughout the day. Before any intervention is implemented, the water supplier analyses the existing situation and undertakes flow and pressure loggings over a representative 24-hour period. The results from the pressure loggings are shown in **Table 2.1.**

If the flow entering a particular water management zone is depicted over a 24-hour period, it may appear as shown in **Figure 2.1**. In this figure it can be seen that the MNF occurs between 2am and 4am with a value of 24 m^3/hr.

Table 2.1: 24-Hour Flow and Pressure Loggings for Slovoville

Time	Zone inflow (m^3/hr)	Pressure (m)		
		Inlet	AZP	Critical
Midnight to 1am	42.01	84.0	102.0	82.0
1am to 2am	42.00	84.0	102.0	82.0
2am to 3am	42.09	85.0	102.0	84.0
3am to 4am	42.93	83.0	102.0	82.0
4am to 5am	43.84	81.0	100.0	80.0
5am to 6am	46.74	73.0	92.0	72.0
6am to 7am	51.98	61.0	78.0	59.5
7am to 8am	56.44	60.0	78.0	59.0
8am to 9am	58.19	60.0	78.9	59.0
9am to 10am	57.39	65.0	82.0	64.0
10am to 11am	54.21	65.0	83.7	64.0
11am to 12am	50.40	72.0	88.0	71.0
12 noon to 1 pm	48.60	71.0	90.1	70.0
1pm to 2pm	48.24	71.0	90.1	70.0
2pm to 3pm	48.60	70.0	88.8	69.1
3pm to 4pm	50.40	70.0	88.4	69.0
4pm to 5pm	52.20	71.0	89.1	70.0
5pm to 6pm	55.26	66.0	78.0	65.0
6pm to 7pm	58.32	61.0	77.0	60.0
7pm to 8pm	57.87	60.0	76.0	59.0
8pm to 9pm	53.81	68.0	86.9	67.0
9 pm to 10 pm	48.60	70.0	89.0	69.0
10 pm to 11 pm	44.97	77.0	95.6	76.0
11 pm to midnight	43.72	79.0	96.1	77.0
Totals/Averages	**1198**	**71.1**	**88.9**	**70.0**

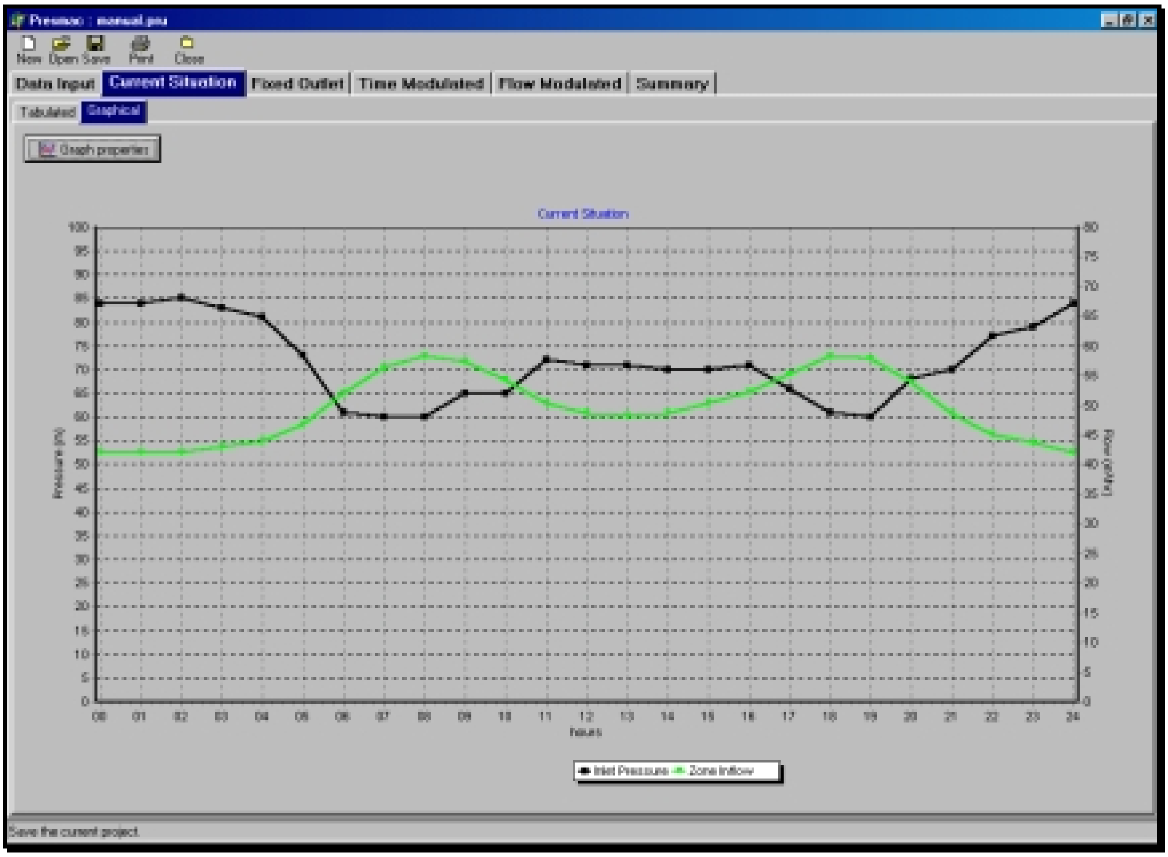


Figure 2.1: Graph of Zone Inflow and Inlet Pressure to Zone from PRESMAC

Table 2.2: Pressure Dependent and pressure independent flows

Time	Zone inflow (m^3/ hr)	Flow Components (m^3/ hr)	
		Pressure Dependent	Pressure Independent
Midnight to 1am	42.8	37.1	5.7
1am to 2am	42.5	37.1	5.4
2am to 3am	42.1	37.1	5.0
3am to 4am	41.4	37.1	4.3
4am to 5am	43.8	36.0	7.8
5am to 6am	46.7	31.8	14.9
6am to 7am	52.0	24.8	27.2
7am to 8am	56.4	24.8	31.6
8am to 9am	58.2	25.2	33.0
9am to 10am	57.4	26.7	30.7
10am to 11am	54.2	27.6	26.6
11am to 12am	50.4	29.7	20.7
12 noon to 1 pm	48.6	30.8	17.8
1pm to 2pm	48.2	30.8	17.4
2pm to 3pm	48.6	30.1	18.5
3pm to 4pm	50.4	29.9	20.5
4pm to 5pm	52.2	30.3	21.9
5pm to 6pm	55.3	24.8	30.5
6pm to 7pm	58.3	24.3	34.0
7pm to 8pm	57.9	23.9	34.0
8pm to 9pm	53.8	29.2	24.6
9 pm to 10 pm	48.6	30.2	18.4
10 pm to 11 pm	45.0	33.7	11.3
11 pm to midnight	43.7	33.9	9.8
Total	**1198**	**727**	**471**
Average	**49.9**	**30.3**	**19.6**

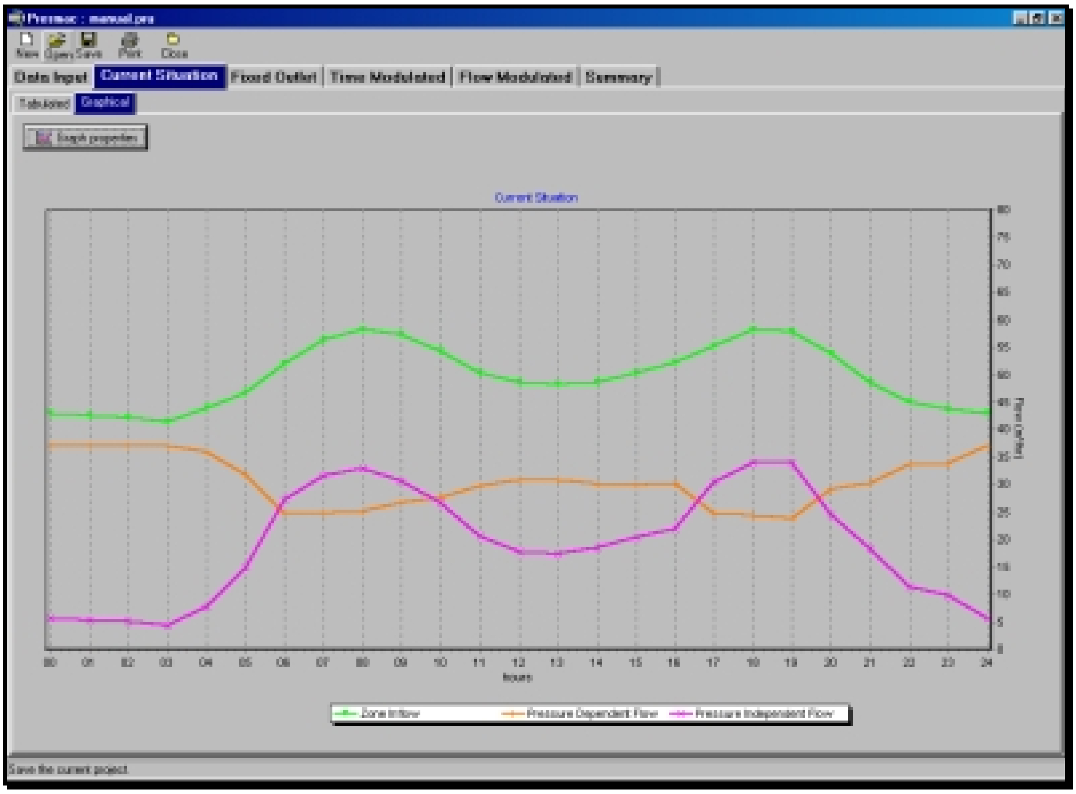


Figure 2.2: Split between pressure dependent and pressure independent flows

From **Figure 2.2** it can be seen that the pressure dependent flows (mainly distribution leakage) are highest at night and tend to drop during the day when the demand for water is at its highest. If some form of pressure management is implemented in the area the influence on the distribution losses will be greatest at night and less during the day. If the minimum night flow is reduced by 10 m^3/hr for example, the saving during the peak demand period will be somewhat less than 10 m^3/hr. The 10 m^3/hr saving on the minimum night-flow cannot simply be multiplied by 24 to give the total daily savings and some other factor must be used if the savings are not to be overestimated. It is this problem that led to the development of the Hour-Day Factor (HDF) which is defined simply as :

The factor which should be applied to the Distribution Losses influenced by pressure during the hour of Minimum Night Flow to provide the total distribution ***losses over the full 24-hour period.***

In most normal systems where the pressures are not controlled by any form of selective pressure reduction, the Hour Day Factor will be in the order of 20. This implies that the pressure dependent flow during the hour of minimum night flow is 120% (i.e. 24/20) of the pressure dependent flow when averaged over the full 24-hour period. An HDF of less than 24 indicates that the pressure dependent flow during the period of MNF is higher than the average daily pressure dependent flow. Conversely, a high HDF of greater than 24 would suggest that the pressure dependent flow during the hour of MNF is less than the average daily pressure dependent flow. A high HDF value would normally only occur in cases where the pressure in the zone is reduced at night to minimise leakage through the use of time or flow modulated pressure control.

For the data presented in **Table 2.1** the Hour Day Factor is 19.6 which indicates a normal system operating without any selective pressure management. The calculation is as follows:

$$\text{HDF} = \frac{\text{Daily Pressure Dependent Flow}}{\text{Pressure Dependent Flow during Hour of MNF}}$$

$$= \frac{727}{37.1} = 19.6$$

The calculation can be repeated to demonstrate the influence of time modulated pressure control on the HDF. The corresponding figures for this example are provided in **Table 2.3**.

Table 2.3: Pressure dependent and pressure independent flows (Time modulated option)

Time	Zone inflow (m^3/ hr)	Flow Components (m^3/ hr)	
		Pressure Dependent	Pressure Independent
Midnight to 1am	14.8	9.0	5.8
1am to 2am	14.4	9.0	5.4
2am to 3am	14.0	9.0	5.0
3am to 4am	13.4	**9.1**	4.3
4am to 5am	16.9	9.1	7.8
5am to 6am	24.0	9.0	15.0
6am to 7am	39.3	12.1	27.2
7am to 8am	43.9	12.3	31.6
8am to 9am	45.4	12.5	32.9
9am to 10am	42.7	12.1	30.6
10am to 11am	39.1	12.5	26.6
11am to 12am	29.3	8.7	20.7
12 noon to 1 pm	26.8	9.0	17.8
1pm to 2pm	26.5	9.0	17.5
2pm to 3pm	27.4	9.0	18.4
3pm to 4pm	29.4	8.9	20.5
4pm to 5pm	30.8	8.9	21.9
5pm to 6pm	41.5	11.0	30.5
6pm to 7pm	45.8	11.8	34.0
7pm to 8pm	45.8	11.8	34.0
8pm to 9pm	37.1	12.5	24.6
9 pm to 10 pm	31.0	12.6	18.4
10 pm to 11 pm	20.3	9.0	11.3
11 pm to midnight	18.7	8.9	9.8
Total	**718**	**247**	**471**
Average	**29.9**	**10.3**	**19.6**

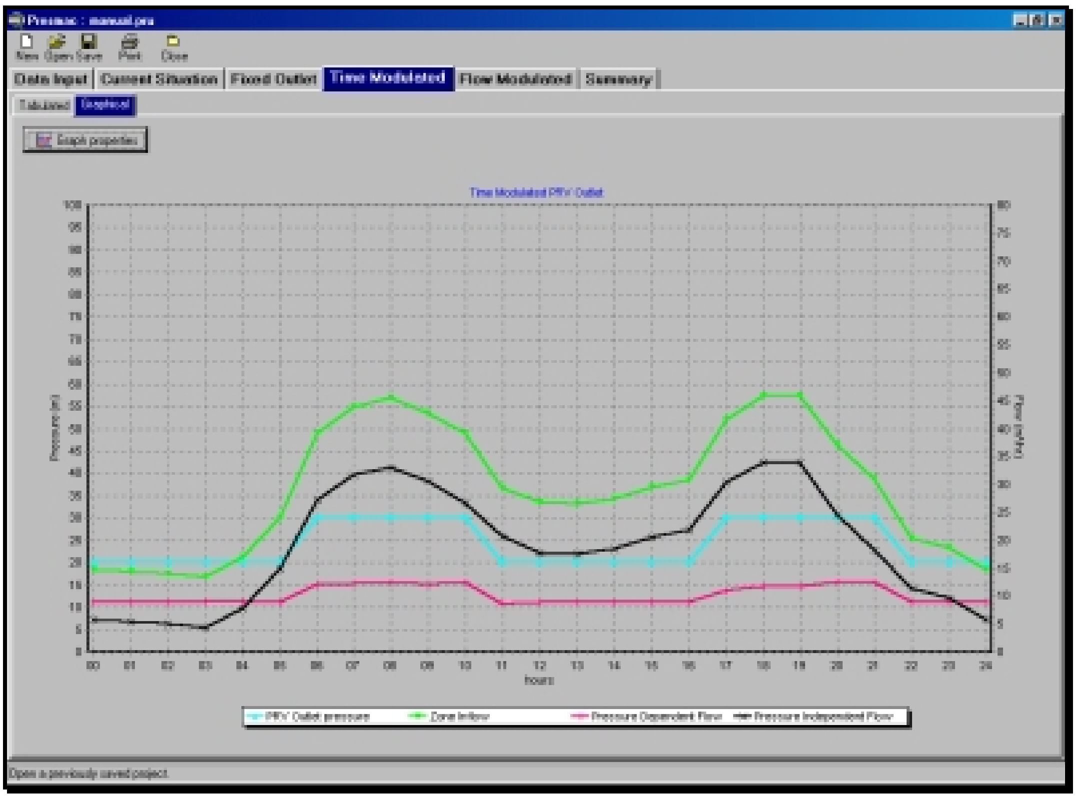


Figure 2.3: Split between pressure dependent and pressure independent flows

For the data presented in **Table 2.3** the Hour Day Factor is 27.2 which is a typical value for a system operating with some form of selective pressure control which reduces the system pressure during the period over which the minimum night flow occurs. The HDF calculation is as follows:

$$\text{HDF} = \frac{\text{Total Daily Pressure Dependent Flow}}{\text{Pressure Dependent Flow during Hour of MNF}}$$

$$= \frac{247}{9.08} = 27.2$$

2.2. CALCULATING THE APPROPRIATE POWER EXPONENT (N1) VALUE

As can be seen from the previous section, in order to estimate the Hour Day Factor it is first necessary to establish the split between pressure dependent and pressure independent flow since the HDF is based only on the pressure dependent flows. This is one of the key calculations which in turn is based on the BABE methodology as described in the PRESMAC User Guide (WRC, 2001) and explained in **Appendix B**.

The N1 value used in HDF is neither the burst nor 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 the event that information is not available to calculate the true value from recorded data.

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

Undertaking a pressure step test can be problematic in some areas since it requires personnel from the water utility to spend several hours at the site of the pressure reducing valve. In many parts of South Africa, working in a manhole between midnight and 4am in the morning can be dangerous and in such cases an alternative procedure is recommended. The recommended approach involves using a time modulated controller to drop the pressure at night while logging the pressure at the Average Zone Point and Inlet point together with the flow entering the zone. This procedure should be undertaken over 2 or 3 consecutive nights and the pressure lowered by an additional 5 to 10 m each evening. In this manner it is possible to get similar results to the pressure step-test without having to have personnel on site during the exercise. While this may not be an ideal approach, it does provide realistic results in cases where the zone is relatively stable i.e., the minimum night flow shows little variation when logged over a 7 to 10 day period.

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

The results from the logging are shown in **Figure 2.4** and it can be seen that they are not consistent with a normal stable pressure-reducing valve installation. While this set of logging results was not intended for use in establishing the N1 value for the zone, it was found that due to failure of the valve mechanism the results are in fact ideal for this purpose.

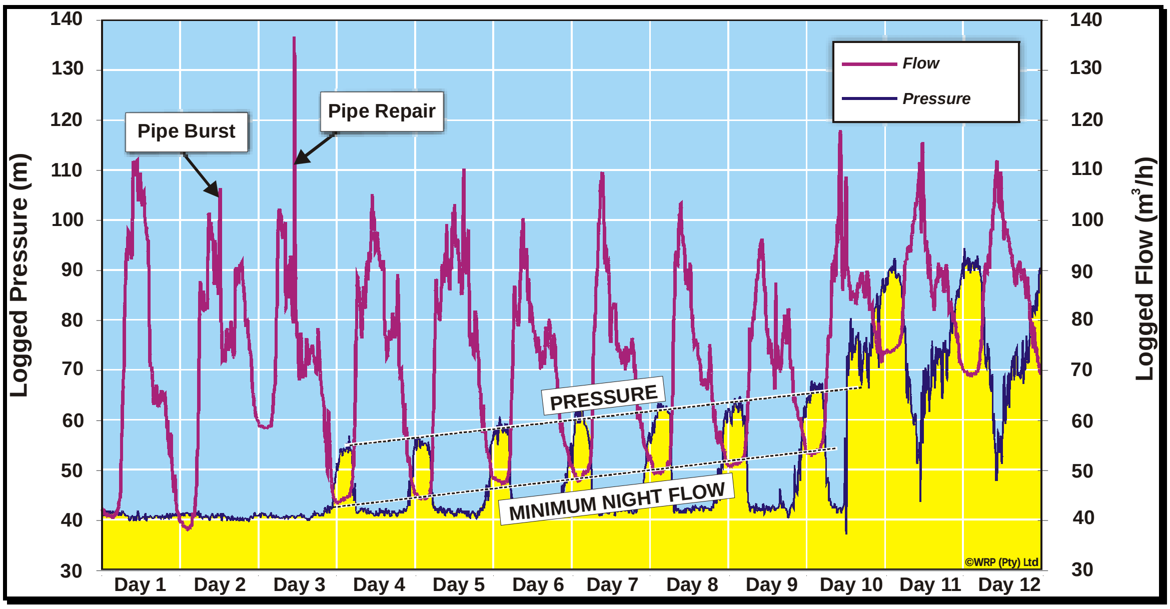


Figure 2.4: Logging results from test data used to calculate N1 value

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

- For the first two days the pressure-reducing valve is stable and the minimum night flow is relatively consistent at approximately 40 m^3/hr.
- On day 2 at noon, a major burst occurs which is evident by the sudden increase in flow of approximately 20 m^3/hr, which also clearly shows up on the minimum night flow, which has also increased to 58 m^3/hr.
- The leak is repaired on day 3 at noon as indicated by the sudden spike of flow caused by the opening of fire hydrants to either reduce the pressure while repairing the leak or to flush the system after the repair. It can be seen that the minimum night flow returns to approximately 44 m^3/hr indicating that the leak has either not been repaired properly or another small leak has also occurred in the system.
- Following the repair of the leak, the pressure-reducing valve starts to fail during the high pressure and low flow period that occurs during the night – at the same time as the minimum night flow occurs. This is evident from the sudden rise in pressure from midnight on day 3 until approximately 6am on day 3 and similarly for each day thereafter. It can also be seen that the maximum pressure occurring each night is gradually increasing from day 4 until day 10 when the valve finally fails completely and the full system pressure is experienced in the zone.
- As a result of the increasing pressure at night, the minimum night flow also increases since a significant portion of the night flow is due to pressure dependent leakage. As the pressure increases, so too does the pressure dependent leakage.

This is an extremely interesting example for a number of reasons. Firstly it highlights the value of continuous logging in a zone-metered area. If the logging results had been available on a real time system, the problem would have been picked up and corrected before the valve failed completely. The failure of the valve in the zone resulted in several new leaks forming and caused considerable inconvenience to consumers not to mention significant loss of water. The example also clearly shows the relationship between pressure and flow. This can be used to estimate the N1 value for the zone in the same way that a normal pressure step-test would be used. The basic data used to estimate the normal night-use is shown in **Table 2.4** while the flow and pressure data used to calculate N1 are shown in **Table 2.5**.

From the information provided in **Table 2.4** and **Table 2.5** it is possible to estimate the N1 value by simply selecting between 2 and 4 pairs of pressures and flows and inserting them into the appropriate cells in the HDF model. It should be noted that this section of the HDF model is optional and need not be used. It is however, useful in cases where the water supplier has the necessary data and would like to estimate the sensitivity of the zone to changes in pressure.

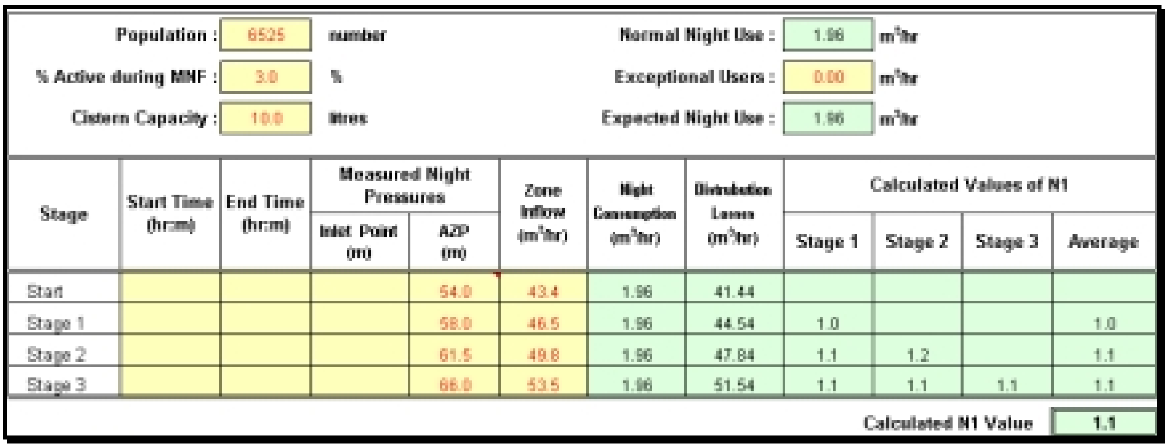
Table 2.4: Calculation of expected normal night use

Description	Value	Units
Population in zone	6 525	No.
Percentage of population active during MNF	3	%
Average water use per toilet flush	10	Litres per flush
Sum of water use by exceptional users	0	Litres/hr
Expected Normal Night Use (6 525 * 0.03 * 10)	**1 957**	**Litres/hr**

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

Table 2.5: MNF and pressure data used to estimate N1 value

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



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

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

Figure 2.5: Sample Calculation of N1 from the HDF Model

While the N1 calculation is discussed in more detail again in **Section 3.3.4**, the results for the data used in this example are shown in **Figure 2.5.** It can be seen from the calculation in **Figure 2.5** that an N1 value of approximately 1.1 is appropriate for this zone. This is a typical value for a normal system in which there are both plastic pipes and some steel or iron pipes.

3. DETAILS OF THE HDF MODEL

3.1. GENERAL

The HDF Model is simply an Excel spreadsheet comprising four forms that utilise certain basic information supplied by the water supplier. The four forms are as follows:

Licence Form: This form provides details of the Licence for the HDF Model. This basically covers some details of the conditions for use of the model including a disclaimer with regards to any problems or errors that occur as a result of using the model.

Base_Data Form: This form is used to capture the basic data used in the calculation of the HDFs. It includes details of the water utility and contact person responsible for the data.

Calcs Form: This form provides details of the calculated HDFs as well as two graphs to portray the information in a simple and easily digestible manner.

Data_Capture Form: This form has no calculations and is simply a template for capturing the basic data used in the HDF calculation. It is included to allow users to print the form and fax it to a water supplier so that another party can undertake the calculations.

Details of each form are provided in the remainder of **Section 3**.

3.2. LICENCE FORM

The Licence Form is shown in **Figure 3.1** and is self-explanatory. It simply provides a few basic conditions of use as well as a statement of limited Liability. Space is provided for water users to add their name and reference number which would normally be allocated by the Water Research Commission (WRC) or the organisation responsible for the distribution of the model.

The HDF Model was developed through the WRC by WRP (Pty) Ltd and support from Mr Allan Lambert through Global Water Resources (GWR). The model is available freely in South Africa through the WRC although the copyright remains jointly with the WRC and GWR.

HDF Version 1.1 - March 2002

This copy is licensed to:	ABC Water Company
Reference No:	123

Conditions of Use:

1. The program is protected with passwords which will not be revealed.
2. No liability will be accepted by the WRC in respect of any viruses transferred or claimed to have been transferred through use of the program. Copies of the disks have been virus checked before dispatch, but the purchaser should also check the disks prior to use.
3. No liability will be accepted by the WRC in respect of the use or misuse of this program by the purchasers or for the interpretation of any data or results arising from the use of the program. The program is customised for the specific situation of South Africa and should not be used for analysis of data from other locations where the assumptions might be inappropriate.
4. By opening the software and proceeding from this Licence Worksheet to the other Worksheets, the User accepts these Conditions of Use.
5. This program is designed to operate using Microsoft Excel. If any difficulties are experienced with the installation or operation of this program, please contact the WRC or the developers (e-mail mckenzie@global.co.za) quoting the name, version and issue date of the program.

Figure 3.1: Licence Form

3.3. BASE DATA FORM

3.3.1. General

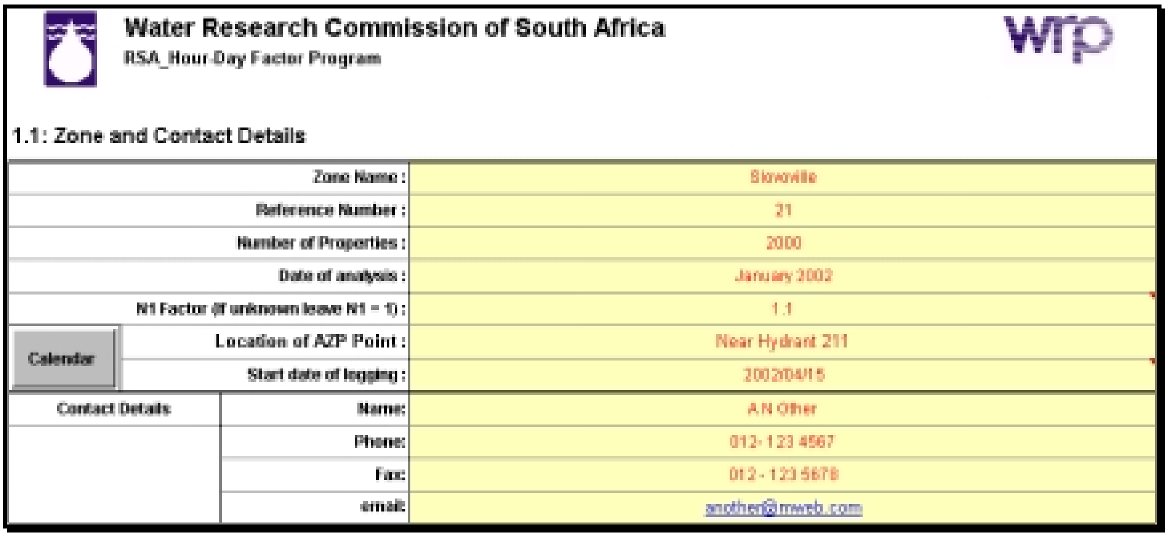
The base data form includes three sections which involve the following:

- **Section 1.1** captures the basic information on the zone being analysed as well as details of the contact person responsible for completion of the form.

- **Section 1.2** captures the average hourly pressures at the Average Zone Point (AZP) for a period of up to 10 days.
- **Section 1.3** is an optional section which allows users to calculate the appropriate N1 value for the zone from information gathered from a "Pressure Step Test".

3.3.2. Zone and Contact Details

This section is self-explanatory and captures some basic information on the zone being analysed as well as details of the person responsible for the analysis. The appropriate section of the form is shown in **Figure 3.2.** It should be noted that a "Calendar" button is included to assist users in specifying the start date for the logging results. It is important that the date is selected using this button to ensure that it is supplied in the format expected by the program.



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1.1: Zone and Contact Details

		Zone Name :	Slowville
		Reference Number :	21
		Number of Properties :	2000
		Date of analysis :	January 2002
		N1 Factor (if unknown leave N1 = 1) :	1.1
Calendar		Location of AZP Point :	Near Hydrant 211
		Start date of logging :	2002/04/15
Contact Details		Name:	A N Other
		Phone:	012- 123 4567
		Fax:	012 - 123 5678
		email:	another@mweb.com

Figure 3.2: Zone and Contact Details

3.3.3. AZP Pressures

In order to calculate the HDF for a particular zone, it is necessary to obtain information on the average hourly pressures at the Average Zone Point. Details on the AZP and how it can be identified in an area are provided in **Appendix C**. It should be noted that the pressure at the AZP should be logged and the results from the loggings should then be recorded on the form for a period of up to 10 days. The HDF is then estimated for each day over the period of record in the manner discussed in **Section 2**. The calculation of the HDFs is discussed in **Section 3.4**.

It should be noted that it is not necessary to have a full 10-day period of pressure recordings and the model can operate on as little as one-day of hourly pressures. By including more than one day of pressures, the user can gain a better understanding of the variability of the HDF and also test the sensitivity to the N1 value used for the zone.

A typical set of pressures is shown in **Figure 3.3**.

1.2: Pressure at AZP for given time of day (m)
(Minimum data requirement : one 24-hour period)

Time of day (hr)	Date of logging										Average
	04/08	04/09	04/10	04/11	04/12	04/13	04/14	04/15	04/16	04/17	
00 to 01	71.8	69.7	70.3	69.8	74.0	74.0	74.0	73.0			72.1
01 to 02	73.2	71.5	71.2	72.7	74.5	74.5	74.5	74.5			73.3
02 to 03	74.8	71.3	71.5	74.7	75.5	75.5	75.5	75.5			74.3
03 to 04	75.3	72.2	71.7	74.3	75.7	75.7	75.7	75.7			74.5
04 to 05	75.0	72.3	71.3	75.0	75.7	75.7	75.7	75.7			74.6
05 to 06	73.7	68.7	72.5	74.0	74.7	74.7	74.7	74.7			73.5
06 to 07	71.5	70.2	72.0	71.8	72.2	72.2	72.2	72.2			71.8
07 to 08	59.3	63.7	60.0	62.5	62.8	62.8	62.8	62.8			62.1
08 to 09	53.3	62.5	61.5	58.3	61.3	61.3	61.3	61.3			60.1
09 to 10	45.0	53.7	56.0	53.7	50.3	50.3	50.3	50.3			51.4
10 to 11	49.5	55.5	55.5	57.8	54.7	54.7	54.7	54.7			54.6
11 to 12	43.7	58.2	50.7	62.8	54.0	54.0	54.0	54.0			53.9
12 to 13	43.2	64.3	57.3	63.8	59.5	59.5	59.5	59.5			58.3
13 to 14	55.3	61.2	65.2	65.5	64.2	64.2	64.2	64.2			63.0
14 to 15	56.3	62.8	66.0	66.3	64.7	64.7	64.7	64.7			63.8
15 to 16	52.0	63.3	60.0	64.8	66.5	66.5	66.5	66.5			63.3
16 to 17	56.7	60.5	51.8	63.3	60.7	60.7	60.7	60.7			59.4
17 to 18	52.5	55.8	52.8	55.3	51.8	51.8	51.8	51.8			53.0
18 to 19	48.7	46.0	50.7	49.3	45.8	45.8	45.8	45.8			47.2
19 to 20	53.0	54.5	50.0	53.8	47.5	47.5	47.5	47.5			50.2
20 to 21	59.2	55.2	59.3	59.5	53.0	53.0	53.0	53.0			55.7
21 to 22	61.2	65.3	63.3	67.3	64.5	64.5	64.5	64.5			64.4
22 to 23	62.7	65.0	63.3	71.5	65.7	65.7	65.7	65.7			65.7
23 to 24	65.0	68.0	68.2	71.8	69.0	69.0	69.0	69.0			69.1
Average	59.7	63.0	62.2	65.0	63.3	63.3	63.3	63.3			62.9
Maximum	75.3	72.3	72.5	75.0	75.7	75.7	75.7	75.7			74.6
Minimum	43.2	46.0	50.0	49.3	45.8	45.8	45.8	45.8			47.2

Figure 3.3: Typical Set of Pressure Values in the HDF Model

3.3.4. N1 Calculation Sheet (Optional)

When calculating the HDF for a specific zone it is necessary to know or estimate a realistic N1 value for the zone since the standard pressure flow equation forms the basis of the HDF calculation. The standard pressure flow equation is fully discussed in the PRESMAC User Guide (WRC, 2001) and is repeated below for reference purposes:

$$Q_2 / Q_1 = (P_2 / P_1)^{N1} \quad \text{or} \quad N1 = \text{Log}(Q_2/ Q_1) / \text{Log}(P_2/ P_1) \qquad \textbf{Equation 3.1}$$

Where:

Q_1 = Pressure dependent flow at time 1 (m^3/hr)

Q_2 = Pressure dependent flow at time 2 (m^3/hr)

P_1 = Average zone pressure at time 1 (m)

P_2 = Average zone pressure at time 2 (m)

N1 = Power exponent for pressure flow relationship

In order to estimate the N1 value for a system, the HDF Model allows the user to provide at least two sets of pressures and flow. Up to four sets may be provided and the N1 value is calculated for all combinations of pressures and flows. For example if only two sets of values are provided, one estimate of the N1 value will be calculated. If three sets are provided, then three estimates of N1 will be obtained (i.e. 1+2), and if four sets are provided, then 6 estimates for N1 will be calculated (i.e. 1+2+3). A typical set of N1 calculations was already presented in **Figure 2.5** and to explain the calculation the N1 value for the first two pairs of pressures and flows is as follows:

Q_1 =	Pressure dependent flow at time 1 =	41.44 m^3/hr
Q_2 =	Pressure dependent flow at time 2 =	44.54 m^3/hr
P_1 =	Average zone pressure at time 1 =	54.0 m
P_2 =	Average zone pressure at time 2 =	58.0 m
N1 =	$\text{Log}(Q_2/ Q_1) / \text{Log}(P_2/ P_1)$ (**Equation 3.1**)	
=	Log(44.54 / 41.44) / Log (58.0 / 54.0)	
=	Log(1.0748) / Log(1.0741) =	1.01

The N1 value of 1.01 is shown in **Figure 2.5** of the previous section and is the first of the six N1 values shown in the table (rounded to 1.0).

It should be remembered that the N1 calculation sheet is optional and can be ignored if no data are available. The HDF model estimates the appropriate HDF for a range of N1 values from 0.5 up to 2.5 which are the minimum and maximum values that can be experienced in any normal water reticulation system. The water supplier can then select the HDF appropriate to its system based on local knowledge of the material and condition of the pipes. In cases where no information is available and the water supplier is not able to suggest a realistic N1 value, it is generally accepted that a value of 1.0 to 1.1 is appropriate and can be used as the “default value” until a more accurate estimate can be made from pressure loggings.

If it is found that the estimated N1 values vary widely from each other, particularly in the event that the calculation is based on a pressure step test undertaken over a period of several hours, it is likely that the assessed customer night use figure is incorrect. In such cases, alternative values of customer night use should be tested in an attempt to derive stable results.

3.4. CALCS FORM

The “Calcs” form provides details of the HDF estimates made by the program and displays the results both in tabulated form and graphics form. The calculations are very straightforward and based on the following equation as discussed in **Section 2**.

$$HDF = \frac{\text{Total Daily Pressure Dependent Flow}}{\text{Pressure Dependent Flow during Hour of MNF}} \qquad \textbf{Equation 3.2}$$

The HDF is calculated for each day of logging information and for the following six N1 values:

N1 = 0.5

N1 = 1.0

N1 = 1.5

N1 = 2.0

N1 = 2.5

N1 = User specified.

Typical results from the model are shown in tabular form in **Figure 3.4** for the basic information previously shown in **Figure 3.3**.

It should be noted that the HDFs are calculated using the standard pressure /flow equation (**Equation 3.1**) discussed in **Section 3.3.4** together with the HDF equation (**Equation 3.2**) mentioned above. Through the use of the two equations, the HDF can be calculated directly from the appropriate pressure values together with the selected N1 value in which case it is not necessary to split the flow into the pressure dependent and pressure independent components. The calculation procedure involves combining **Equation 3.1** and **Equation 3.2** to yield **Equation 3.3**.

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Hour-day factors

N1 value	Date of logging										Average hour-day factor
	04/15	04/16	04/17	04/18	04/19	04/20	04/21	04/22	04/23	04/24	
0.50	21.3	22.4	22.3	22.4	21.9	21.9	21.9	21.9			**22.0**
0.75	20.1	21.6	21.5	21.7	20.9	20.9	20.9	20.9			**21.1**
1.00	19.0	20.9	20.8	21.0	20.1	20.1	20.1	20.1			**20.3**
1.25	18.1	20.3	20.1	20.3	19.3	19.3	19.3	19.2			**19.5**
1.50	17.1	19.6	19.5	19.7	18.5	18.5	18.5	18.5			**18.8**
1.75	16.3	19.0	18.9	19.1	17.8	17.8	17.8	17.8			**18.1**
2.00	15.6	18.5	18.3	18.6	17.1	17.1	17.1	17.1			**17.4**
1.10	18.6	20.7	20.5	20.7	19.7	19.7	19.7	19.7			**19.9**

Hour of MNF : 03 to 04

Maximum hour-day factor :	22.0
Minimum hour-day factor :	17.4
Hour-day factor for N1 = 1 :	20.3
Hour-day factor for user defined N1 value (Defined in cell "F13" in "Base Data"):	19.9

Figure 3.4: HDF values as calculated in the HDF Model.

$$HDF = \frac{\sum Q_{MNF}(P_X/P_{MNF})^{N1} \text{ for } x = 1 \text{ to } 24}{Q_{MNF}} \qquad \textbf{Equation 3.3}$$

This can be further simplified to **Equation 3.4** as follows:

$$HDF = \frac{\sum (P_X)^{N1} \text{ for } x = 1 \text{ to } 24}{(P_{MNF})^{N1}} \qquad \textbf{Equation 3.4}$$

For example if we wish to calculate the HDF for the second day using an N1 value of 2.0 and taking the hour for the MNF as 3am to 4am, the calculation is as shown in **Table 3.1**.

It should be noted that in most cases the MNF can be assumed to occur between 3am and 4am. The model has, however, been developed to accommodate a MNF occurring at some other hour and the user can simply select the appropriate hour. This facility also allows the user to test the sensitivity of the results on the MNF hour selected.

Using the figures from **Table 3.1** the HDF value can be calculated as follows:

HDF = 96 308 / 5 213 = 18.5

The remaining HDF values for each of six N1 values and for each day of recorded pressures are calculated in the same manner and the results are as indicated in **Figure 3.4**. It should be noted that if there is an unusually large discrepancy between the HDF values for certain days, it could be due to an error in the estimation of the normal night-use which in turn is based on the population and typical unit night use for the area.

Table 3.1 : Calculation of HDF for Day 2 with an N1 value of 2.0

Hour = x	Pressure at Hour x (= P_X)	$(P_X)^{N1}$
Midnight to 1am	69.7	4 858
1am to 2am	71.5	5 112
2am to 3am	71.3	5 084
3am to 4am	72.2	5 213
4am to 5am	72.3	5 227
5am to 6am	68.7	4 720
6am to 7am	70.2	4 928
7am to 8am	63.7	4 058
8am to 9am	62.5	3 906
9am to 10am	53.7	2 884
10am to 11am	55.5	3 080
11am to 12am	58.2	3 387
12 noon to 1 pm	64.3	4 134
1pm to 2pm	61.2	3 745
2pm to 3pm	62.8	3 944
3pm to 4pm	63.3	4 007
4pm to 5pm	60.5	3 660
5pm to 6pm	55.8	3 114
6pm to 7pm	46.0	2 116
7pm to 8pm	54.5	2 970
8pm to 9pm	55.2	3 047
9 pm to 10 pm	65.3	4 264
10 pm to 11 pm	65.0	4 225
11 pm to midnight	68.0	4 624
Total		**96 308**

Having calculated the HDF values for the various 24-hour periods and for the different N1 values, the results are also displayed graphically to highlight the range in values. This information provides the user with a visual check on how reliable the estimates are likely to be. In view of the many assumptions on which the calculations are based, it was not considered appropriate to predict error margins or reliability envelopes. Instead, the information shown in **Figures 3.5** is considered sufficient for most purposes.

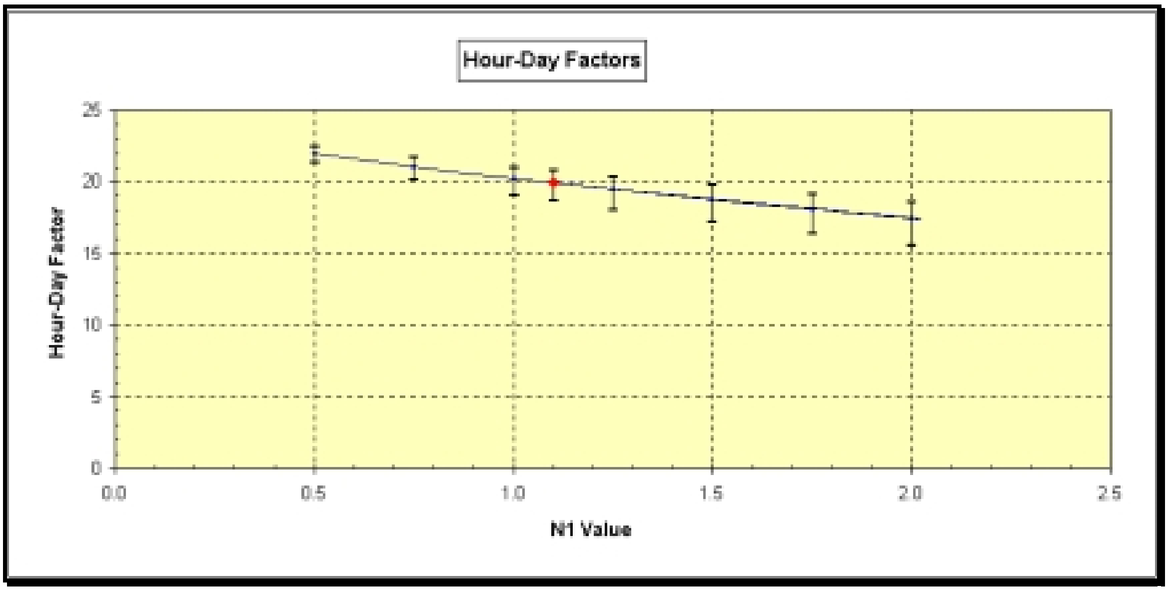


Figure 3.5: Variation in HDF values for different N1 values

In addition to the graph of N1 values, a graph is also provided to show the pressure variation and range over the 24-hour period. Again, this is mainly to provide an indication of the quality and stability of the data on which the HDF calculations are based.

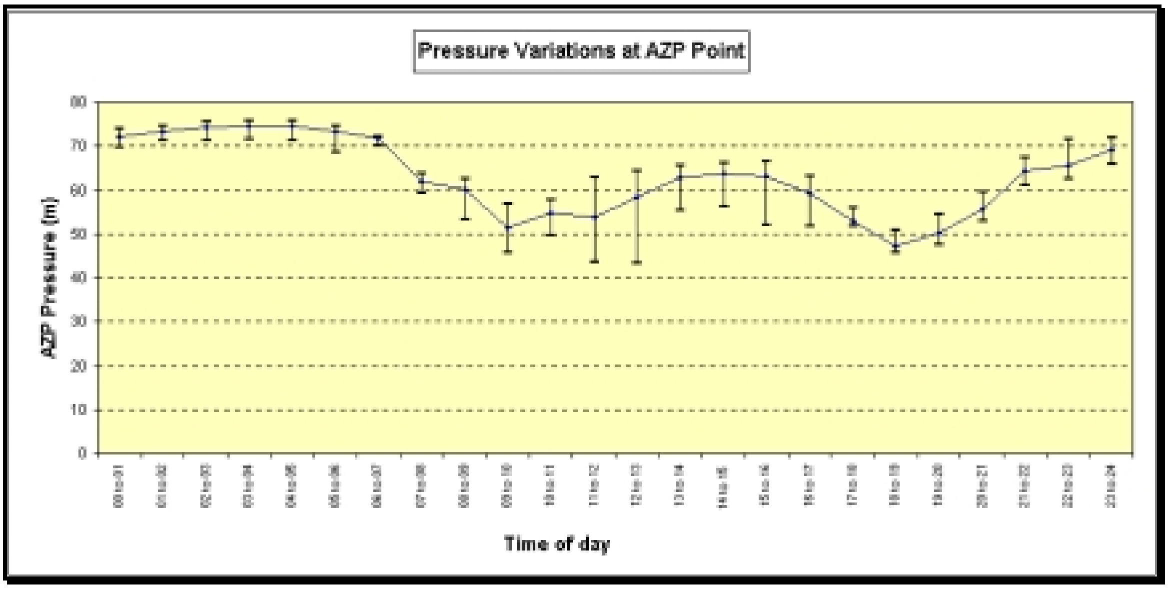


Figure 3.6: Graph showing pressure variability from the various 24-hour periods

3.5. DATA CAPTURE FORM

In certain cases a water supplier may not have access to a suitable computer or the Excel spreadsheet program. In such cases, the water supplier can simply complete the data capture form and send the information to the model developers or another organisation that is able to process the results. While the form is included as part of the HDF Model for completeness, it can simply be photo-copied from the manual and faxed after the base information has been added to the form.

A listing of the data capture form is included in **Appendix D**.

4. USING HDF

HARDWARE AND SOFTWARE REQUIREMENTS

In order to run the HDF Model the user requires a basic PC with the Windows operating system and the EXCEL spreadsheet program. If the EXCEL program is not available, the user should copy and complete the data request form and send the information to another organisation with access to Excel.

INSTALLING HDF

The HDF Model can be downloaded directly from the WRC web site. It is a relatively small file at approximately 702K and can be run from anywhere on the user's PC as long as the Excel program can be accessed. There is no sophisticated installation shield and it is simply the case of copying the **HDF.XLS** file into a suitable directory and using the model in the same manner as a normal Excel spreadsheet.

DATA REQUIREMENTS

The HDF Model is colour-coded in the following manner:

- Yellow blocks should be completed by the user;
- Green blocks are calculated fields and require no user input.

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

- System name and contact details (**Section D1**)
- Hourly average pressures for up to 10 24-hour periods
- Data required to estimate the normal night use if the N1 value is to be calculated.

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

5. REFERENCES

- LAMBERT AO, (1997) **Pressure Management/Leakage Relationships: Theory, Concepts and Practical Applications**. Conference on Minimising Losses in Water Supply Systems, Apr. 1997. IQPC Ltd, London.
- MAY J (1994) ***Pressure Dependent Leakage***. World Water and Environmental Engineering, October 1994
- NATIONAL WATER COUNCIL STANDING TECHNICAL COMMITTEE, (1980). Report No. 26, Technical Working Group on Waste of Water. **Leakage Control Policy and Practice**. ISBN 0 904561 95 X
- UK WATER INDUSTRY, 1994**.** The 'Managing Leakage' Series of Reports

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

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

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

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

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

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

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

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

  Report J: **Leakage Management Techniques, Technology & Training**. ISBN: 1 898920 14 1
- WRC, 1999, **SANFLOW: Development of a standardised approach to evaluate bursts and background losses in water distribution systems in South Africa.** Report Number TT 109/99, ISBN 1 86845 490 8. (Author: Mckenzie, RS).
- WRC, 2001, **PRESMAC: Development of a pragmatic approach to evaluate the potential savings from pressure management in potable water distribution systems in South Africa** . Report Number TT152/01, ISBN 1 86845 722 2 (Author: Mckenzie, RS).

APPENDIX A

GLOSSARY OF TERMS

APPENDIX A: GLOSSARY OF TERMS

Average Zone Pressure

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

Average Zone Point

A point in a system at which the pressure is considered to represent the weighted average pressure for the whole zone. The pressure measured at this point is considered to be the Average Zone Pressure and is used in numerous BABE calculations. The point is normally derived by considering the number of stands (or sometimes fire hydrants) in various elevation ranges from which an average elevation is derived. The AZP is then selected by finding a suitable property or fire hydrant at the specified elevation and at an appropriate point in the system. Details of the methodology used to identify the AZP for a system are provided in **Appendix C**.

Burst Leakage

Burst Leakage is considered to be the sum of all large leaks in a system where a large leak is defined as being larger than 0.25 m^3/hr.

Background Leakage

Background leakage is the sum of all leaks smaller than 0.25 m^3/hr in a system. It is normally calculated by adding the mains leakage, connection leakage and property leakage in the standard BABE approach (see SANFLOW User Guide, WRC, 1999)

Exceptional Users

In some zones there may be specific large users which can consume significant quantities of water during the night-time period which in turn will influence the minimum night flow. In such cases it is important to identify and quantify the water use by such consumers so that the HDF calculations are based on realistic estimates of the pressure dependent flows.

Hour Day Factor

The HDF is a factor that can be applied to a reduction (or increase) in the pressure dependent flow occurring at the hour of Minimum Night Flow to provide an indication of the total daily saving (or increase) in pressure dependent flow that can be expected over the whole 24-hour period. In most normal systems a value of between 18 and 22 can be expected while in areas that are already operating under some form of pressure control, values in excess of 24 can be expected.

Minimum Night Flow

The MNF is the minimum flow entering a water management zone over a 24-hour period. It normally occurs between the hours of 2am and 4am in most normal zones although this can vary from country to country.

Normal Night Use

The normal night use is the expected water used by the consumers during the hour of minimum night flow. An indication of the level of leakage (i.e. reported and unreported bursts) can be established by subtracting the normal night use (including background leakage) from the minimum night flow,

Pressure Dependent and Pressure Independent Flow

Water entering any system can be split into pressure dependent and pressure independent flow. Pressure dependent flow is often considered to be all flow that is not consumed after the customer meter. While this is known to be over simplistic, the calculation is relatively simple and generally realistic. Pressure Dependent flow is therefore considered to be the sum of the background leakage and the burst leakage. In some cases an adjustment for pressure dependent household use can be made although the additional quantity is generally relatively small.

APPENDIX B

Introduction to BABE and FAVAD Concepts

APPENDIX B : INTRODUCTION TO BABE AND FAVAD CONCEPTS

B1: HISTORICAL BACKGROUND

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

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

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

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

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

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

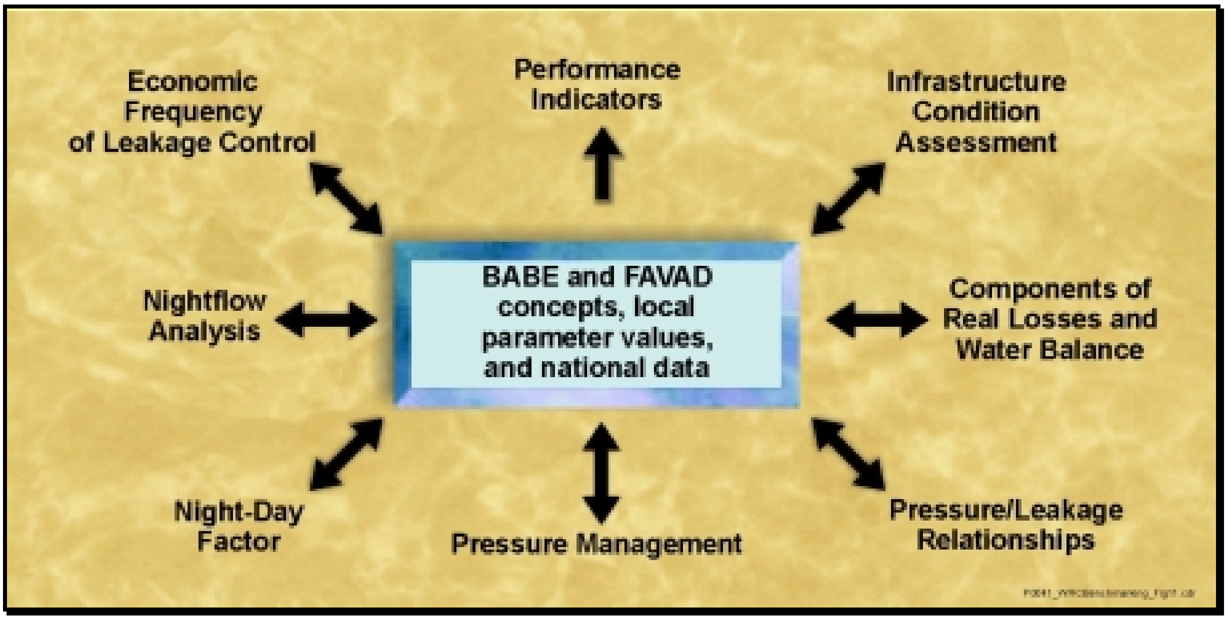


Figure B.1: Problem-Solving using BABE and FAVAD concepts

B2: BURST AND BACKGROUND ESTIMATE (BABE) procedures

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

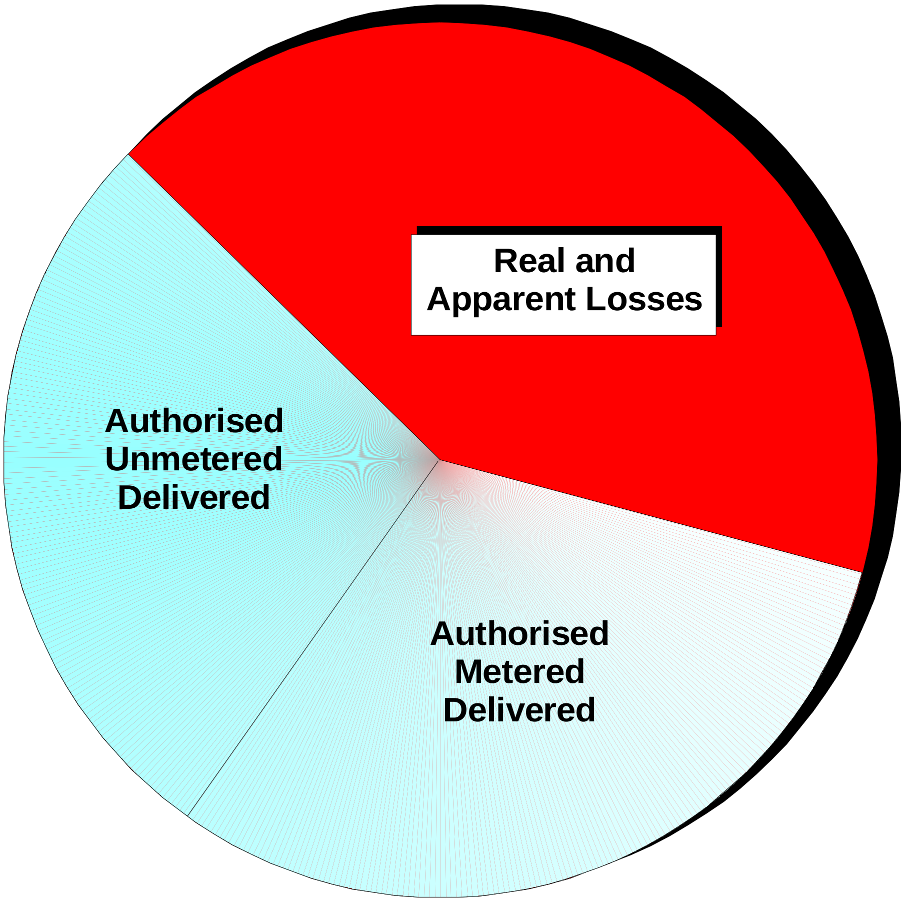


Figure B.2: Traditional Water Balance.

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

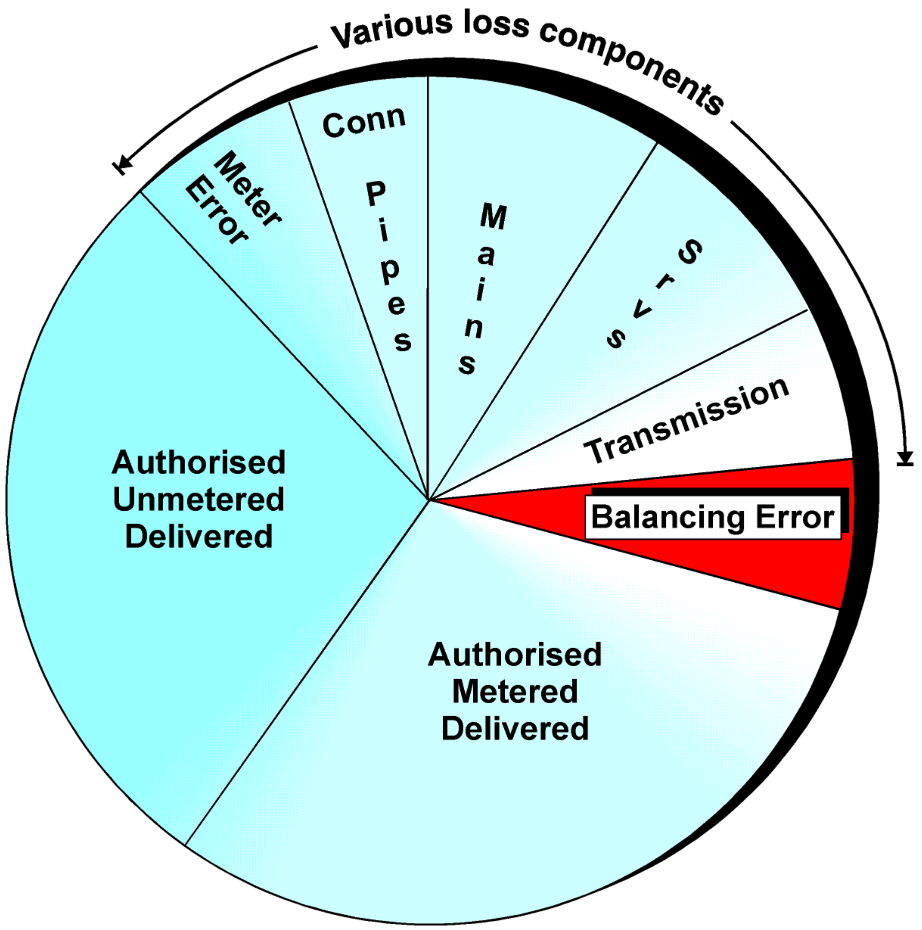
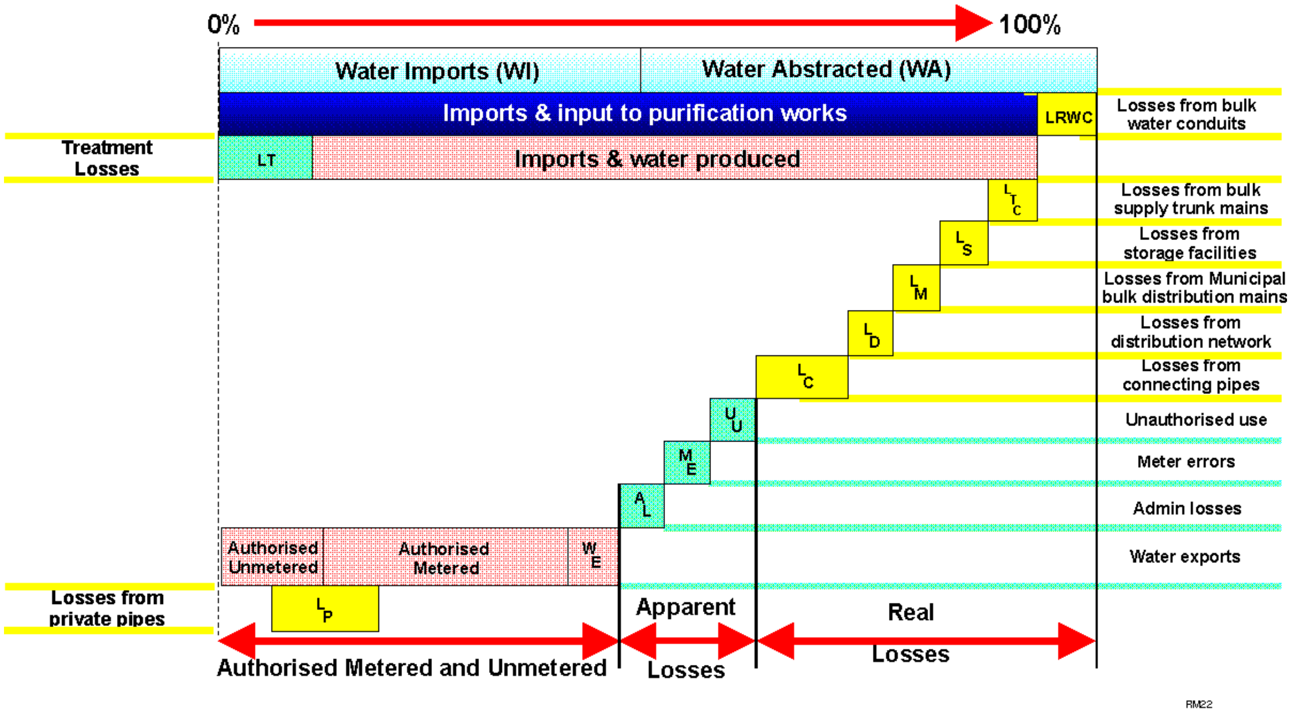


Figure B.3: BABE Water Balance Approach.

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



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

Figure B.4: Recommended BABE Water Balance Components.

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

B3: WHAT ARE BURST AND BACKGROUND LEAKS ?

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

Events >	**250 ℓ/h**	**=**	**Bursts**

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

In all water supply systems there are likely to be both bursts and background leaks since it is not possible to develop a system completely free of leakage.

B4 : FIXED AREA VARIABLE AREA DISCHARGES (FAVAD)

In order to calculate the pressure dependent leakage in a water distribution system, it is necessary to understand the pressure/leakage relationship for the system being analysed. Considerable work has been undertaken in this regard over the past 10 years in many parts of the world to establish how leakage from a water distribution system reacts to pressure. From this work it is now generally accepted that leakage from a hole in a pipe will react to pressure in accordance with normal hydraulic theory which indicates a square root power relationship between flow and pressure. The power exponent, shown as N1 in the equation below is therefore assigned a value of 0.5.

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

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 real water distribution systems the leakage has been found to react by a factor greater than 0.5 and in some cases as high as 2.5. This has caused considerable debate and confusion especially when trying to establish the likely savings that can be achieved 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 which has gained wide acceptance in many parts of the world including South Africa (Lambert, 1997). In 1994, John May (May, 1994) from the UK first suggested the possibility of fixed area and variable area discharges (FIVAD). He carried out considerable research on this topic and found that systems will react differently to pressure, depending upon the type of leak most prominent in the system being investigated. 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 N1 value should be used when estimating the influence of pressure on leakage flow. In general, it is recommended that a power exponent of 0.5 should be used for all burst flows since a burst pipe is usually a fixed area discharge. In the case of the background losses, however, the leaks are likely to be variable area discharges in which case a larger power exponent should be used. A power exponent of 1.5 is usually used for the background losses, which is considered to represent a collection of leaks that have factors of between 0.5 and 2.5. If all of the pipe work is known to be plastic, a higher value may be appropriate and conversely, if the pipes are made from cast-iron, a lower value (e.g. 0.7) should be used.

APPENDIX C

Methods Of Calculating Average Pressure In Distribution Systems

APPENDIX C: METHODS OF CALCULATING AVERAGE PRESSURE IN DISTRIBUTION SYSTEMS

C1: A SYSTEMATIC APPROACH TO CALCULATING AVERAGE PRESSURE

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

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

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

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

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

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

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

C2. AVERAGE ZONE PRESSURES WHERE NO NETWORK MODELS EXIST

C2.1 Calculate Weighted Average Ground Level for Each Sector

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

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

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

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

Table C1: Example calculation of weighted ground level

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

Weighted Average Ground Level = 3907 / 357 = 10.9 m

C2.2 Measure or Calculate Average Zone Pressure

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

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

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

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

C2.3 Calculate Weighted Average Pressure for Aggregation of Zones

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

Table C2: Example calculation of weighted ground level

Area Reference	Number of Service Connections	Average Zone Pressure	Number of service Connections * AZP
A	420	55.5	23 310
B	527	59.1	31 146
C	443	69.1	30 611
D	1352	73.3	99 102
E	225	64.1	14 423
F	837	42.0	35 154
G	1109	63.7	70 643
H	499	56.3	28 094
I	1520	57.0	86 640
	6932		**419 122**

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

C3. AVERAGE ZONE PRESSURES USING NETWORK MODELS

C3.1 Calculate Weighted Average Ground Level for Each Sector

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

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

APPENDIX D

Listing of the HDF Model