Aqualite

Water balance software

USER GUIDE

Version 2.1: August 2006

Designed by:
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AquaLite

Water balance software

VERSION 2.0.2

User Guide

By

Ronnie Mckenzie

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PREFACE

This document is the User Manual for the AquaLite Benchmarking Software which has been developed by Ronnie Mckenzie with support of various individuals. The objectives of the Software and the Manual are:

- to introduce a standard terminology for components of the annual water balance calculation in line with the latest IWA methodology;
- to encourage water suppliers throughout the world to calculate components of Non-Revenue Water, Apparent Losses and Real Losses using the standard annual water balance
- to promote Performance Indicators suitable for national and international benchmarking of performance in managing water losses from public water supply transmission and distribution systems.

The methodologies used in AquaLite draw strongly on recent recommendations of Task Forces of the International Water Association (IWA). The AquaLite model can be downloaded from the WRC web site (www.wrc.org.za) or obtained from:

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It should be noted that the methodologies for quantifying water losses contained in the AquaLite model are not the only methods used worldwide. They are, however, well accepted and used extensively in many parts of the world and are rapidly being recognised as the most appropriate and pragmatic techniques for assessing the water balance components for potable water distribution systems. It should always be noted that every technique has its own inherent strengths and limitations, with corresponding sensitivities which impact on the results achieved. The practitioner and other users should be aware of the sensitivities and limitations when using the results of particular methods with particular reference to the Performance Indicators.

The term ‘95% Confidence Limits’ has been used in the AquaLite model for expressing the highest likely margin of error for each Performance Indicator. It is important to note that the ‘95% Confidence Limits’ calculated will not relate to the pure statistical definition of ‘95% Confidence Limits’ since data entry will involve ‘best estimates’ for some water balance components and the estimation of the error terms as defined by the user will always be subjective to some degree.

AquaLite also includes the calculation of the Unavoidable Annual Real Losses (UARL) as well as the use of the Infrastructure Leakage Index (ILI) as a key performance indicator. These two parameters are currently the subject of considerable attention and debate throughout the world and are being used in many countries. When used properly they can provided very useful information on the performance of a water distribution system but must be used with care to ensure that the results are meaningful since there are situations where the estimates can be misleading. They are fully described in this manual and the limitations on their use are clearly defined.

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ACKNOWLEDGEMENTS

The development of AquaLite was undertaken by Ronnie Mckenzie over a number of years and is based on the combined efforts of many individuals and organisations throughout the world. While there are too many individuals to list, the following individuals and organisations are noted for their significant contributions to the final product (in alphabetical order).

Name	Organisation	Comments
De Villiers, Etienne	Specialist Software Development	Etienne was responsible for much of the initial Delphi programming of AquaLite. Many features are not available through the standard Delphi package and were developed by Etienne specifically for AquaLite.
Fanner, Paul	Fanner & Associates Ltd.	Paul has provided considerable support in the development of AquaLite and was one of the key specialists assisting with the overall model development over a period of almost 2 years.
Liemberger, Roland	Liemberger and Partners GmbH	Roland provided support in the development of AquaLite based on his practical experience from many parts of the world and in particular developing countries.
Nyland, Grant	WRP (Pty) Ltd	Grant helped with the final Delphi coding of the model and in streamlining the reporting forms and presentation of results.
Seago, Caryn	WRP (Pty) Ltd	Caryn provided support on the testing of the model on various water utilities and in the design of many forms.
Waldron, Tim	CEO, Wide Bay Water	Tim also provided considerable support to promote the concepts of the Water Balance Methodology throughout Australia and SA by organising and participating in the various workshops.
Wegelin, Willem	WRP (Pty) Ltd	Willem assisted with the model testing and in evaluating many data sets using the model.

AQUALITE: WATER BALANCE SOFTWARE

USER GUIDE

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1 INTRODUCTION

1.1 GENERAL

In recent years there has been a growing realisation that a standard methodology and terminology is required to assist Water Utilities in assessing the water balance of their systems.

A transition from traditional familiar terminology and methods is never easy to accomplish, and a commitment is needed from all Water Suppliers if improved assessment and comparisons of water losses are to be implemented. For example, the terms 'Non-Revenue Water' and 'Water Losses' should replace the familiar (but vague) term 'Unaccounted-for-Water' – because, with modern techniques, it is possible to account for all water entering a water distribution system. Also, the use of percentages to express real losses is now recognised internationally as being potentially misleading when used as a measure of the operational efficiency of managing real losses (leakage and overflows) from distribution systems with different levels of consumption. Comparisons between water utilities are further complicated by a wide range of operating pressures, density of connections per km of mains, and large numbers of unmetered residential properties in many systems. AquaLite offers a solution to these common problems and is based on a widely accepted approach that deals with these issues effectively and allows leakage in different systems to be compared in a pragmatic and unbiased manner.

AquaLite has been designed to provide a pragmatic and straight-forward approach to a relatively complex issue and its design is based on the experience of many specialists dealing with such issues on a daily basis in many parts of the world. The model therefore incorporates the current 'best practice' and has been designed in such a manner that it can be used by water utilities throughout the world without the need for modification or customisation.

Water Utilities using AquaLite will be able to express their water balance using the standard International Water Association (IWA) terminology to assess the levels of Real Losses and Non-Revenue Water in their systems. The calculation of components of water losses and performance indicators is automated, to a large extent and by entering estimates of 95% confidence limits for each item of data entry, the 95% confidence limits for each component of water balance, and each Performance Indicator, are automatically calculated.

AquaLite also calculates the 'Unavoidable' annual real losses for any system exceeding 5000 service connections. This calculation is based on the Length of Mains, Length of Underground Pipe from Street Edge to Customer Meter (optional and not required in many countries), Number of Service Connections and Average Operating Pressure. Once calculated, the Unavoidable Annual Real Losses are used to produce a new and versatile Performance Indicator for Real Losses – the Infrastructure Leakage Index (ILI) – which is the ratio of the Current Annual Real Losses to the Unavoidable Annual Real Losses. For many countries, with a diverse range of operating situations, the ILI is an effective Performance Indicator for comparing performance in operational management of Real Losses.

This User Manual explains the background to the development of the IWA recommended methodologies, and takes the reader through the AQUALITE calculations on a step-by-step basis.

It is recommended that all organisations involved in Water Supply use the AquaLite software for calculating and comparing their performance in managing Water Losses in this standard format. All Water Supply organisations should at least undertake an annual calculation on a 'whole system' basis. The model can also be used for smaller areas down to approximately 2 000 properties to identify specific problem areas. When using the model at District level, however, care must be taken when interpreting the results since anomalies may occur due to localised land use conditions which would have a relatively small influence when analysing a whole water distribution system.

1.2 BACKGROUND TO AQUALITE

AQUALITE is the first of a new generation of models designed to assist water suppliers in managing their non-revenue water. It is effectively an annual water-audit model based on the latest IWA best practice. It has been developed through close co-operation of numerous internationally recognised water loss managers from several countries and incorporates a host of features, many of which are not available in other water audit models. The 2007 version of the model is designed to evaluate the level of real losses occurring from a water distribution system based on the traditional IWA top down water balance shown in **Figure 1**.

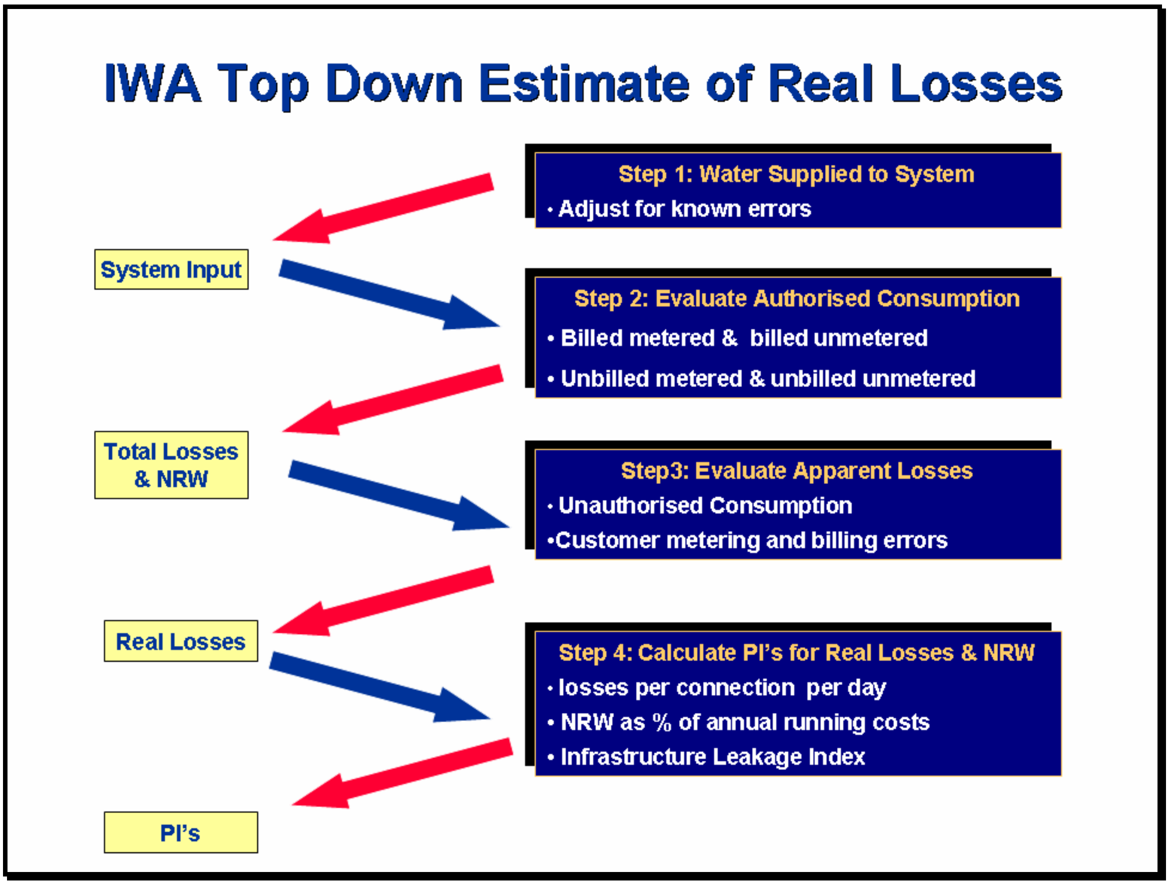


Figure 1: General top-down water balance for evaluation of real losses

This involves completing a basic water balance of water supplied to the system compared to water that can be accounted for in the usual manner. Having established the total losses from the system, the real losses are finally derived by reducing the total losses in accordance with the measured or estimated Apparent Losses. Each component of the calculation is undertaken in accordance with internationally accepted best practice as recommended by the IWA. This 'top-down' water balance provides the first estimate of the real losses from the system and the calculations are supported by a number of Performance Indicators which in turn are used by most water loss practitioners worldwide.

1.3 KEY FEATURES OF AQUALITE

Although several water balance models have been available for several years, AquaLite has been developed to accommodate users who wish to use the model in a variety of circumstances and in many different countries. As a result, the model may appear more complex and comprehensive than many other water balance models, however, the basic methodology used in AquaLite is similar to most other models. In addition, the model has many useful additional features which are summarised below and discussed in more detail later in this user guide.

The AquaLite model incorporates amongst others, the following features:

- A selection of 7 different units of measure for use in different countries where the standard metric units are not appropriate. The units available in AquaLite include:
    - Cubic meters (m^3);
    - Million cubic meters (m^3*10^6);
    - Megalitres (Ml);
    - Million US Gallons;
    - Million imperial gallons
    - Acre feet;
    - Million cubic feet.
- User defined confidence limits on all key variables included in the data sets;
- Facility to differentiate between trunk and distribution mains which often have different pressure profiles. The user can specify the appropriate pressure and % of time pressurised separately to both types of mains;
- Ability to specify system pressures in a tabular format in order to derive the average system pressure for the distribution mains;
- Ability to differentiate between connections and customers in certain calculations;
- Detailed reporting forms which can be user-defined to provide either a summary report of a full detailed report;
- Based on modern object orientated software design principles (DELPHI) thus requiring no third party software to run the model.
- Can be customised quickly and easily to user's requirements including language and general labeling.

2 DETAILS OF AQUALITE

2.1 GENERAL

AquaLite is supplied as an executable file (AquaLite.EXE) together with a sample data file (Sample.wbm). The program is written in Delphi and has been developed for use on most of the windows operating systems (i.e. Windows NT, Windows 2000, Windows XP, Windows 98 etc). To date there have been no problems experienced with the model concerning the operating system.

AquaLite will not alter any system files anywhere on the computer and is a self contained program which has been checked for viruses and any know problems. Those using the model can do so with the confidence that it will not corrupt or destroy any information on the computer on which it is used. The model is run by simply double clicking on the file which can be copied onto any directory on the computer. It has no self installation procedures and can be deleted or overwritten in the same manner as a normal data file is deleted or overwritten.

2.2 PURPOSE OF AQUALITE

AquaLite is designed to assist water suppliers in creating an annual water audit for a specific water supply system. The original intention of the model is to allow a Municipality or Metro to complete an annual water audit for the whole supply system. The model can, however, also be used to complete a water balance for a portion of a larger system and in this manner it can be used to identify areas which experience abnormally high levels of leakage.

The model is used to create an annual water balance for a specific water supply area based on the available data concerning the water supplied to the system and the breakdown of the water that can be accounted for by the supplier. The model provides a summary of the water balance in the standard International Water Association format and also provides a selection of performance indicators which can be used to evaluate the levels of leakage as well as the effectiveness of the management of the system.

2.3 USING THE MODEL

AquaLite is extremely user-friendly and easy to use having been developed in the Delphi environment. The model is simply a series of drop-down forms in which the user can input the available data for the system being analysed. The model has been designed by the author to provide a simple and pragmatic approach to the annual water audit and the level of detail that can be accommodated within the model should be more than sufficient for most water audits being undertaken worldwide. The basic structure of the model is shown in **Figure 2** which highlights the 12 forms making up AquaLite each of which is discussed in more detail at a later stage in this User Guide.

To complete an annual water audit, the user must simply complete each of the 12 forms as shown in **Figure 2** and although the order of completion is not critical, it is suggested that they are completed in the basic order shown in the figure.

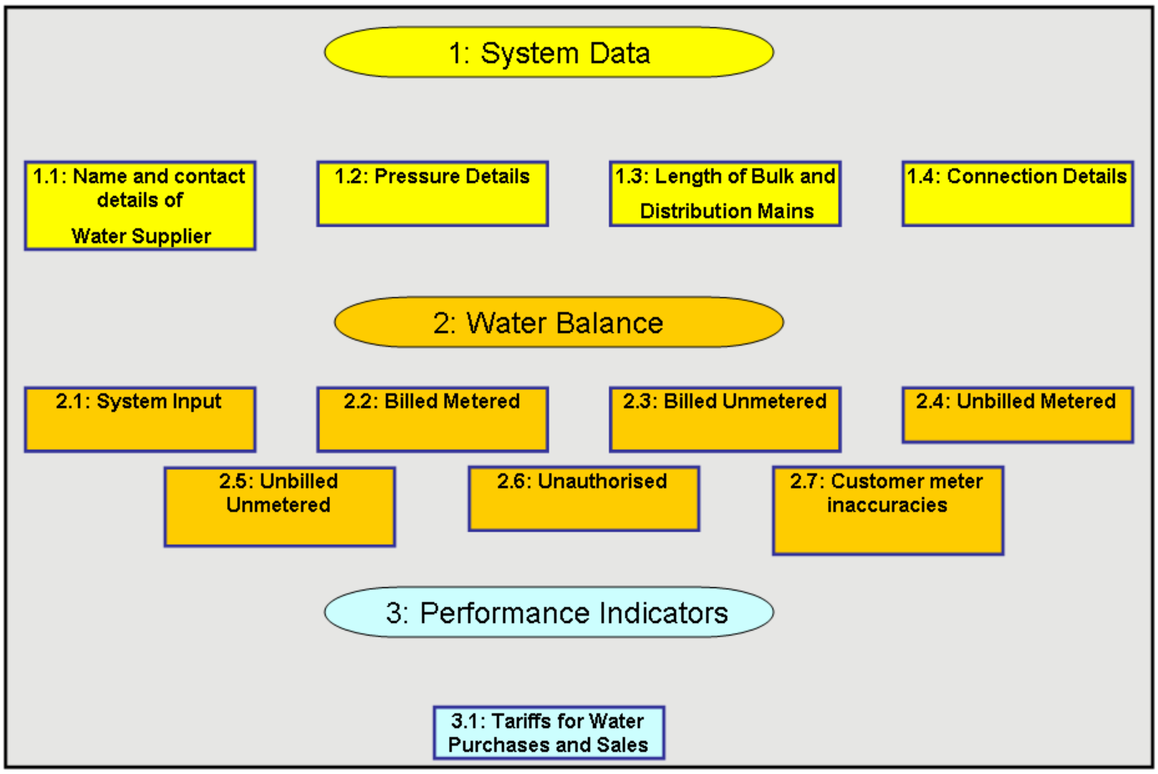


Figure 2: Details of data required for AquaLite

2.4 MAIN FORM

To run the model the user should copy the two files provided into a new directory after which the AquaLite program can be run by simply clicking on the AquaLite.exe icon (as shown in **Figure 3**) in the normal manner.

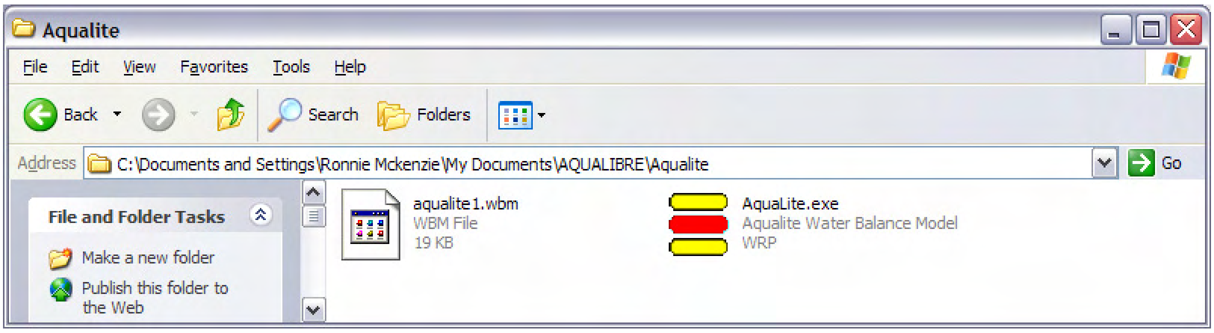


Figure 3: Typical directory structure used for AquaLite

When opening AquaLite the user will see the Main Form as shown in **Figure 4.**

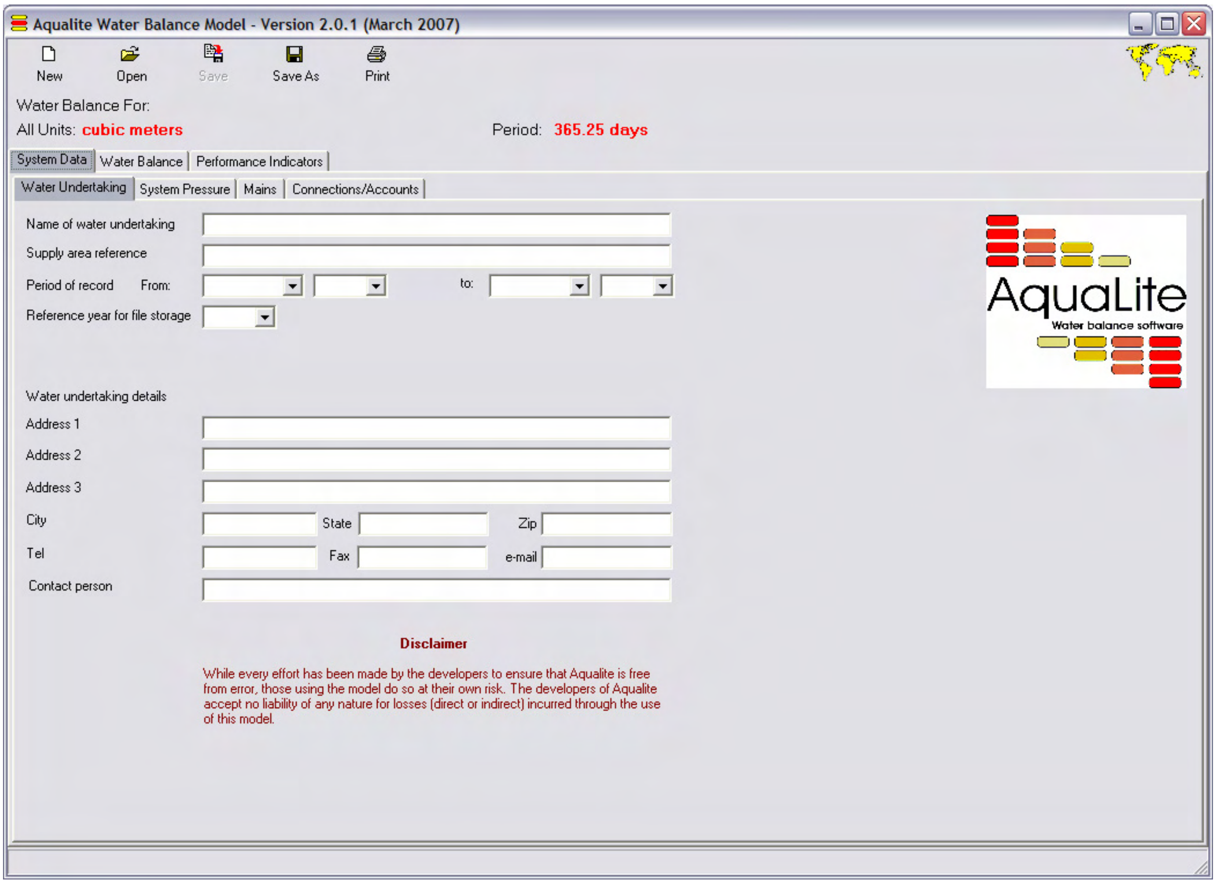


Figure 4: Main form of AquaLite

At the top of the main form there are 5 icons which allow the user to choose from:

- NEW;
- OPEN;
- SAVE;

- SAVE AS;
- PRINT;

The **NEW** icon can be selected at any time by the user to create a new data set for a specific water supply system;

The **OPEN** icon is used to select an existing data file with the "**.wbm**" extension. When the OPEN icon is selected, the user will see a form as shown in **Figure 5** which provides details of all "**.wbm**" files in the currently selected directory. The model is supplied with a sample date set called **AquaLite1.wbm**. It should be noted that all data files used with AquaLite are created with the "**.wbm**" extension for ease of use and storage of data files.

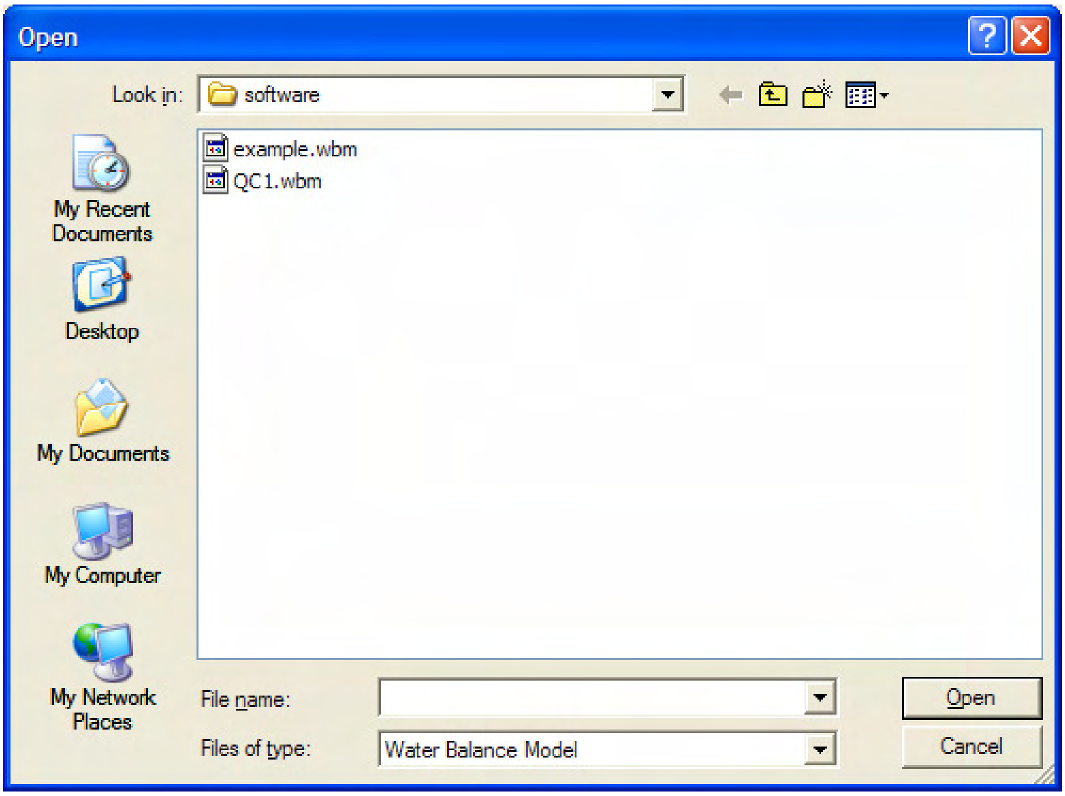


Figure 5: The OPEN screen in AquaLite

The user can browse through his/her directory structure in the normal manner to find the required file. The file is opened by selecting the required file and then selecting the "Open" button located in the lower right hand corner of the form.

The **SAVE** and **SAVE AS** icons are the normal Windows file saving and re-naming features available on all modern computers. While the **SAVE** icon simply updates the current data file with any changes made since the last save, the **SAVE AS** icon opens up a new window as shown in **Figure 6** to allow the user to save the data set as a new file on the computer.

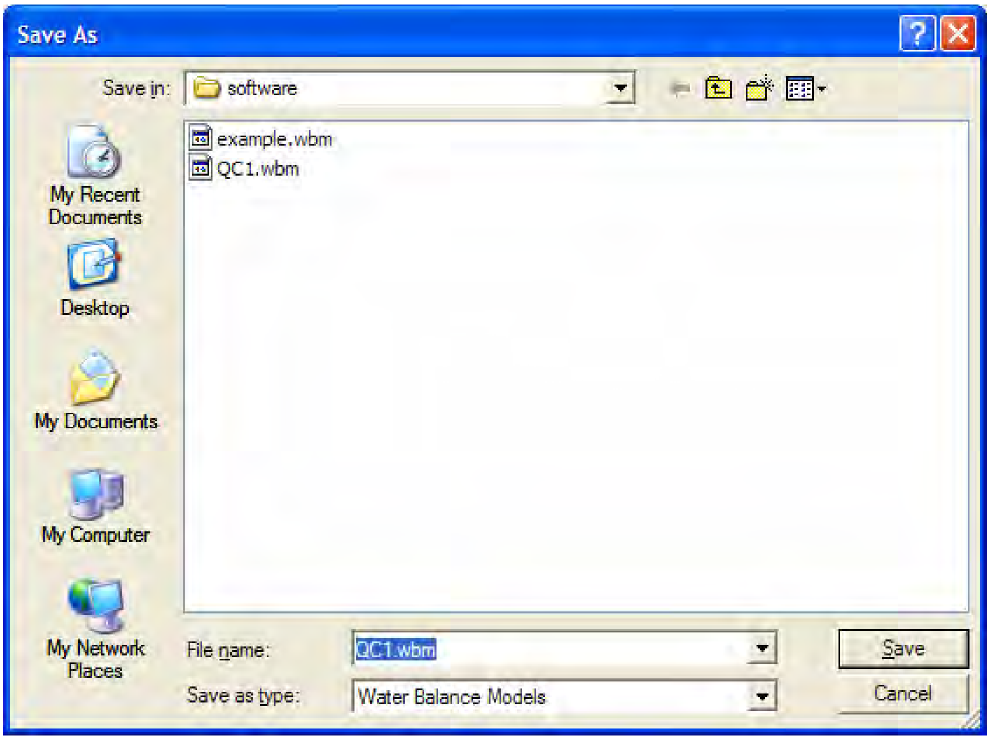


Figure 6: The SAVE AS screen in AquaLite

The **PRINT** icon allows the user to create a report from the model and to print it on any printer available to the computer. The user can select a full detailed report or select specific components of the full report as appropriate. When selecting the **PRINT** icon, the user will see the print selection form as shown in **Figure 7**.

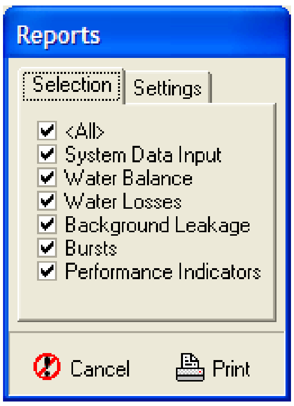


Figure 7: The PRINT form in AquaLite

Having selected the data file to open or having created a new data file, the user is presented with a choice of the five 1st level forms namely:

- **System Data** (input of basic system data)
- **Leakage Parameters** (input of leakage parameters for bottom-up balance)
- **Water Balance** (main top-down water balance)
- **Losses** (bottom up assessment of real losses – optional)
- **Performance Indicators** (key PI's from top-down water balance)

In addition to the various 1st level forms shown on the main form there are several other components which the user may find useful. The small world map highlighted in yellow in the upper right hand corner of the main form provides details of the model version number when the user places the cursor over the map. This is often useful in identifying whether or not the version being used is in fact the latest revision. At the time of writing this user guide, the latest version was **2.0.1 of March 2007**.The model does not incorporate any form of copy protection and can therefore be copied without any problem.

2.5 SYSTEM DATA FORM

The system data form is used to collect the basic system information for the water utility being analyzed. The form has four sub-forms which capture the following:

- **Water Undertaking**
- **System Pressure**
- **Mains**
- **Connections/Accounts**

2.5.1 Water Undertaking

The **Water Undertaking** form is shown in **Figure 8** and basically captures the key information on the water supply system as well as details of the contact person responsible for providing the data and/or completing the form.

The Water Undertaking form also allows the user to select the year for analysis which can be a calendar year or financial year. Based on the year, the model calculates the number of days in the period of analysis which is then displayed in red at the top of the form. It should also be noted that the units used in the analysis are displayed in red at the top left of the form. The units can be changed at any time by clicking on the current units (cubic meters in the example) and then selecting the new units from the drop-down menu which will appear as shown in **Figure 9**.

It should be noted that every new data set is saved together with the units selected by the user for the analysis. Certain default parameters are rounded up or down in some of the unit sets and when the user converts from one set of units to another, the default values may now differ slightly from those shown in the model which are a direct and accurate conversion from the original units to the new units. More details on the units are provided in **Appendix A.**

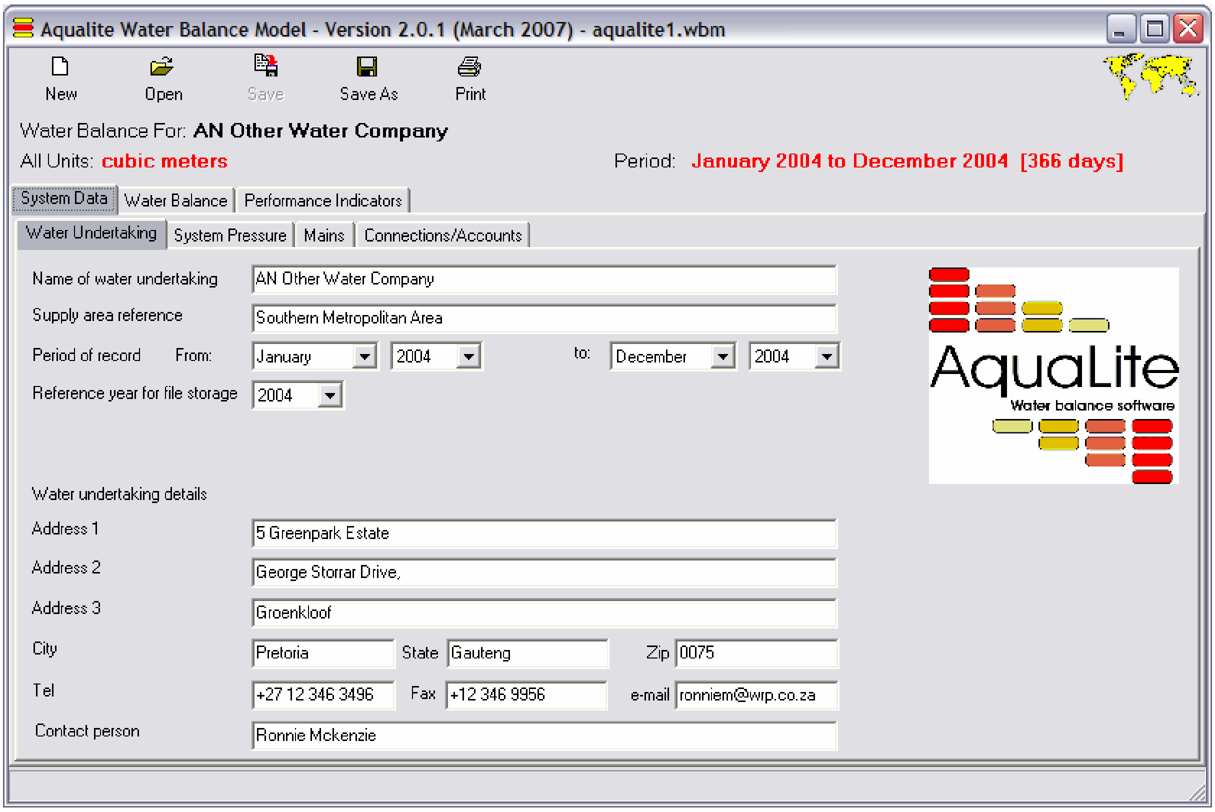


Figure 8: The Water Undertaking form

Figure 9: Available unit sets in AquaLite

2.5.2 System Pressure

System pressure is one of the key parameters in AquaLite model and the user can choose to supply a single value or provide a table of values from which the weighted system pressure will be calculated. An example is shown in **Figure 10**.

It should be noted that the user has the option of differentiating between the pressure of the bulk transmission (or trunk) mains as well as the distribution mains. In many systems, the bulk mains supply water at very high pressures which then feed into concrete storage tanks which in turn supply the distribution system at a lower pressure. The user may select a simple or detailed approach to the pressure form. If a simple approach is to be used, the user may for example use a pressure of 50 m as shown in **Figure 11.**

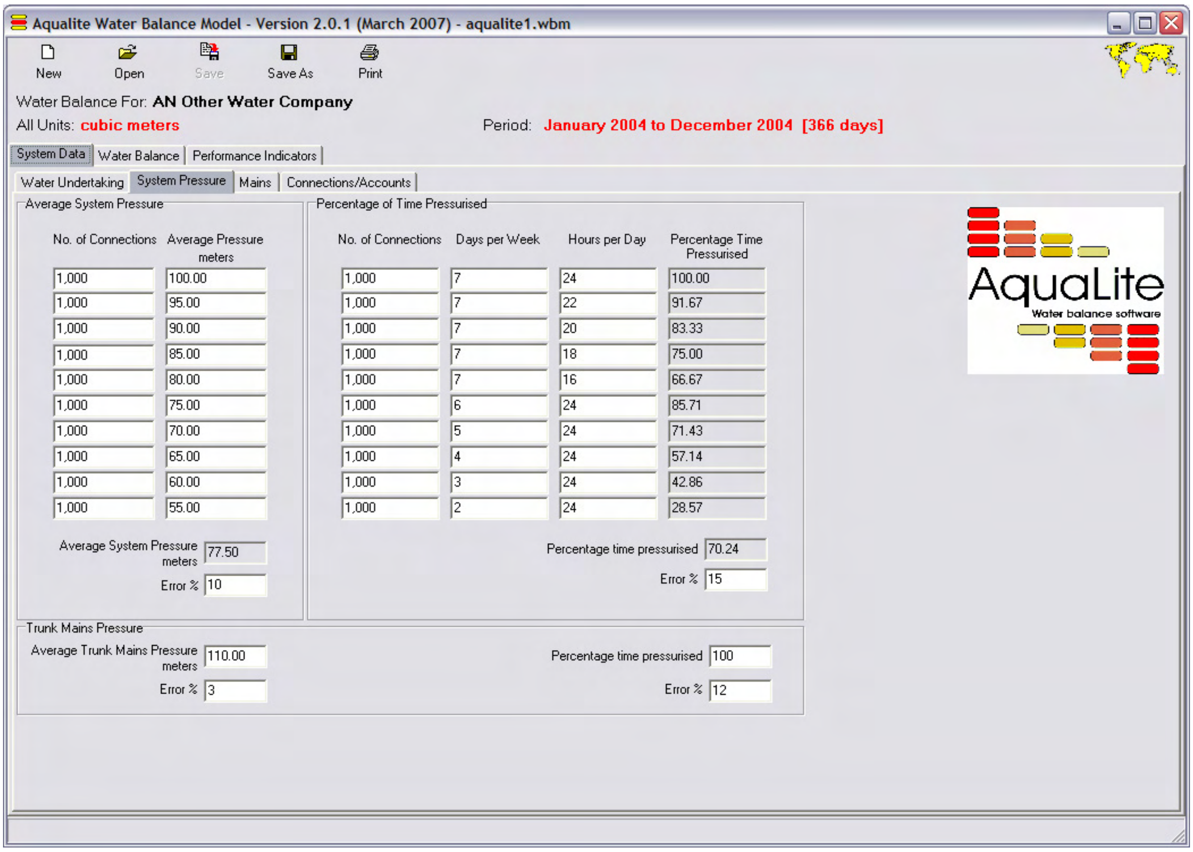


Figure 10: Sample of completed pressure form in AquaLite

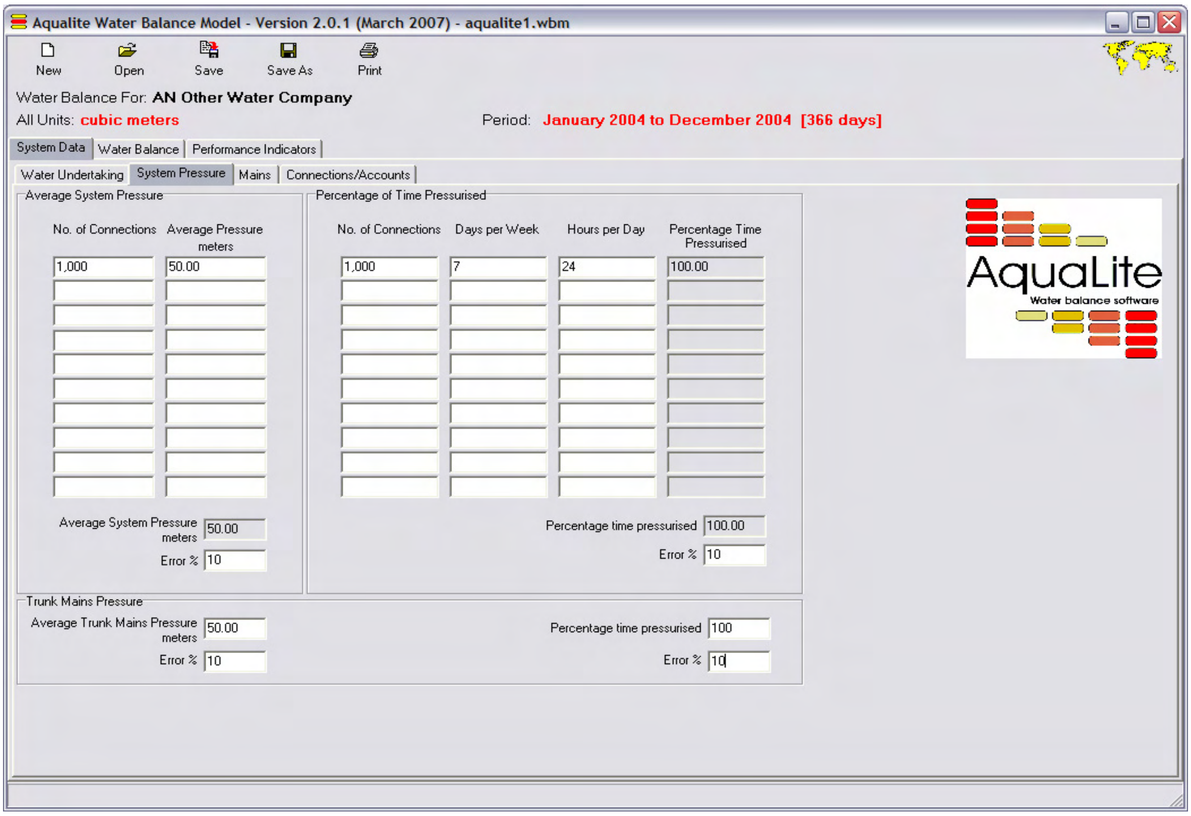


Figure 11: Sample of simple pressure profile in AquaLite

2.5.3 Mains

The mains tab is shown in **Figure 12** and allows the user to supply length of trunk (bulk) mains as well as distribution mains. AquaLite uses the various mains lengths together with the specified pressures to calculate the Unavoidable Annual Real Losses (UARL) which forms part of the PI calculations. The length of mains and associated pressures are also used in the optional bottom-up water balance to calculate the background leakage as well as certain burst leakage calculations.

2.5.4 Connections and Accounts

The connections and accounts form is shown in **Figure 13** and it requires the user to supply information used to estimate the number of connections and accounts in the distribution system as well as the average length of pipe from the property boundary to the water meter. Typical house connections are shown in **Figure 27** and **Figure 28** which show situations where the length of underground pipe is zero (when the meter is at street edge) as is the case in many countries such as South Africa while it is not zero in most parts of the USA. If the meter is at street edge, then the length of underground pipe should be set to zero as shown in the simplified example shown in **Figure 14**.

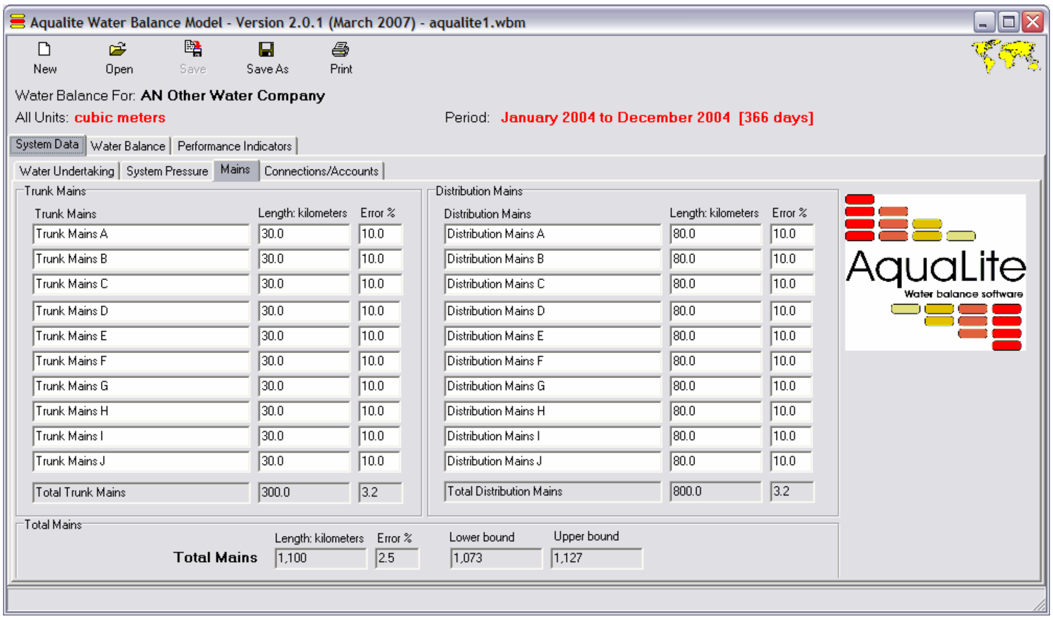


Figure 12: Sample of Mains Form in AquaLite

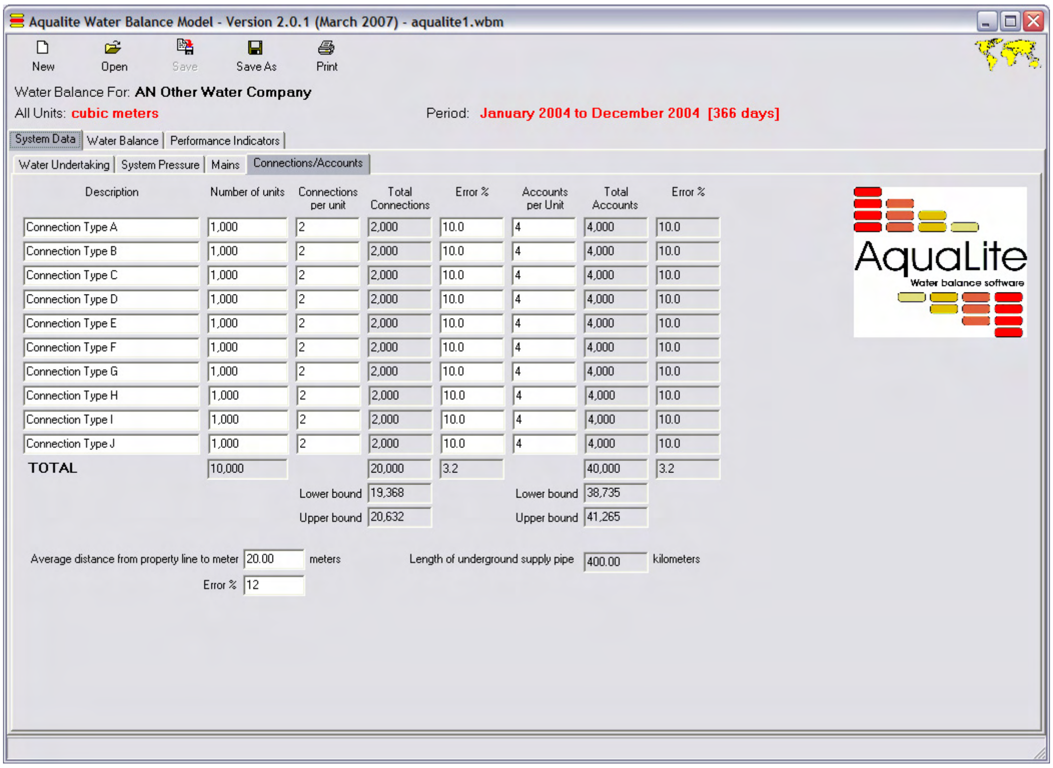


Figure 13: Sample of Connections and Accounts Form in AquaLite

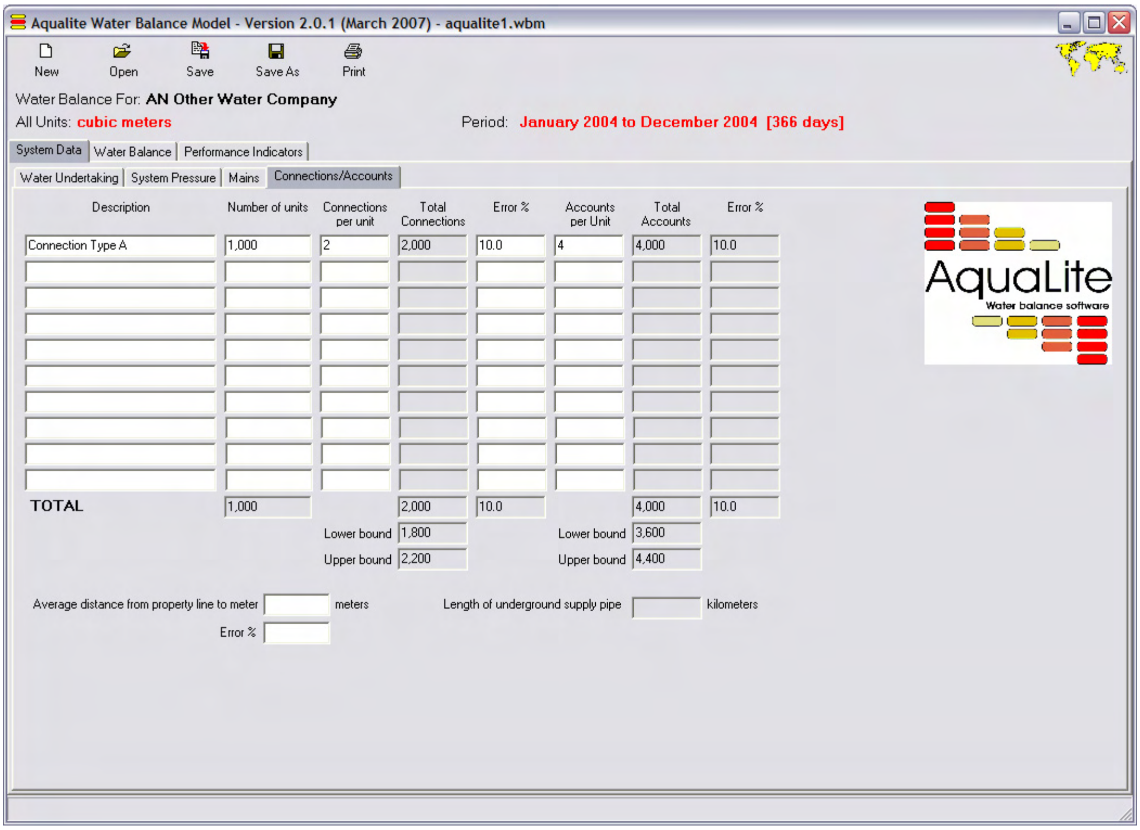


Figure 14: Sample of a simplified Connections and Accounts form

2.6 WATER BALANCE FORM

2.6.1 General

The water balance form is the key form in AquaLite and is the main area of the model where the top-down water balance is undertaken. A typical example in metric units is shown in **Figure 15**. From the figure it can be seen that it follows the IWA structure discussed in **Figure 26** with one slight difference. The Real Losses are shown as a single component and have not been split into the various components as shown in **Figure 26**. The AquaLite model allows the user to investigate the real losses in greater detail than many other models and for this reason the user can select the "Losses" water balance which does provide the breakdown of the real losses into its contributing components.

It should be remembered, that the real losses shown on the main water balance represent the "unknown element" of the water balance and that the user is required to supply data on each other component of the water balance and the resulting element as calculated from the overall balance is the real losses.

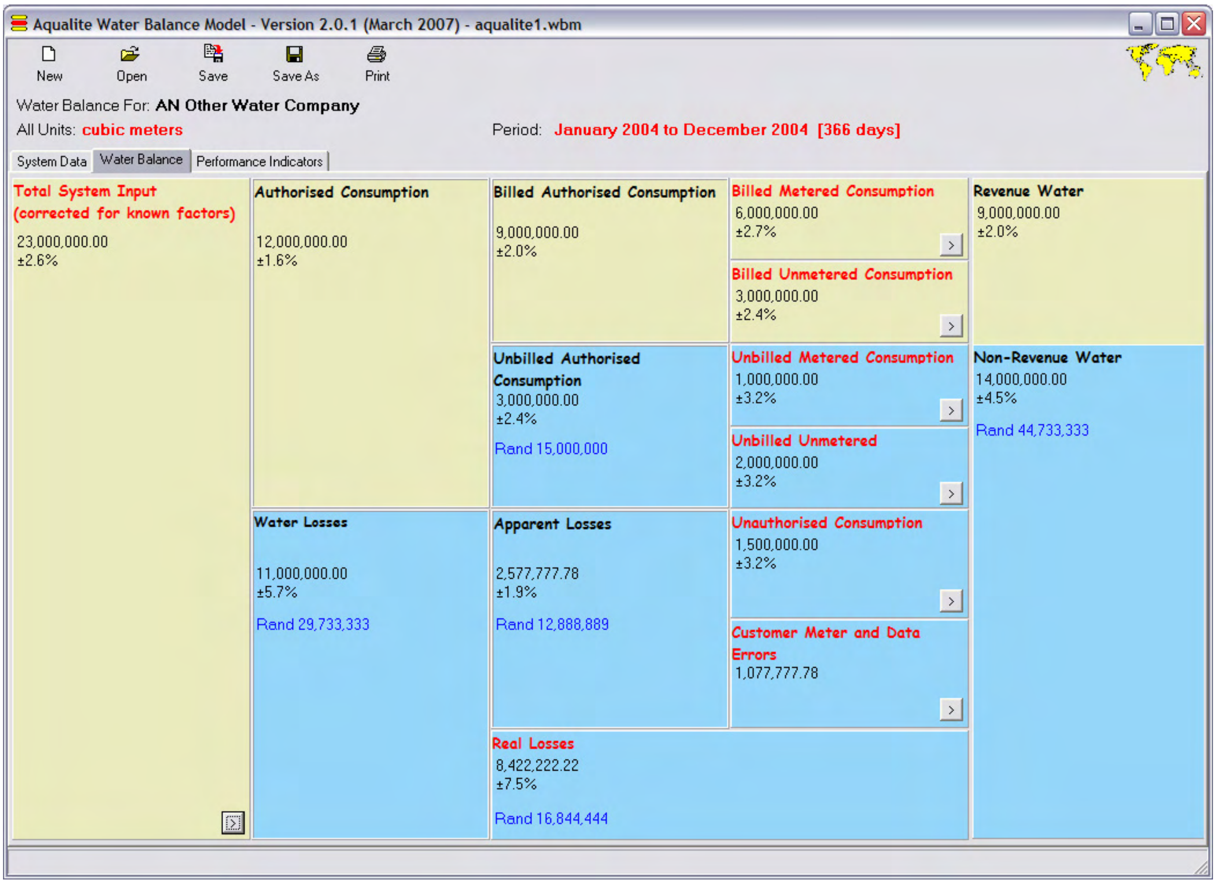


Figure 15: Main water balance form in AquaLite

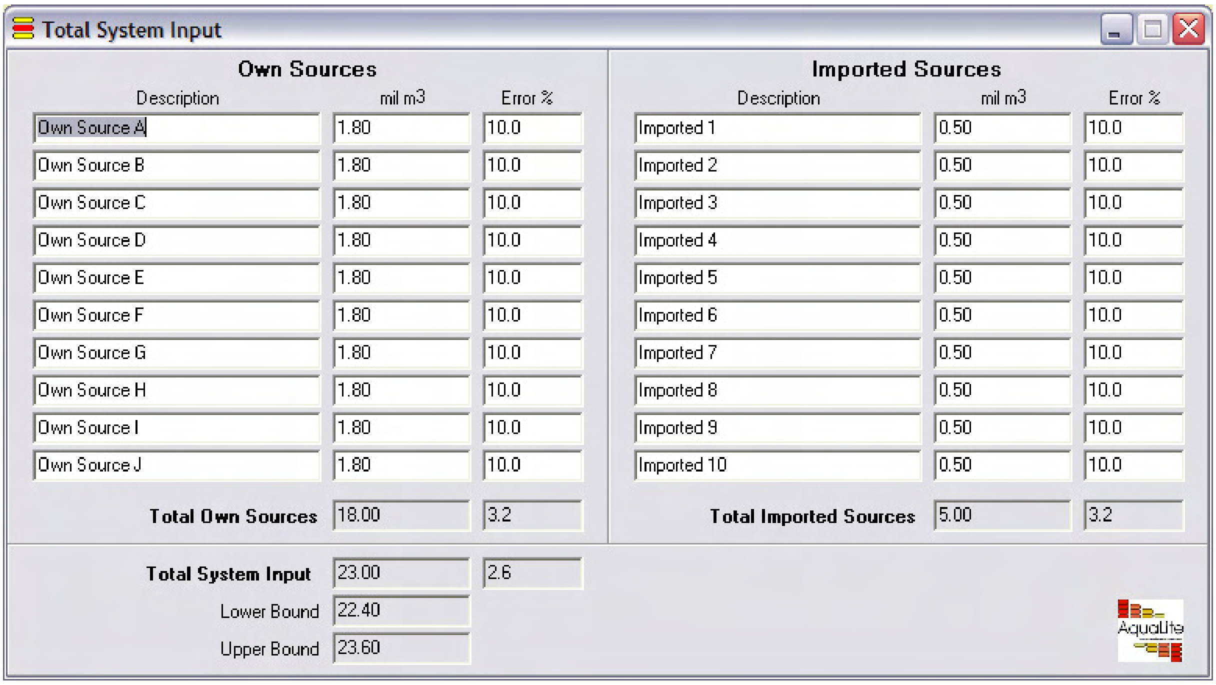
Although the main water balance form appears very simple and straight forward, the user can in fact provide detailed information on most of the other elements included in the overall balance. The following elements require some form of user information/data.

- System Input;
- Billed Metered Consumption;
- Billed Unmetered Consumption;
- Unbilled Metered Consumption;
- Unbilled Unmetered Consumption;
- Unauthorised Consumption;
- Customer Meter Inaccuracies.

All components of the water balance that can accept user information (excluding the real losses) have a small “data button” located at the lower right hand corner of the data block. When the user selects the data button, a new form for each component of the water balance is displayed in which the user can supply the appropriate data. Each component that can accept data is discussed in more detail in the remainder of **Section 3.5**.

2.6.2 Water Input (Adjusted for Known Errors)

This element provides information on the water supplied into the system which is one of the key components of any water balance. The information on the water supplied into the system is captured in the form shown in **Figure 16.**



Total System Input

Own Sources			Imported Sources		
Description	mil m3	Error %	Description	mil m3	Error %
Own Source A	1.80	10.0	Imported 1	0.50	10.0
Own Source B	1.80	10.0	Imported 2	0.50	10.0
Own Source C	1.80	10.0	Imported 3	0.50	10.0
Own Source D	1.80	10.0	Imported 4	0.50	10.0
Own Source E	1.80	10.0	Imported 5	0.50	10.0
Own Source F	1.80	10.0	Imported 6	0.50	10.0
Own Source G	1.80	10.0	Imported 7	0.50	10.0
Own Source H	1.80	10.0	Imported 8	0.50	10.0
Own Source I	1.80	10.0	Imported 9	0.50	10.0
Own Source J	1.80	10.0	Imported 10	0.50	10.0
Total Own Sources	18.00	3.2	**Total Imported Sources**	5.00	3.2

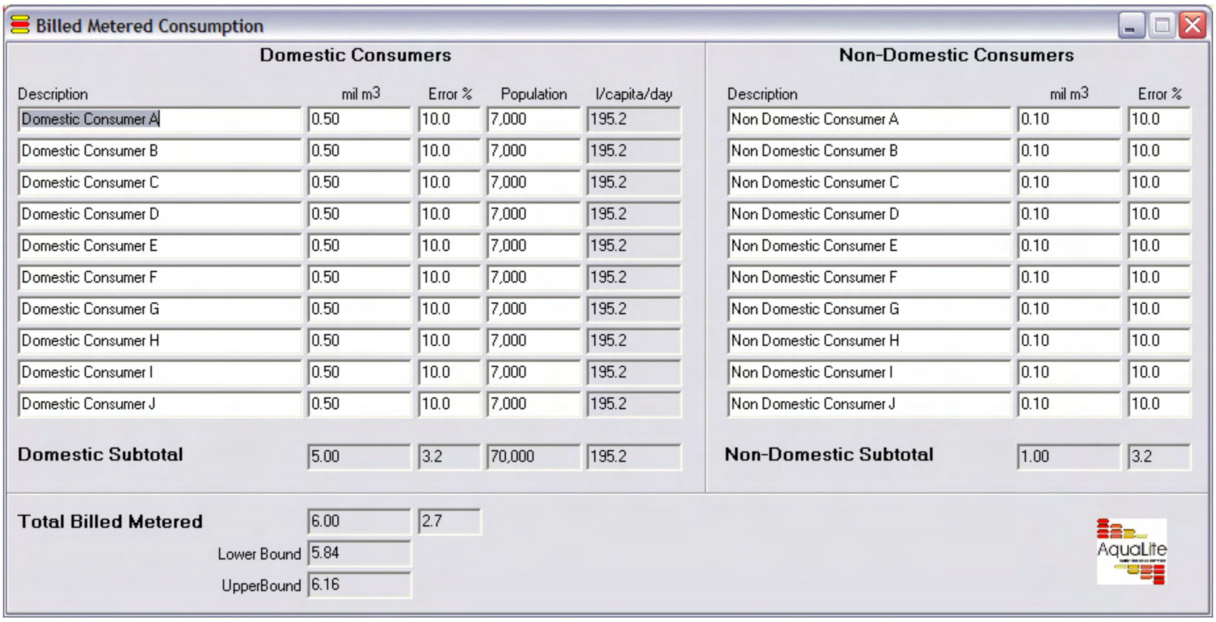
Total System Input	23.00	2.6
Lower Bound	22.40	
Upper Bound	23.60	

Figure 16: Sample of Total System Input form in AquaLite

As can be seen, the user has the option of splitting up the supply into various components if this is appropriate. In many cases, the water supplied into the system will simply involve a single data entry.

2.6.3 Billed Metered Consumption

When clicking on the detail tab for the Billed Metered Consumption on the main water balance, a new form appears in which the user can supply the relevant information for the water that has been billed and metered. The form is shown in **Figure 17** and includes data for domestic consumers and non-domestic consumers.


Billed Metered Consumption

Domestic Consumers

Description	mil m3	Error %	Population	l/capita/day
Domestic Consumer A	0.50	10.0	7,000	195.2
Domestic Consumer B	0.50	10.0	7,000	195.2
Domestic Consumer C	0.50	10.0	7,000	195.2
Domestic Consumer D	0.50	10.0	7,000	195.2
Domestic Consumer E	0.50	10.0	7,000	195.2
Domestic Consumer F	0.50	10.0	7,000	195.2
Domestic Consumer G	0.50	10.0	7,000	195.2
Domestic Consumer H	0.50	10.0	7,000	195.2
Domestic Consumer I	0.50	10.0	7,000	195.2
Domestic Consumer J	0.50	10.0	7,000	195.2
Domestic Subtotal	5.00	3.2	70,000	195.2

Non-Domestic Consumers

Description	mil m3	Error %
Non Domestic Consumer A	0.10	10.0
Non Domestic Consumer B	0.10	10.0
Non Domestic Consumer C	0.10	10.0
Non Domestic Consumer D	0.10	10.0
Non Domestic Consumer E	0.10	10.0
Non Domestic Consumer F	0.10	10.0
Non Domestic Consumer G	0.10	10.0
Non Domestic Consumer H	0.10	10.0
Non Domestic Consumer I	0.10	10.0
Non Domestic Consumer J	0.10	10.0
Non-Domestic Subtotal	1.00	3.2

Total Billed Metered	6.00	2.7
Lower Bound	5.84	
UpperBound	6.16	

AquaLite

Figure 17: Sample of Billed Metered Data form in AquaLite

Once again there are ten rows for each type of consumer although in most cases one or two rows will normally suffice. It should also be noted that under the domestic metered consumption, the user can also supply the population supplied. The population figures have no influence on the overall water balance and are used solely to provide information on the per-capita consumption which is a useful indicator when judging if the data supplied are realistic.

2.6.4 Billed Unmetered Consumption

When clicking on the detail tab for the Billed Unmetered Consumption on the main water balance, a new form appears in which the user can supply the relevant information for the water that has been billed but was not metered. This is often appropriate in areas where water is charged on a fixed monthly charge and not based on metered consumption. The form is shown in **Figure 18** and is similar to the previous form (Billed Metered) in that it allows for:

- Domestic Consumers
- Non-Domestic Consumers

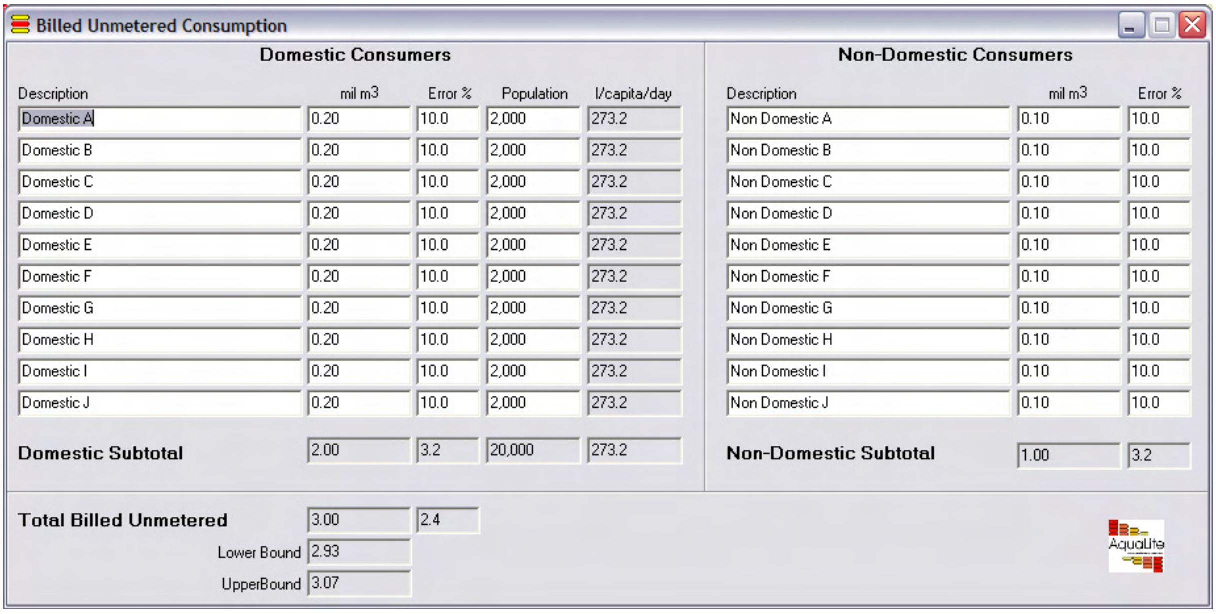


Figure 18: Sample of Billed Unmetered data form in AquaLite

2.6.5 Unbilled Metered Consumption

The Unbilled Metered form is shown in **Figure 19** and is self explanatory.

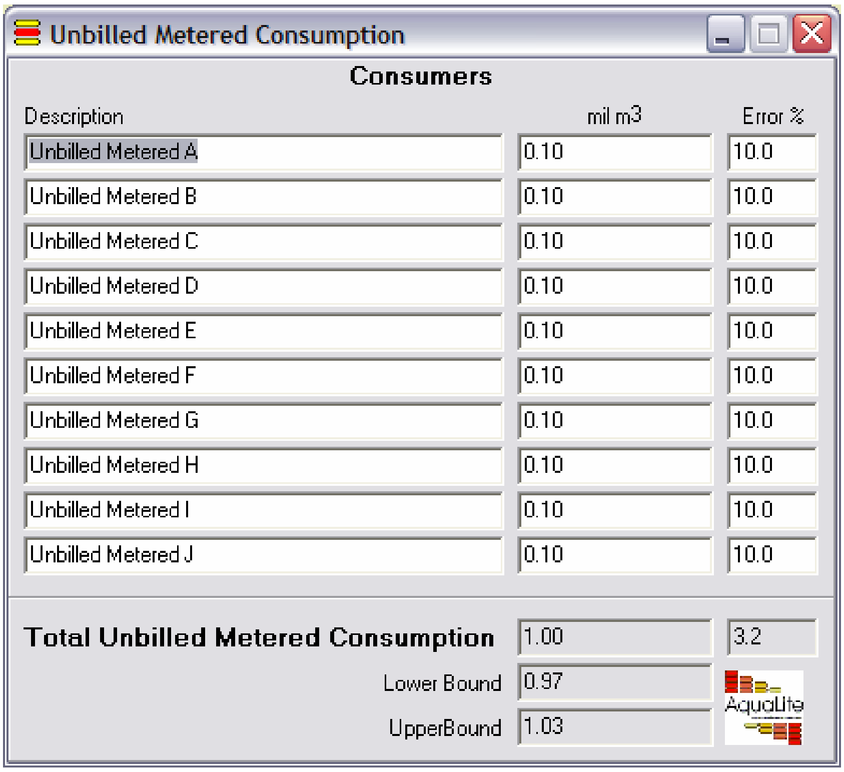
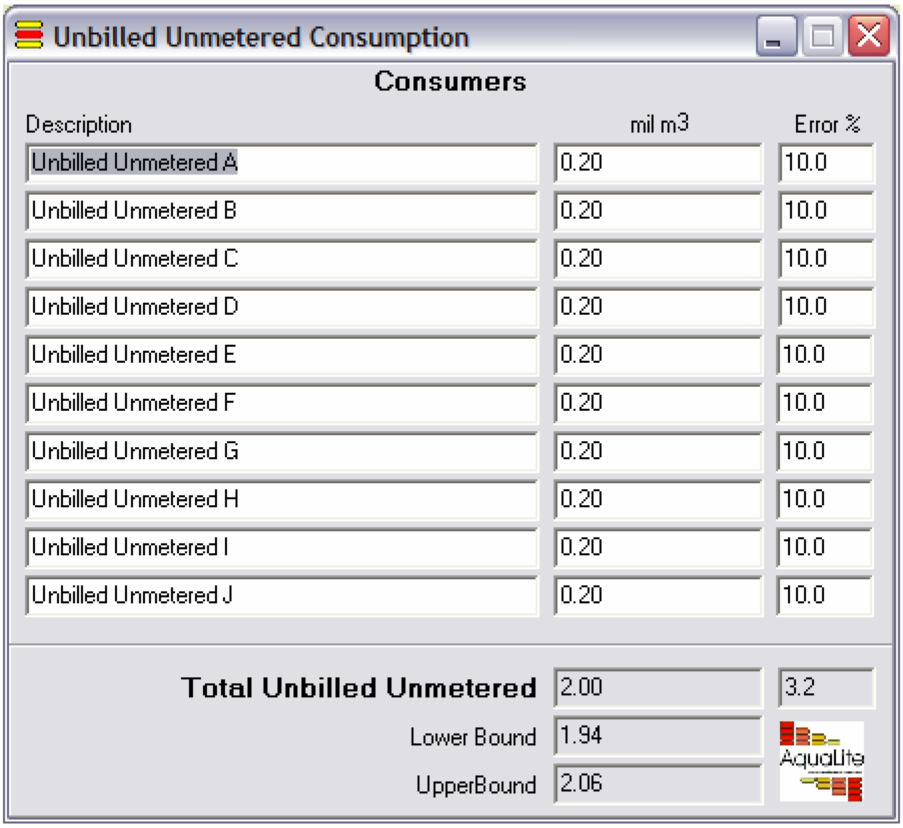


Figure 19: Sample of Unbilled Metered data form in AquaLite

This form is included to record users such as fire fighting in cases where the water used by the fire department is metered as is the case in some parts of the USA and certain other countries. Other similar users may include water used in parks and public gardens where the water is measured but no bill is sent to the municipality.

2.6.6 Unbilled Unmetered Consumption

The Unbilled Unmetered Consumption form shown in **Figure 20** is basically the form where the water utility estimates the amount of water that is used officially but is neither metered nor billed. Ideally this form of water use should be relatively small and may include such items as mains flushing or even fire fighting in cases where the fire fighting water is not metered.



Unbilled Unmetered Consumption

Consumers

Description	mil m3	Error %
Unbilled Unmetered A	0.20	10.0
Unbilled Unmetered B	0.20	10.0
Unbilled Unmetered C	0.20	10.0
Unbilled Unmetered D	0.20	10.0
Unbilled Unmetered E	0.20	10.0
Unbilled Unmetered F	0.20	10.0
Unbilled Unmetered G	0.20	10.0
Unbilled Unmetered H	0.20	10.0
Unbilled Unmetered I	0.20	10.0
Unbilled Unmetered J	0.20	10.0
Total Unbilled Unmetered	2.00	3.2
Lower Bound	1.94	
UpperBound	2.06	

AquaLite

Figure 20: Sample of Unbilled Unmetered data form in AquaLite

2.6.7 Unauthorised Consumption

In many parts of the world the Unauthorised Consumption will be negligible and the values entered into the form should be small. In other parts of the world, however, theft of water is a major issue and can be a significant portion of the overall water balance. The form used to enter the Unauthorised consumption is shown in **Figure 21.**

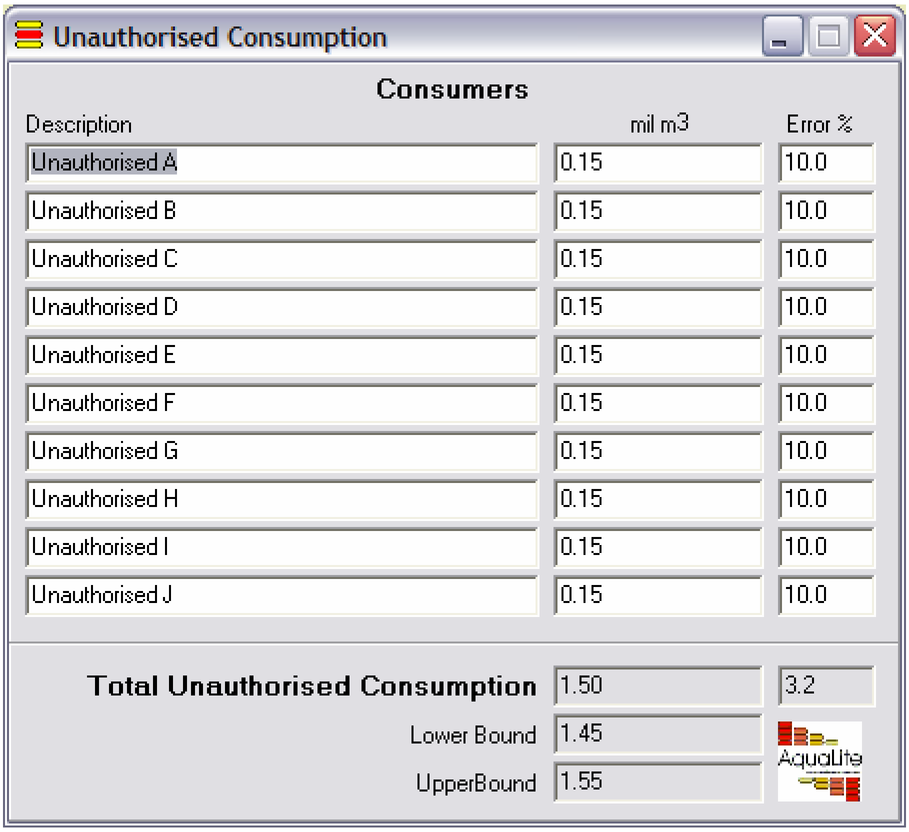


Figure 21: Sample of Unauthorised Consumption data form in AquaLite

2.6.8 Customer Meter Inaccuracies

The Customer Meter Inaccuracies form is shown in **Figure 22** and is slightly different to the previous forms in the respect that the user does not supply a quantity of water in the form but rather the percentage under-registration of the meters. In most water supply systems the customer meters are replaced on a regular basis with the result that they may be relatively accurate and the under0registration may be only a percent or two. In other areas, the meters may be old and known to be inaccurate with the result that the level of under-registration is much higher. The level of under-registration is usually assessed by checking a sample of the meters in the system against newly calibrated meters or by filling a known volume of water and comparing to the metered volume.

Care should be taken not to confuse the % Under registration value provided in the form with the % error which is given in the last column in the form. As is the case with all of the other forms, the % error term is effectively an error term associated with the accuracy of the data and reflects the confidence of the user in the data supplied to the model. In the current example, the user could have undertaken a complete assessment of all domestic meters and derived a value for the % under registration of perhaps 15% which he/she considers to be very reliable. In this case, the % error term could be reduced to 1% or 2% or even zero.

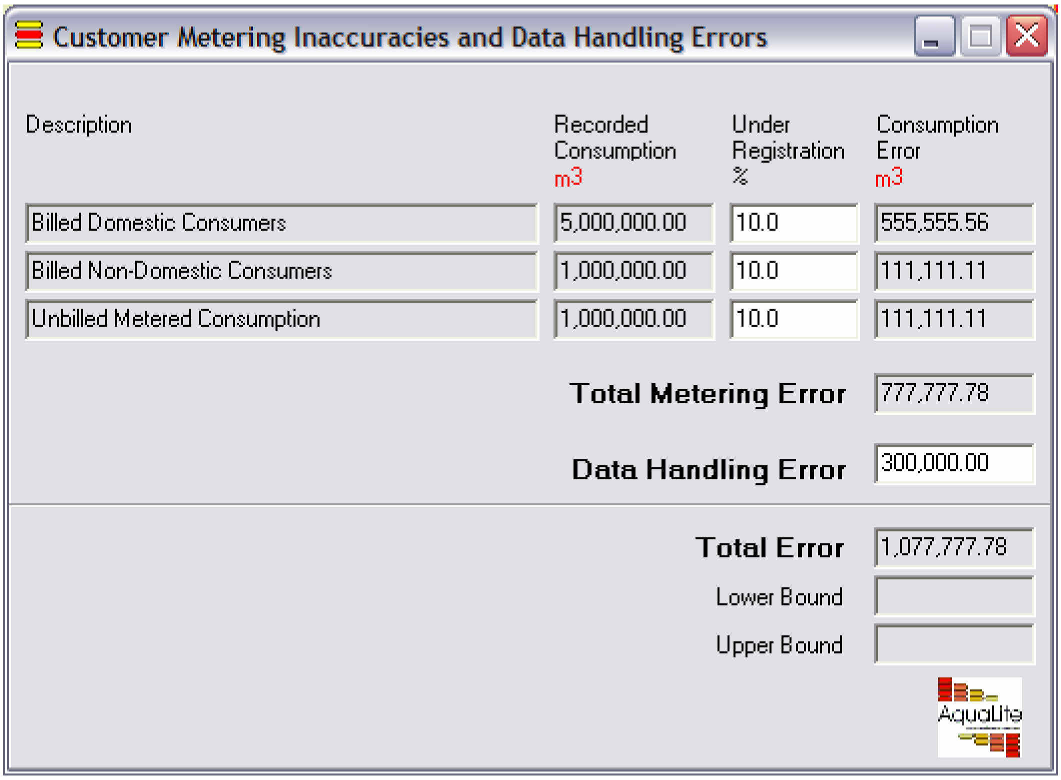


Figure 22: Sample of Customer Meter Inaccuracies data form in AquaLite

2.7 PERFORMANCE INDICATORS FORM

The Performance Indicators Form is the final form in AquaLite model and is shown in **Figure** 23. The form is made up of 4 main sections namely:

- The basic input data used to calculate the Unavoidable Annual Real Losses
- The calculation of the Unavoidable Annual Real Losses
- The cost components for the water
- The Key Performance Indicators.

Each component of the Performance Indicators form is discussed below.

Before discussing the individual Performance Indicators, it is often useful to change the system units and to examine the PI's in US or imperial units for example. Some of the PI's will change while others should remain constant. An example of the same data set where the PI's are calculated in US units is provided in **Figure 24** for comparative purposes. The following PI's should not change when the different units are selected without changing any of the base data:

- Non revenue water as % input by volume
- Infrastructure leakage Index (ILI)

The remaining PI's will change since the output units are based on either gallons or litres with or without the influence of pressure in m or psi. It should be noted that when changing the units from metric to US, the cost factors also change to reflect the different volume units, however, the overall cost for running the system as well as the currency used (i.e. Rands in the example) do not chance since this would require appropriate currency conversions.

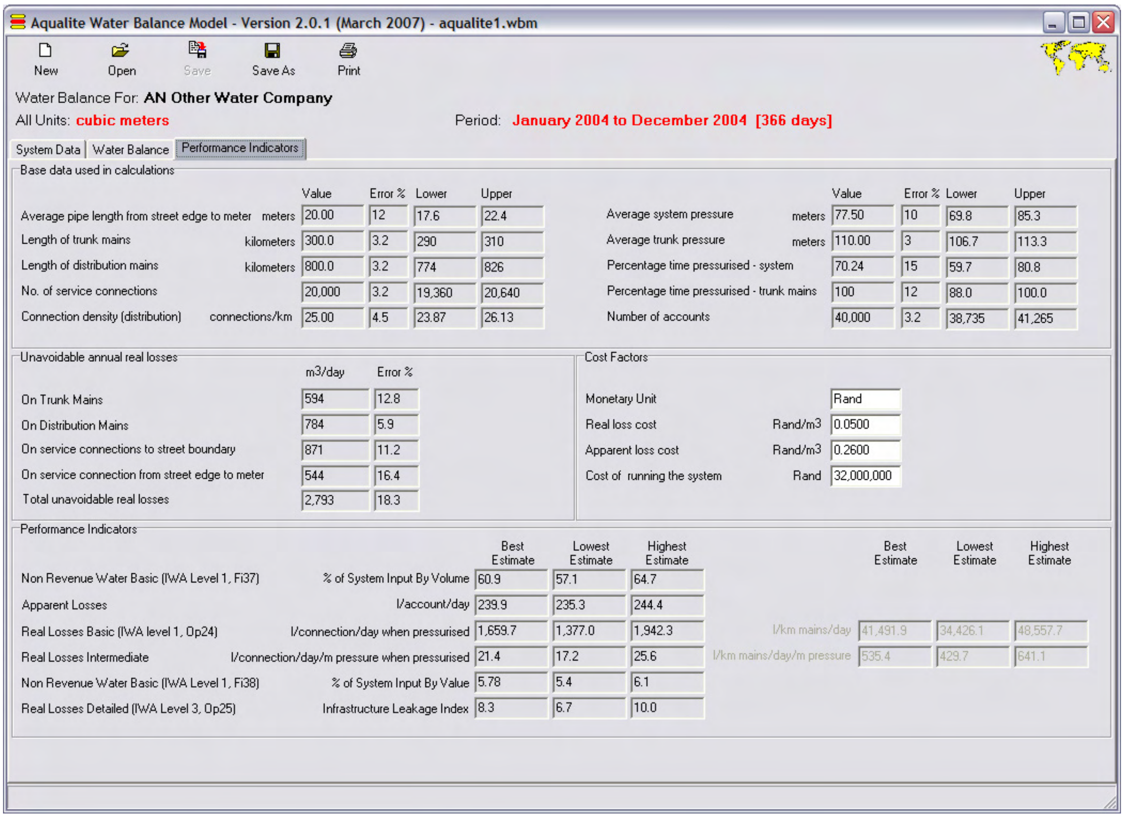


Figure 23: Sample of Performance Indicators form (metric units)

2.7.1 Base Data Used in the Calculations

The base data used in the calculations is carried forward from the main System Data form and no further input is required from the user. The data used in the calculations as shown above includes:

- Average pipe length from street edge to meter;
- Length of trunk mains;
- Length of distribution mains
- Number of service connections;
- Connection density (calculated as a check);
- Average operating pressure of system;
- Average operating pressure of the trunk mains;
- Percentage of time system pressurised;
- Percentage of time trunk mains pressurised;
- Number of accounts.

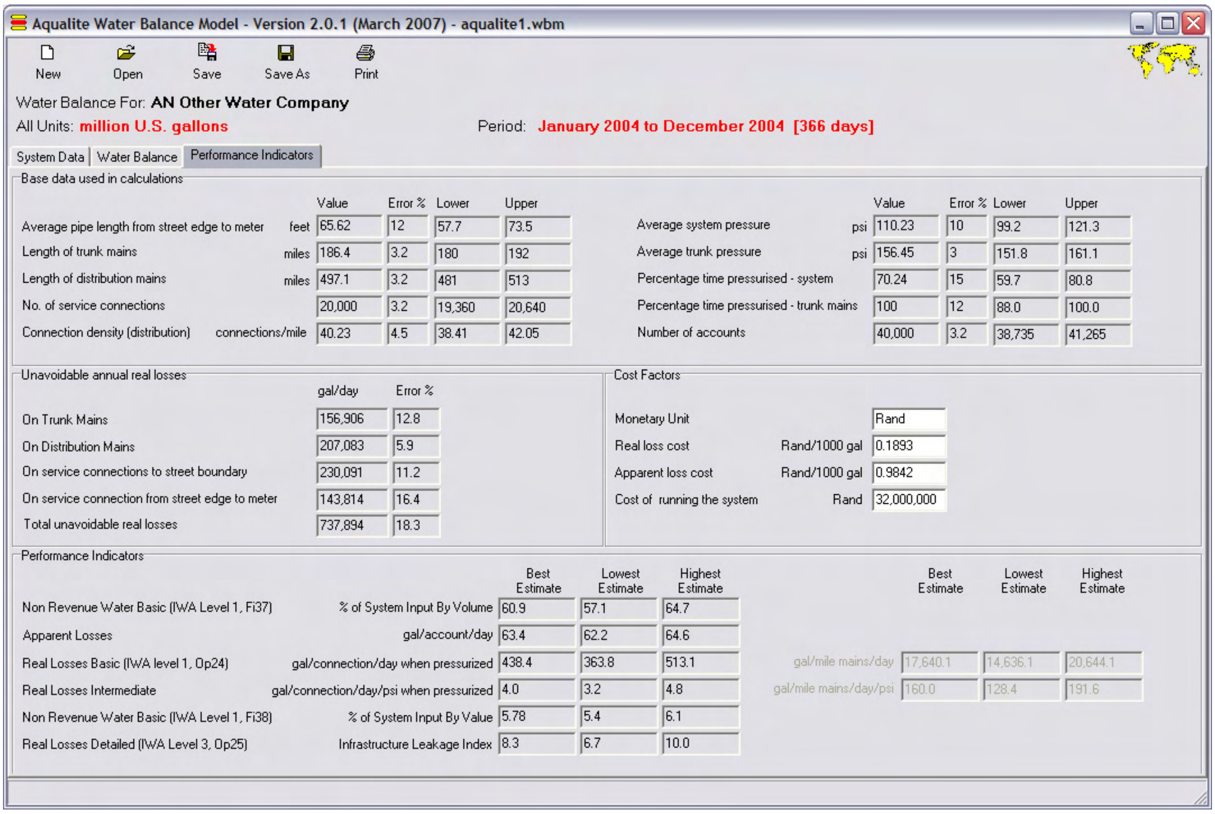


Figure 24: Sample of Performance Indicators form (US units)

2.7.2 Calculation of the UARL

The second block in the PI's form provides details of the calculation of the UARL to enable the user to understand the subsequent ILI calculation. The unavoidable annual real losses are calculated in the manner discussed in **Section 1.5**. The values shown are expressed in gallons per day and are multiplied internally in the model by 365.25 to provide the annual losses. The calculation for the values shown in the example is as follows:

- Average pipe length from street edge to meter of 20 m;
- 300 km of trunk mains;
- 800 km of distribution mains;
- 20 000 service connections;
- 77.5 m average system pressure;
- 110.0 m average trunk mains pressure;
- System pressurised 70.24% of time;
- Trunk mains pressurised 100% of time;
- 40 000 accounts.

UARL: (18 * 300 * 110) + (18 * 800 * 77.5 * 0.7024) + (0.8 * 20 000 * 77.5 * 0.7024) + (25 * 20 000 * 0.020 * 77.5* 0.7024) litres/day

594 + 784 + 871 + 544 m^3/day

2 793 m^3/day

1 022 238 m^3/year (based on 366 days)

140 litres per connection per day when pressurised

It should be noted that some of the figures given in the example above are formatted to many decimal places despite the fact that the overall calculations are relatively course and to use such ‘accuracy’ may seem meaningless. The figures are shown in the same format that they are applied in the model and if the full figures are not used then certain small rounding errors enter the calculation and the user may feel that the model is incorrect.

2.7.3 Cost Components of the Water

In order to evaluate the Non Revenue Water as a percentage of the annual running costs for the system it is necessary for the user to provide the following:

- Cost of real losses
- Cost of apparent losses
- Annual cost of running the system.

The cost of the real losses is effectively the purchase cost of water to the water utility which will normally be relatively low unless the utility is buying the water from another water supplier. In most cases it will be the cost of abstraction plus the purification costs as well as any costs associated with conveying the water to the bulk mains (e.g. pumping costs etc). Reducing the real losses (i.e. physical leakage) will reduce the water that the utility has to produce and will not necessarily result in increased sales unless the system is experiencing a demand for water that is greater than it has the capacity to supply.

The cost associated with the apparent losses represents the average selling price of water by the utility since apparent losses are in fact used by consumers and if the utility can reduce the apparent losses it will increase the water sold in most cases. For this reason the cost associated with the apparent losses is generally significantly higher than the costs associated with the real losses.

The cost of running the system represents all costs (running, financial and personnel) associated with running the water utility for a year. In cases where the utility also deals with sewage, only the staff and costs associated with the water supply component of the business should be considered.

In the example the following costs have been used:

- Cost of real losses = R0.05/m^3
- Cost of apparent losses = R0.26/m^3
- Cost of running the system per year = R32 million.

2.7.4 Key Performance Indicators

The AquaLite model provides 6 key performance indicators namely:

- Non revenue water as a % of the system input by volume
- Non revenue water as a % of the running costs
- Apparent losses in litres/account/day
- Real losses in litres/connection/day when pressurised
- Real losses in litres/connection/day/m of pressure when pressurised
- Infrastructure Leakage Index.

Non revenue water as % of system input: Although it was stated previously that percentages should not be used to evaluate the level of real losses and non revenue water it remains an indicator that all water utilities will wish to see. It is also retained as a 'financial performance indicator' by the IWA and for this reason it is included as one of the 6 performance indicators used in AquaLite. In the example provided the performance indicator is calculated in the following manner:

NRW as % of system input volume
= 14 000 000 / 23 000 000 *100
= 60.9%

Apparent losses in litres/account/day when pressurised: This is a relatively new indicator for assessing apparent losses and uses the number of accounts as opposed to the number of connections. It is calculated for the sample data set in the following manner

Apparent losses in litres/account/day when pressurised
= 2 466 666.67 / 40 000 / 366 / 0.7024
= 239.9 litres/account/day

Non revenue water as % of running costs: This is a more useful form of using percentages in the evaluation of non revenue water and is calculated by multiplying the real losses by the real loss cost and adding to the apparent losses multiplied by the apparent loss cost. In addition the additional unbilled water is multiplied by the apparent loss cost to give the total cost of the non revenue water.

NRW as % of system input volume
= 1 786 533 / 32 000 000 *100
= 5.78%

Real losses in m^3 per connection per day: This is the preferred performance indicator for real losses and is simply the real losses divided by the number of connections and expressed as a loss per day. It is calculated in the following manner:

Real losses in litres per connection per day when pressurised
= 8 533 333.33 / 20 000 / 0.7024/ 366
= 1 659.7 litres/conn/day when pressurised

Real losses per connection per psi per day: This is simply a variation of the previous indicator which has been modified to take the system pressure into account. In the example it is calculated in the following manner:

Real losses in litres per connection per day per m pressure when pressurised
= 8 533 333.33 / 20 000 / 0.7024/ 366 / 77.5
= 21.4 litres/conn/day/m when pressurised

Infrastructure Leakage Index: This is the final and most recent addition to the various performance indicators used in the AquaLite model. The ILI is calculated as discussed in **Section 2.6** and in the example provided it is calculated in the following manner:

ILI = Real Losses/UARL
= (8 533 333.33 / 366) / 2 793
= 8.35

It should be noted that the PI for real losses in litres per connection per day is used for most systems where the density of connections is 20 connections per Km of mains or greater. If the density of connections drops to below 20 per km of mains, then the alternative PI is used based on the leakage in m^3 per km mains per day. The reasoning behind this approach is that for most systems in urban areas, the main issue driving the leakage is the number of service connections. In rural systems, however, the number of service connections may be low compared to the length of mains in which case the mains leakage may be dominant. In such cases a PI based on the length of mains is more appropriate.

3 REFERENCES

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

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

Fortunately a second set of 10 manuals titled “Managing and Reducing Losses from Water Distribution Systems” has recently (2005) been produced by the Environment Protection Agency in Queensland, Australia in association with Wide Bay Water. Each manual focuses on a key area of water loss management either through real, physical losses or apparent, ‘paper’ losses. In addition to a comprehensive presentation of theory, the manuals include detailed case studies and implementation action plans. Topics include water audits, pressure management, real loss management, managing apparent losses, sectorisation and the economics of water loss management. These manuals clearly supersede the UK “Managing Leakage” reports and are an essential addition to any Water Utility library.

Details of the South African Models as well as various other reports and books on the subject of Water Demand Management are provided in **Table 1**.

Table 1: Some useful WDM references

Authors	Title	Publisher	Reference
Alegre, H., Hirner, W., Baptista, J. and Parena, R, 2000	Performance Indicators for Water Supply Services	IWA Publishing 'Manuals of Best Practice' Series, 2000	ISBN 1-900222- 272
American Water Works Association	Manual of Water Supply Practices: Water Audits and Leak Detection: AWWA M36	Available from the AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235, USA.	ISBN 1-58321-018-0
Farley, M & Trou, S, April 2003	Losses in Water Distribution Networks – A Practitioner's Guide to Assessment, Monitoring and Control	IWA Publications, Portland Customer Services. sales@portland-services.com	ISBN 1-900222-116
Lambert A., Brown T.G., Takizawa M., Weimer D, 1999	A Review of Performance Indicators for Real Losses from Water Supply Systems	AQUA, Dec 1999	ISSN 0003-7214
May, J, 1994	Pressure Dependent Leakage	World Water and Environmental Engineering	
Mckenzie, R.S., 1999. .	Development of a standardised approach to evaluate burst and background losses in potable water distribution systems: SANFLOW User Guide	South African Water Research Commission, Available from the internet on www.wrc.org.za.	Report TT 109/99, ISBN 1-86845-490-8.
Mckenzie, R.S., 1999. .	Development of a standardised approach to evaluate burst and background losses in potable water distribution systems: SANFLOW User Guide	South African Water Research Commission, Available from the internet on www.wrc.org.za.	Report TT 109/99, ISBN 1-86845-490-8.
Mckenzie, R.S., 2001	Development of a pragmatic approach to evaluate the potential savings from pressure management in potable water distribution systems - PRESMAC User Guide.	South African Water Research Commission, Report Number Available from the internet on www.wrc.org.za.	TT 152/01 ISBN 1-86845-772-2.
Mckenzie, R.S., and Lambert A.O., 2001.	Development of a simple and pragmatic approach to benchmark real losses in potable water distribution systems - BENCHLEAK User Guide.	South African Water Research Commission, Report Number Available from the internet on www.wrc.org.za.	TT 159/01 ISBN 1-86845-773-7
Mckenzie, R.S., Meyer, N and Lambert A.O., 2002.	Calculating Hour-Day factors in Potable Water Distribution Systems - HDF User Guide.	South African Water Research Commission, Report Number Available from the internet on www.wrc.org.za.	TT 184/02 ISBN 1-86845-879-2
Mckenzie, RS, 2001	Greater Johannesburg Metropolitan Council Water Conservation and Demand Management Strategy	UN Habitat in association with Greater Johannesburg Metropolitan Council	
Mckenzie, RS, Wegelin, W and Meyer, N. 2002	Leakage Reduction Projects Undertaken by Rand Water	Rand Water in association with UN Habitat	ISBN 0-620-29503-1
National Water Council Standing Technical Committee,1980	Report No. 26, Technical Working Group on Waste of Water. Leakage Control Policy and Practice.	UK Water Industry	ISBN 0 904561 95 X
Office of Water Services (UK), 1998	1997/98 Report on leakage and water efficiency	OFWAT	ISBN 1 874234 42 6
Queensland Environmental Protection Agency & Wide Bay Water, 2001	Managing and reducing losses from Water Distribution Systems : Manual 1 - Introduction	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9491 0
Queensland Environmental Protection Agency & Wide Bay Water, 2002	Managing and reducing losses from Water Distribution Systems : Manual 2 – Water Audits	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9492 9
Queensland Environmental Protection Agency &	Managing and reducing losses from Water Distribution Systems : Manual 3 – The Economics of Water Loss	Queensland Environmental Protection Agency & Wide Bay Water. Further details and	ISBN 0 7242 9495 3

Authors	Title	Publisher	Reference
Wide Bay Water	Management	costs from: DavidW@herveybay.qld.gov.au	
Queensland Environmental Protection Agency & Wide Bay Water, 2002	Managing and reducing losses from Water Distribution Systems : Manual 4 – Establishing Pressure Management Zones and District Metered Areas: The Toolkit	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9493 7
Queensland Environmental Protection Agency & Wide Bay Water	Managing and reducing losses from Water Distribution Systems : Manual 5 – Advanced Pressure Management and PRV Selection	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9496 1
Queensland Environmental Protection Agency & Wide Bay Water, 2003	Managing and reducing losses from Water Distribution Systems : Manual 6 – Real Loss Management	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9494 5
Queensland Environmental Protection Agency & Wide Bay Water	Managing and reducing losses from Water Distribution Systems : Manual 7 – Managing Apparent Losses	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9499 6
Queensland Environmental Protection Agency & Wide Bay Water, 2003	Managing and reducing losses from Water Distribution Systems : Manual 8 – Case Studies in Water Loss Management	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9490 2
Queensland Environmental Protection Agency & Wide Bay Water	Managing and reducing losses from Water Distribution Systems : Manual 9 – Rural Water Loss Management	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9497 X
Queensland Environmental Protection Agency & Wide Bay Water	Managing and reducing losses from Water Distribution Systems : Manual 10 – Executive Summary	Queensland Environmental Protection Agency & Wide Bay Water. Further details and costs from: DavidW@herveybay.qld.gov.au	ISBN 0 7242 9498 8
Thornton, J, 2002	Water loss Control Manual	McGraw Hill or through the American Water Works Association. www.awwa.org.	ISBN 0 07 137434 5
UK Water Industry, 1994.	Managing Leakage, Report A: Summary Report	UK Water Industry	ISBN: 1 898920 06 0
UK Water Industry, 1994.	Managing Leakage, Report B: Reporting Comparative Leakage Performance	UK Water Industry	ISBN: 1 898920 07 9
UK Water Industry, 1994.	Managing Leakage, Report C: Setting Economic Leakage Targets	UK Water Industry	ISBN: 1 898920 08 7
UK Water Industry, 1994.	Managing Leakage, Report D: Estimating Unmeasured Water Delivered	UK Water Industry	ISBN: 1 898920 09 5
UK Water Industry, 1994.	Managing Leakage, Report E: Interpreting Measured Night Flows	UK Water Industry	ISBN: 1 898920 10 9
UK Water Industry, 1994.	Managing Leakage, Report F: Using Night Flow Data	UK Water Industry	ISBN: 1 898920 11 7
UK Water Industry, 1994.	Managing Leakage, Report G: Managing Water Pressure	UK Water Industry	ISBN: 1 898920 12 5
UK Water Industry, 1994.	Managing Leakage, Report H: Dealing with Customer's Leakage	UK Water Industry	ISBN: 1 898920 13 3
UK Water Industry, 1994.	Managing Leakage, Report J: Leakage management Techniques, Technology and Training	UK Water Industry	ISBN: 1 898920 14 1
Wegelin, W and Mckenzie, R.S.,	Leakage Reduction through Pressure Management in South Africa: Concepts	South African Water Research Commission, Report Number Available from the internet on	TT 186/02 ISBN 1-86845-878-2

Authors	Title	Publisher	Reference
2002.	and Case Studies.	www.wrc.org.za.	
Vickers, A	Handbook of Water Use and Conservation	Available from WaterPlow Press, PO Box 2475, Amherst, MA 01004-2475, USA. www.waterplowpress.com	ISBN 1-931579-07-5

APPENDIX A

BACKGROUND TO THE BURST AND BACKGROUND ESTIMATE METHODOLOGY

APPENDIX A: BACKGROUND TO BABE METHODOLOGY

A.1. OVERVIEW

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 larger detectable events are referred to as bursts (breaks in the USA), while those too small to be located (if not visible) are referred to as background leaks. The threshold between bursts and background leaks can vary from country to country, depending upon factors such as minimum depth of pipes, type of ground and surface, etc. In the UK a threshold limit of 500 litres/hour (approximately 132 US gallons/hr) was used in the 1994 Managing Leakage Reports, but advances in leak location technology and various other factors suggest that a figure of around 250 litres/hour (68 US gallons per hour) is more appropriate in most countries. In other words:

Events	**>**	**250 litres/hour (68 US gallons/hour)**	**=**	**Bursts**

Events	**<**	**250 litres/hour (68 US gallons/hour)**	**=**	**Background Leaks**

In all water supply systems there are likely to be both burst and background leaks since it is not possible to develop a system completely free from leakage. The aim is to identify the key components of leakage to ensure that the correct leakage reduction interventions can be selected.

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, 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. These reports have formed the basis for most leakage management in potable water distribution systems over the past 10 years and have only recently been superseded by the recently published Australian reports. The new reports from Australia represent a major step forward in the battle to reduce leakage and are an essential addition to any water utility library or WDM specialist wishing to remain abreast of the latest leakage reduction technology.

In 1999 and 2000, the IWA Task Forces on Water Losses, and Performance Indicators, published their conclusions based on over three years research, analyses and discussions. Non-Revenue Water, Water Losses, Apparent Losses and Real Losses were considered in some detail and it was recommended that:

- A standard terminology should be developed for international use, with clear and concise definitions and procedures for assessing the various components of the Annual Water Balance.

- Selected performance indicators should be used for the various components of the water balance including the new Infrastructure Leakage Index (ILI).

The work of the IWA in this regard is discussed in detail by Lambert et. al.(1999) and represents a major step forward in defining the "best practice" approach to assessing and presenting components of Non-Revenue Water, for more rational comparisons of performance in diverse systems within a single organization, within the same country, and between countries.

The Burst and Background Estimate (BABE) concepts involve a very straightforward and pragmatic approach to the complex problem of quantifying and controlling leakage in water reticulation networks. While the key concepts are in themselves relatively simple, they can be combined in various ways to develop sophisticated and powerful tools that can greatly assist water utilities in understanding and managing their leakage. In the development of the

BABE techniques, it was accepted that four principle issues concerning leakage should be addressed by water utilities as shown in **Figure 25**.

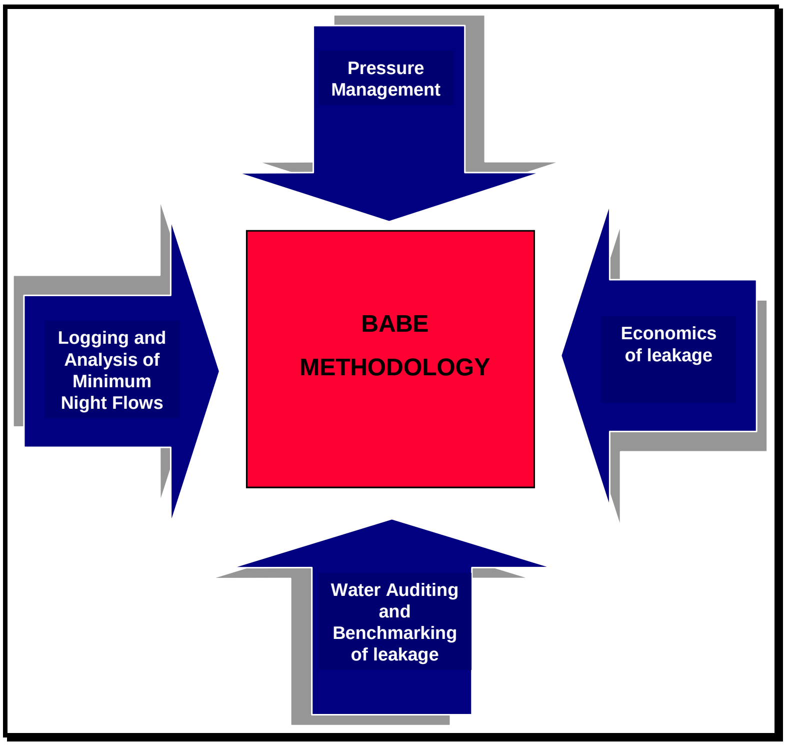


Figure 25: Main components of BABE procedures

As can be seen in **Figure 25** the four key elements of BABE are:

- Logging and analysis of minimum night flows;
- Water auditing and benchmarking of leakage;
- Economics of leakage;
- Pressure management.

In addition to the BABE concepts, several new concepts have also been developed which further strengthen the overall methodology and these include:

- FAVAD: The Fixed Area Variable Area Discharge Theory
- UARL: The concept of Unavoidable Annual Real Losses in a system
- ILI: The infrastructure Leakage Index.

A.2. STANDARD TERMINOLOGY

One of the main problems when assessing water losses in a water distribution system concerns the lack of a standard terminology for expressing leakage. Many water utilities have their own terminology which may or may not agree with that used by other utilities. Before developing a standard water auditing procedure, it is therefore essential to develop and use the same standard terminology. In this regard, AquaLite is based on the standard terminology used by the International Water Association (IWA). The elements of the water balance to be used in the model are shown in **Figure 26**.

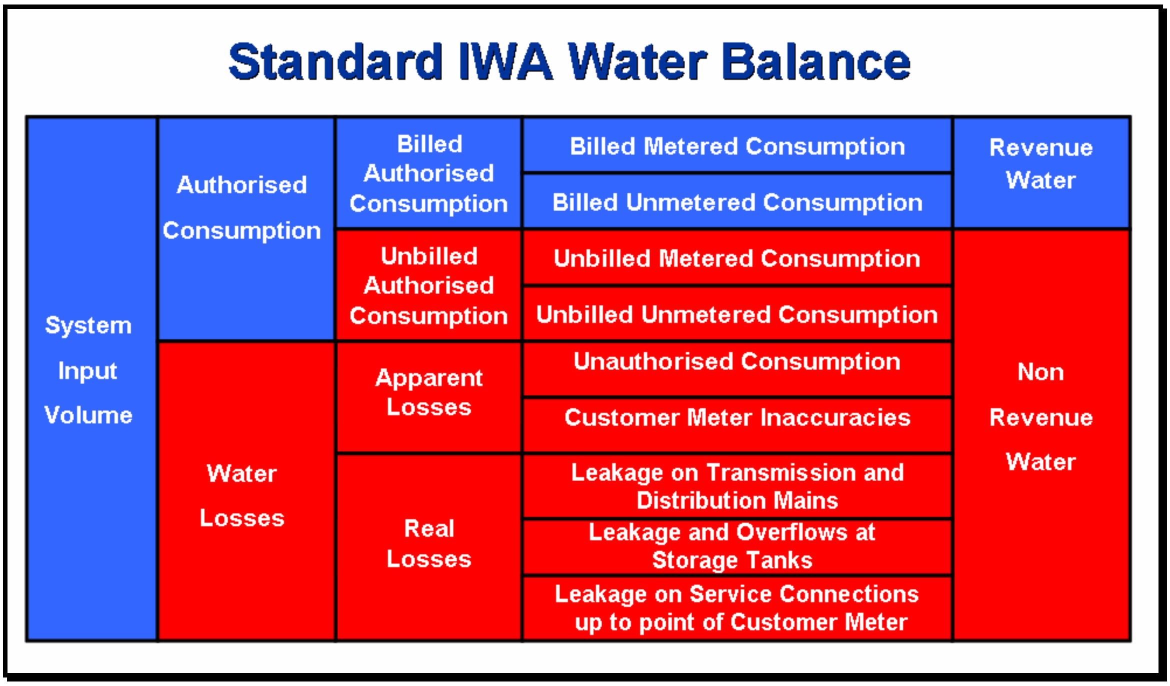


Figure 26: The standard IWA water balance

Apparent Losses

Apparent Losses are made up from the **Unauthorised Consumption** (theft or illegal use) plus all technical and administrative inaccuracies associated with customer metering and indicated as **Customer Meter Inaccuracies** in **Figure 26**. While it should be noted that the **Apparent Losses** should not be a major component of water balance in most developed countries, it can represent the major element of the total losses in many developing countries. A systematic estimate should be made from local knowledge of the system and an analysis of technical and administrative aspects of the customer metering system.

Authorised Consumption

Authorised Consumption is the volume of metered (**Authorised Metered**) and/or unmetered (**Authorised Unmetered**) water taken by registered customers, the water supplier and others who are implicitly or explicitly authorised to do so by the water supplier, for residential, commercial and industrial purposes.

It should be noted that in the AquaLite Model the **Authorised Consumption** also includes 'Water Exported' and, in some cases may include items such as fire-fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered or unmetered, according to local practice.

Billed Authorised Consumption

Billed Authorised Consumption is the volume of authorised consumption which is billed by the water utility and paid for by the customer. It is effectively the **Revenue Water** which, in turn, comprises:

- Billed Metered Consumption;
- Billed Unmetered Consumption.

Non-Revenue Water

Non-Revenue Water is becoming the standard term replacing Unaccounted-for Water (UFW) in many water balance calculations and is the term recommended by the IWA in preference to UFW. It is a term that can be clearly defined, unlike the Unaccounted-for Water term which often represents different components to the various water suppliers. Non-Revenue Water incorporates the following items:

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

Real Losses

Real Losses are the physical water losses from the pressurised system, up to the point of measurement of customer use. In most cases, the **Real Losses** represent the unknown component in the overall water balance and the purpose of most water balance models is therefore to estimate the magnitude of the **Real Losses** so that the water utility can gauge whether or not it has a serious leakage problem. The **Real Losses** are generally calculated as the difference between the **Total Losses** and the estimated **Apparent Losses.**

System Input

The **System Input** represents the volume input to the water supply system from the utilities own sources allowing for all known errors (i.e. errors on bulk water meters) as well as any water imported from other sources – also corrected for known bulk metering errors.

Unbilled Authorised Consumption

The **Unbilled Authorised Consumption** is the volume of authorised consumption that is not billed or paid for. The level of **Unbilled Authorised Consumption** will vary from utility to utility and in some areas virtually all water is metered and billed in some manner with the result that the **Unbilled Authorised Consumption** is zero.

Water Losses

Water Losses are the sum of the real and apparent losses and are calculated from the difference between the **Total System Input** and the **Authorized Consumption**.

A.3. PROBLEM OF USING PERCENTAGES TO DEFINE LEAKAGE

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

Over the last decade, however, it has been recognised that the term 'Unaccounted-for Water' and the use of percentages are often unsuitable and can be very misleading due to the fact that percentage figures are strongly influenced by the consumption.

A simple example can be used to highlight this problem. In this example a distribution system with 250 000 consumers and 1 000 km of mains experiences real losses of 10 m^3/km mains/day. The % Real Losses can easily be calculated for a range of different unit consumption as shown in **Table 2**. The same example is shown in **Table 3** in US units for a system with 1 000 miles of mains and real losses of 3 000 US gallons per day.

Table 2: Problem of using percentages to quantify leakage

Per capita Consumption (litres/head/day)	Daily Consumption (m^3 per day)	Distribution Losses (m^3 per day)	Daily Input (m^3 per day)	Losses (%)
25 (Standpipe)	6 250	10 000	16 250	62
50 (Jordan)	12 500	10 000	22 500	44
100 (Czech Rep)	25 000	10 000	35 000	27
150 (UK, France)	37 500	10 000	47 500	21
300 (Japan)	75 000	10 000	85 000	12
400 (USA)	100 000	10 000	110 000	9

From **Table 2** it can be seen that although the real losses in m^3 per day are identical in all cases, the percentage losses vary between 9% and 62%. It is clearly not meaningful to compare the percentage losses of a water distribution system in parts of Africa for example with a system in the USA. Similarly it may not be meaningful to use percentages to compare a system in the USA with another system even if they are adjacent to each other since the average per-capita water use may be different which in turn will influence the results. If one utility has a single large consumer, it will have the effect of lowering the percentage losses and if the consumer re-locates to another area, the percentage losses will increase despite the fact that the real losses may not have changed. Conversely if the water utility is able to persuade all users to use MORE water, the percentage real losses will decrease – hardly an acceptable WDM measure!

Table 3: Problem of using percentages to quantify leakage in US units

Per capita consumption (gallons/capita/day)	Actual consumption (mil gal/day)	Real Losses (mil.gal/day)	Total Water supplied (mil.gal/day)	Real losses as % of water supplied
6 (standpipe in Africa)	**1.5**	**3.0**	**4 .5**	**67 %**
13 (Jordan)	**3.25**	**3.0**	**6. 25**	**48 %**
25 (Czech Republic)	**6.25**	**3.0**	**9 .25**	**32 %**
40 (UK, France)	**10.0**	**3.0**	**13.0**	**23 %**
80 (Japan)	**20.0**	**3.0**	**23.0**	**13 %**
100 (USA)	**25.0**	**3.0**	**28.0**	**11 %**

Another interesting point to be considered is the implementation of a water demand management programme to promote more efficient water use amongst the consumers. If such a programme is successful it may reduce the per-capita consumption significantly which would be an indication of a successful programme. In such a case, however, the percentage losses will increase and not decrease unless action is also taken to reduce the real losses.

The problem to be addressed is therefore how to express real losses in such terms that the leakage in one system can be meaningfully compared to the leakage in other systems. To address this problem a new PI has been developed called the Infrastructure Leakage Index. This relatively simple indicator is discussed in **Sections 2.4 and 2.5**.

A.4. UARL: UNAVOIDABLE ANNUAL REAL LOSSES

One of the most important concepts used in the BABE procedures and the AquaLite model concerns the minimum or unavoidable level of leakage for any given system. Effectively, it is a simple concept based on the fact that no system can be entirely free from leakage and that every system will have some level of leakage which cannot be reduced any further. Even a new reticulation system with no use will have some level of leakage, although it may be relatively small. The minimum level of leakage for a system is termed the unavoidable annual real losses or UARL. This is the level of leakage that can be achieved if the system:

- Is in top physical condition and is well-maintained

- All reported leaks are repaired quickly and effectively

- Active leakage control is practiced to reduce losses from unreported leaks

The procedure to estimate the UARL was developed by Lambert during the period of the International Water Association's Task Force on Water Losses. The methodology is described in a paper in AQUA (Lambert et al., 1999) and the original metric parameters have been converted to US units as indicated in certain tables. The estimation of the UARL involves estimating the unavoidable real 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.

The various elements of the distribution network included in the UARL calculation are shown in **Figure 27** and **Figure 28** which highlight the two most common configurations – one where the meter is located at the property boundary and the second where the meter is located just inside the property.

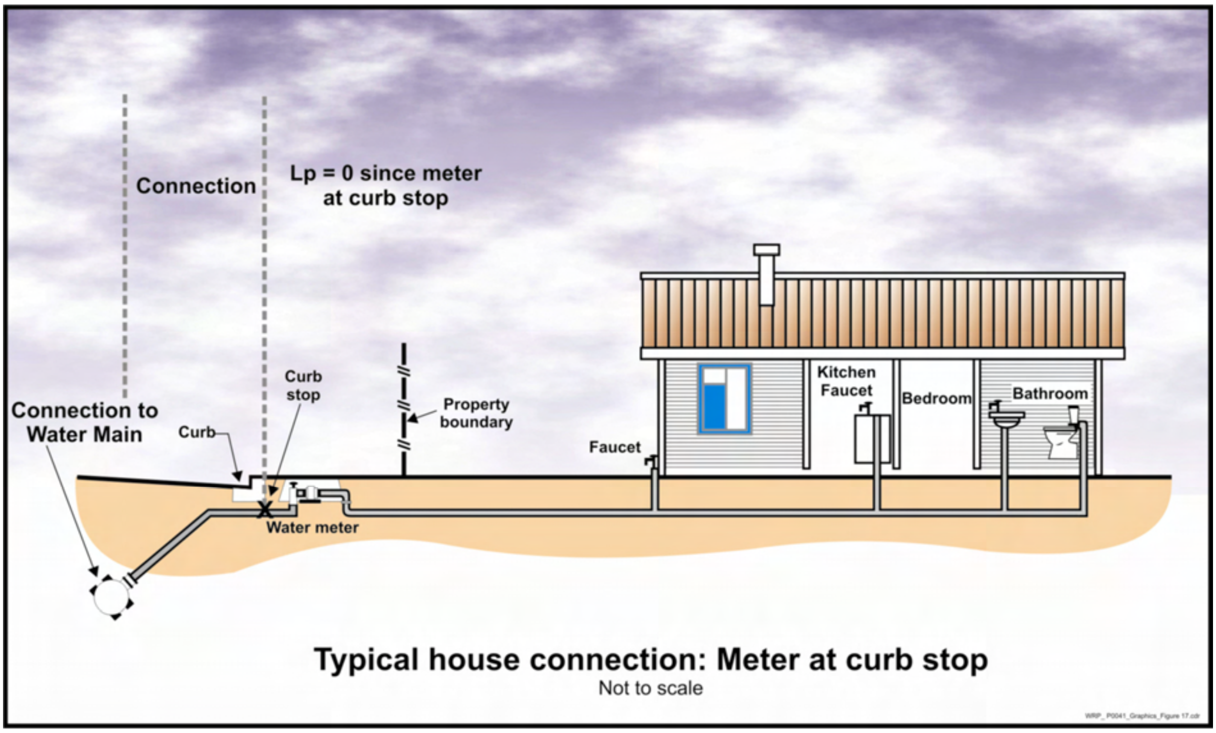


Figure 27: Configuration with meter at property boundary

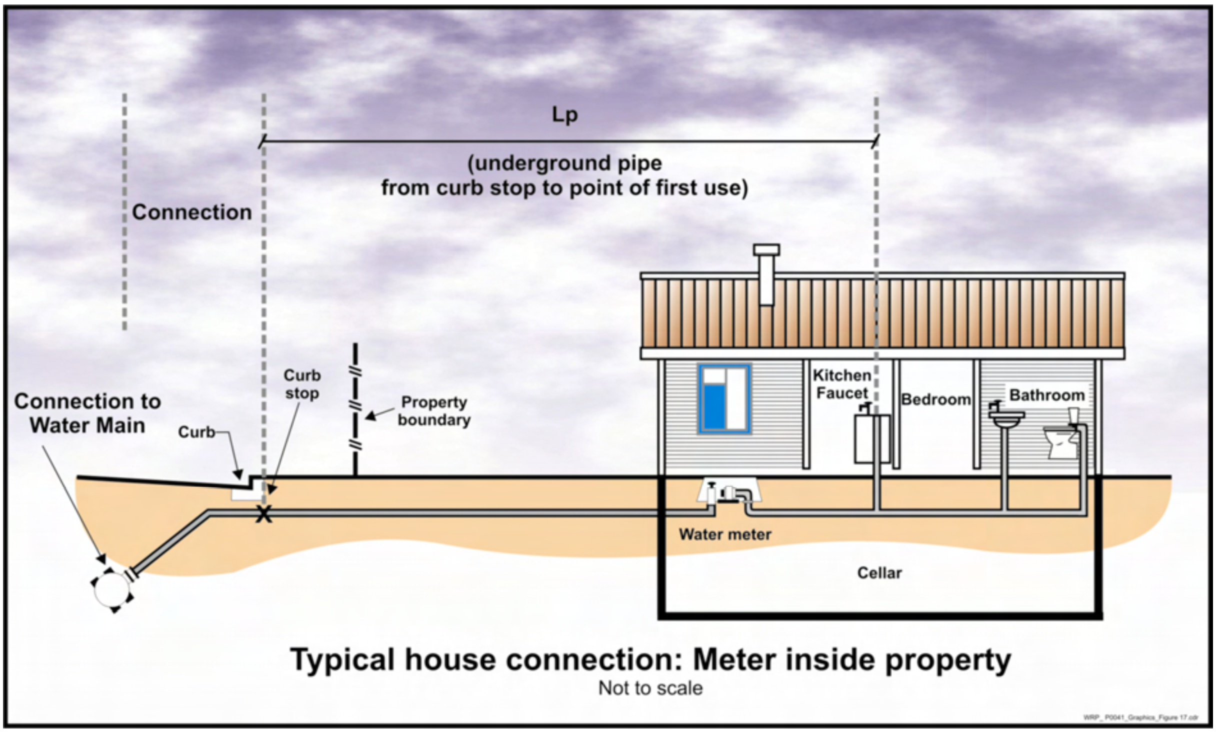


Figure 28: Configuration with meter inside property

The parameters used in the calculation of the losses are indicated in **Table 4**.

Table 4 : Parameters required for the calculation of the UARL

Component	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

**** = at standard pressure of 50 m***

From **Table 4** it can be seen that the one variable which is common to all elements is pressure. This is also the one variable that is normally excluded from most commonly used leakage performance indicators such as percentage, leakage per connection per year and leakage per km of mains per year. It should be noted that the various leakage rates used in the original calculation of UARL were all based on a standard pressure of 50m (71.12 psi) and the final value of UARL was then scaled up or scaled down according to the actual system pressure. This often invokes some debate since the UARL for a system operating at 100 m will be twice that of a system operating at 50 m. Some managers feel that the systems operating at 100 m should be penalised for designing systems to operate under such high pressures while the UARL calculation effectively assumes that the system pressure is outside the control of the utility and is a feature of the topography. This is a valid concern and when using the UARL, the manager should realise that the estimated minimum leakage is based on the current pressure profile and that it may be beneficial to reduce the pressure if possible which in turn will lower the unavoidable losses. In some systems, the management of the system is so efficient that the only option available to the water utility to lower leakage further is to reduce pressure.

For the purpose of this section, all calculations shown in the tables are based on the original metric parameters as discussed in the paper by Lambert et al., (1999). The final parameters are converted to US units at the end of the section and explained through the use of an example.

Each of the elements in **Table 4** can be allocated a value which is appropriate to infrastructure in good condition, operated in accordance with best practice, based on the analysis of data from numerous systems throughout the world. The results are provided in

Table 5. It should be noted that the general guideline for infrastructure replacement is in the order of 2% per annum.

Table 5 : Parameter values used in the calculation of the UARL

Component of Infrastructure	**Background losses**	**Reported bursts**	**Unreported bursts**
Mains	20* litre/km/hr	0.124 bursts /km/year at 12 m^3/hr/ burst* average duration of 3 days	0.006 bursts /km/year at 6 m^3/hr /burst* average duration of 50 days
Service connections to street/property line	1.25* litre/km/hr	2.25/1 000 connections/year at 1.6 m^3/hr/ burst* average duration of 8 days	0.75/1 000 conn/yr at 1.6 m^3/hr/ burst* average duration of 100 days
Unmetered Service connections after street/property line	0.50* litre/km/hr based on 15 m length per connection	1.5/1 000 connections/year at 1.6 m^3/hr / burst* average duration of 9 days	0.50/1 000 conn/yr at 1.6 m^3/hr / burst* average duration of 101 days

**** these flow rates are initially specified at 50m pressure (71.11 psi)***

The parameter values indicated in **Table 5** include data for minimum background loss rates and typical burst frequencies for infrastructure in good condition, and for typical average flow rates of bursts and background leakage at 50 m (71.11 psi) pressure. The average duration assumed for reported bursts is based on best practice world-wide. The average duration for unreported bursts is based on intensive active leakage control, approximating to night-flow measurements once per month on highly sectorised water distribution systems.

Assuming a simplified linear relationship between leakage rate and pressure, the components of UARL can be expressed in modular form for ease of calculation as shown in **Table 6**. Sensitivity testing shows that differences in assumptions for parameters used in the 'Bursts' components have relatively little influence on the 'Total UARL' values in the 5th column of **Table 6**.

Table 6 : Calculated components of UARL in metric units

Component of Infrastructure	Background Losses	Reported Bursts	Unreported Bursts	Total UARL	Units
Mains	9.6	5.8	2.6	18	Litres/km mains/d per m of pressure
Service connections to street/property line	0.60	0.04	0.16	0.8	litres/conn/d/ m of pressure
Unmetered Service connections after street/property line	16.0	1.9	7.1	25	litres/km underground. pipe/day/m of pressure

Based on the figures provided in **Table 6,** the calculation of the UARL in metric terms can be expressed as follows:

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

Where:

UARL = Unavoidable annual real losses (litres/d)

Lm = Length of mains (km)

Nc = Number of service connections (main to meter)

Lp = Length of unmetered underground pipe from street edge to customer meters (km)

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

The values provided in **Table 6** have been converted in AquaLite to US units as shown in **Table 7**.

Table 7 : Calculated components of UARL in US units

Component of Infrastructure	Background Losses	Reported Bursts	Unreported Bursts	Total UARL	Units
Mains	2.8696	1.7337	0.7771	5.3804	gallons/mile mains/d per psi of pressure
Service connections to street/property line	0.1115	0.0074	0.0297	0.1486	gallons/conn/d/ psi of pressure
Unmetered Service connections after street/property line	4.7826	0.5679	2.1223	7.4728	gallons/mile underground. pipe/day/psi of pressure

Based on the figures provided in **Table 7,** the calculation of the UARL in US terms can be expressed as follows:

UARL = (5.3804 * Lm + 0.1486 * Nc + 7.4728 * Lp) * P

Where:

UARL = Unavoidable annual real losses (gallons/d)

Lm = Length of mains (miles)

Nc = Number of service connections (main to meter)

Lp = Length of unmetered underground pipe from street edge to customer meters (miles)

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

Example (metric): A system has 280 km of mains, 14 000 service connections located 30 m (i.e. 0.030 km) from street edge and an average operating pressure of 50 m.

UARL = (18 * 280 + 0.80 * 14 000 + 25 * 0.030*14 000) * 50 litres/day

= 252 000 + 560 000 + 525 000 litres/day

= 1 337 000 litres/day

= 1 337 m^3/day

= 488 339 m^3/year

= 95.5 litres/conn/day

Example (US): A system has 173.98 miles of mains, 14 000 service connections located 98.42 feet (i.e. 0.01864 miles) from street edge and an average operating pressure of 71.11 psi.

UARL = (5.3804 * 173.98 + 0.1486 * 14 000 + 7.4728 * 0.01864*14 000) * 71.11 gallons/day

= 66 565 + 147 937 + 138 672 gallons/day

= 353 174 gallons/day

= 129 million gallons/year

= 25.23 gallons/conn/day (= 95.5 litres/conn/day)

A.5. FAVAD: FIXED AREA VARIABLE AREA DISCHARGES

Although the AquaLite model does not require the user to provide any information regarding the influence of pressure on leakage, it is nonetheless one of the key components of the BABE methodology and for this reason some brief details have been provided for completeness. Those wishing to use the model without further delay should therefore proceed to the next section while those wishing to gain a thorough understanding of leakage in their water distribution system will find the information provided informative and useful.

When considering leakage in a water distribution system, one of the key concepts relates to pressure. It has always been known that leakage increases with pressure and it was originally thought that the leakage would follow the general principles of flow through a hole which follows a square route relationship with pressure. In other words, the pressure exponent shown in Equation 1 would be 0.5. .

Equation 1 : Pressure-loss equation

L0/L1 = (P0/P1)N1

Or

Equation 2 : Alternative pressure-loss equation

L1 = L0 x (P1/P0)N1

Where:

$\mathbf{L_0}$ = initial leakage loss in m^3/hr

$\mathbf{L_1}$ = new leakage loss in m^3/hr

$\mathbf{P_0}$ = initial pressure (m)

$\mathbf{P_1}$ = new pressure (m)

N1 = pressure exponent (non-dimensional)

Considerable research has been undertaken on the value of the N1 pressure exponent and it has been found to vary considerably from one system to another with values from around 0.5 up to 2.5. High N1 values indicate that the leakage in the particular system is more sensitive to pressure than conventional theory would suggest. This issue was finally explained by John May (1994) who developed the Fixed Area Variable Area Discharge theory (FAVAD) which has become the accepted theory regarding the leakage/pressure relationship from water reticulation systems.

The FAVAD theory is based on the fact that the N1 value used in **Equation 1** represents the power exponent for all distribution losses in the system influenced by pressure. It is generally used to represent a "lumped" parameter for both burst and background losses although in some calculations a separate N1 value for bursts and background leakage can be used. Through considerable research it was found that leaks in a distribution system tend to be either fixed area leaks such as those found as pin-holes in metal pipes or variable area leaks such as cracks in plastic or asbestos cement pipes. Fixed leaks tend to follow more closely the traditional theory of flow through an orifice in which cases the N1 value tends to be close to 0.5 – i.e. a square root relationship. With variable area leaks, however, the area of flow tends to increase with pressure as well as the velocity through the hole resulting in N1 values of between 1.0 and 2.5. The "lumped" N1 value for a system will therefore depend on the combination of fixed area leaks to the variable area leaks. If no other information is available, a value of 1.0 can be used since research has shown that this is often a realistic estimate of N1 for most mixed systems. The value for N1 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.

The influence of the N1 value of the leakage from a system is shown in **Table 8** for metric units and **Table 9** for US units which demonstrates the importance of selecting a realistic N1 value when assessing the influence of changing pressure on the leakage in a system.

Table 8: Influence of N1 on leakage in metric units

Average Zone Pressure (m)	Pressure Correction Factors		
	Using index = 0.5 (Metal Pipes)	Using index = 1.0 (Combination)	Using index = 1.5 (Plastic Pipes)
20	0.63	0.40	0.25
30	0.77	0.60	0.46
40	0.89	0.80	0.71
50	1.00	1.00	1.00
60	1.09	1.20	1.31
70	1.18	1.40	1.65
80	1.26	1.60	2.02
90	1.34	1.80	2.41
100	1.41	2.00	2.83
110	1.48	2.20	3.26
120	1.55	2.40	3.72

Table 9: Influence of N1 on leakage in US units

System Pressure (psi)	Pressure Correction Factor		
	Steel Pipes N1 = 0.5	Mixed Pipes N1 = 1.0	Plastic Pipes N1 = 1.5
20	0.53	0.28	0.15
30	0.65	0.42	0.27
40	0.75	0.56	0.42
50	0.84	0.70	0.59
60	0.92	0.84	0.78
71.1	**1.00**	**1.00**	**1.00**
80	1.06	1.13	1.19
100	1.19	1.41	1.67
120	1.30	1.69	2.19
140	1.40	1.97	2.76
160	1.50	2.25	3.38
180	1.59	2.53	4.03
200	1.68	2.81	4.72

A.6. ILI: INFRASTRUCTURE LEAKAGE INDEX

As mentioned previously, the use of percentages is not recommended as a performance indicator for water leakage in a distribution system since it is heavily influenced by the per capita (or per connection) water use. The best of the traditional performance indicators is considered to be:

m^3/service connection/day – metric units
gallons/service connection/day – US Units

This indicator will be suitable for most systems where the density of connections is greater than 32 connections per mile of mains (i.e. 20 connections per km mains). In cases where the density of connections drops below 32 per mile of mains, it is often appropriate to rather use the following indicator:

m^3/km mains/day – metric units
gallons/mile of mains/day – US Units

The above basic operational Performance Indicators, however, do not take account of two 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);

To address this problem a new Performance Indicator has been developed and is now being used fruitfully in many parts of the world namely: the Infrastructure Leakage Index (ILI). The ILI is very simply the ratio of the actual real losses from the system to the unavoidable real losses from the system:

Infrastructure Leakage Index ILI = CARL/UARL

A.7. ACCURACY IN WATER BALANCE AND PI CALCS

One of the more recent developments with many new water balance models is the inclusion of error terms for many of the key input parameters where the user may not know the actual figures accurately. In such cases, the user can specify an estimated error margin which is then used in the calculations to provide upper and lower bounds for certain key parameters and performance indicators. Each component of the main water balance has three values namely:

- The best estimate;
- The upper bound and
- The lower bound.

It should be noted that the error terms are provided to allow the user to test the sensitivity of possible inaccuracies in the main input data on the resulting water balance and PIs. The methodology used in the model to incorporate the error terms is relatively simple and should be considered as an approximate approach rather than a mathematically rigorous approach. There is little sense in attempting to undertake a detailed rigorous analysis of the errors when the actual error terms used in the calculations are relatively subjective and based on the 95% confidence intervals. Few if any individuals really know what error term to select for a 95% confidence interval compared to the value they would select at say a 90% confidence interval. The approach is therefore highly subjective and the error terms in the model are provided simply to give the user additional confidence in the end result and to enable him/her to assess the sensitivity of certain key input parameters on the final results.

The key input variables where the user can provide an error term to indicate the reliability of the information include;

- infrastructure (numbers of connections, mains length, properties etc);
- average pressures;
- metered volumes, estimated unmetered volumes etc;

The above variables are used in the calculation of Water Balance and Performance Indicators. Clearly none of these items of data can be considered as being a precisely correct value – they are all 'best estimates' to a greater or lesser extent. Consequently, a question which is often asked is 'How accurate is the calculation of Non-Revenue Water, Apparent Losses, Real losses, and their Performance Indicators?

Data errors can be systematic, or random, or both. For example, if check calibration of a system input meter shows that it has over-recorded by between 2% and 4%, then there is a systematic error with a best estimate of 3% over-recording of system input volume. Systematic errors in system input volume should therefore be corrected as part of the Water Balance calculation process.

In the above example, there will also be a random error of approximately +/- 1% of the corrected system input volume. Similar random errors will exist for almost every item of data used in AquaLite; for example, in the figures entered for length of mains, or the calculated average pressure, or the estimates of components of unmetered consumption etc.

Engineers often express the probable range of such random errors by statements such as ‘I think the figure I have used is within +/- X % of the true value’. Estimated values of ‘X’ are based on local knowledge, general experience, published data, and consideration of the methodology used to obtain the data.

For most of the parameters used in AquaLite, if systematic errors are identified and dealt with, the remaining random errors are equally likely to be greater than, or less than, the true value. A practical approach for assessing probable errors in calculated components of NRW, and PIs, can then be developed, using the statistical properties of a probability distribution known as the ‘Normal’ or ‘Gaussian’ distribution. It is necessary, however, to be aware that the probability distributions of some items of data used in leakage management do not follow ‘Normal’ distributions. For example, if the individual metered flow rates into a large number of residential properties are measured at night, then it will be found that the total night consumption is generated by a small proportion (p) of ‘active’ properties. The majority of properties are ‘inactive’, having zero metered flow at night. In such cases the use of a Normal or Gaussian distribution to represent the data is technically not appropriate, and the data should ideally be analysed using a Binomial probability distribution. Once again it must be remembered that the error calculations are relatively course and since they are based on many subjective estimates made by the user it is not considered appropriate to delve into different probability distributions for each variable.

The Normal Distribution

The Normal distribution (sometimes called the Gaussian Distribution) is widely used for statistical analysis. It is characterised by:

- A mean value (the arithmetic average of all the data)
- Approximately half the items being greater than, and half less than, the mean
- The greater the difference from the mean, the smaller the probability
- A ‘standard deviation’ – a measure of dispersion about the mean value

A typical normal distribution curve is shown in **Figure 29**. It can be seen from the figure that the area within 1, 2 and 3 standard deviations from the mean are approximately 68.3%, 95.5% and 99.7% respectively of the whole area.

The density function for the Normal (Gaussian) distribution which can be fitted to these values is represented by the equation:

$$f(\chi) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(\chi - \mu)^2 / 2\sigma^2} \quad -\infty < \chi < \infty$$

Where M is the mean value and SD is the standard deviation. The ‘Standard Error’ (SE) is the Standard Deviation expressed as a % of the mean.

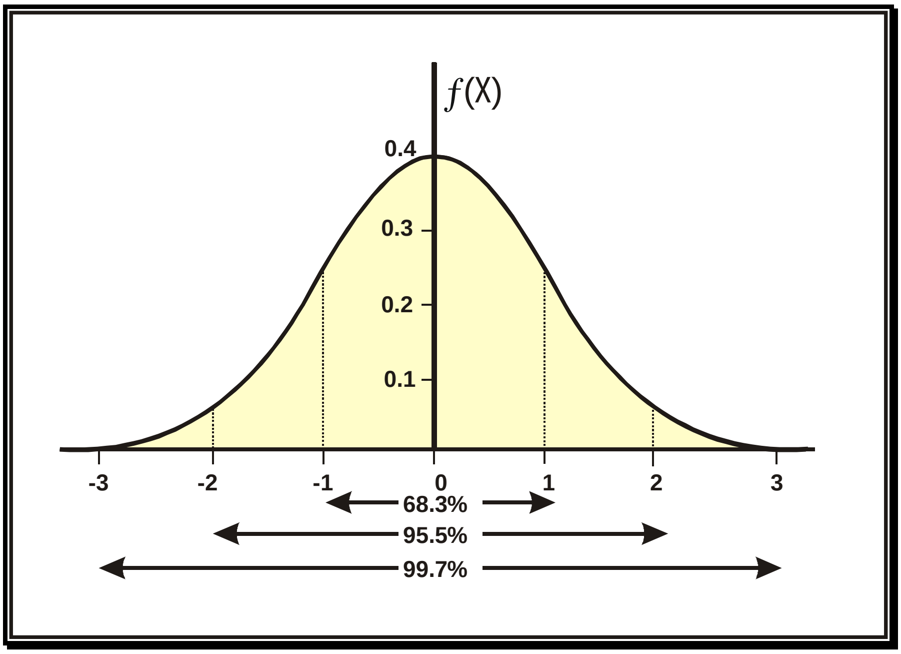


Figure 29: Typical Normal Distribution

If a frequency distribution has a mean of 50 units, and an SD of 5 units, then:

- 68.3% of all values should lie within +/- 1 Standard Deviations of the mean, i.e. between 45 and 55 units
- 95.5% of all values should lie within +/- 2 Standard Deviations of the mean, i.e. between 40 and 50 units
- The Standard Error will be (100 x SD/Mean)% = 100 x 5/50 = 10%

Application to water balance and PI calculations

AquaLite requires the user to enter a 'best estimated' value for each input parameter. Then, to make a judgement as follows:

'I think the figure I have entered is probably within +/- X % of the true value'. The value of X is then assumed to represent the 95% confidence limits, expressed as a % of the best estimated value.

The model divides X by 2 to obtain the Standard Error (%), then calculates the Standard Deviation as X/(2x100) x 'Best Estimated Value'. Taking the example in A2 above, if the 'Best Estimated Value' is 50 units, and the 95% confidence limits ('X') are +/- 20%, then the Standard Deviation is 20/(2x100) x 50) = 5 units.

Using the estimated 95% confidence limits for input data, the model uses routine statistical calculations to calculate 95% confidence limits for derived data, such as:

- the sum or difference of volumes in the water balance
- performance indicators which use combinations of items with different measurement units

APPENDIX B

VARIOUS CONVERSION FACTORS USED IN AQUALITE

APPENDIX B: CONVERSION FACTORS

METRIC TO USA

Description	Metric	USA	Factor/notes
Pressure	metres	lb/in^2	1 m = 1.4223 lb/in^2
Default pressure	50 m	71.115 lb/in^2	
Length of mains	km	mile	1 km = 0.621371 miles
Length of underground pipe	m	ft	1 m = 3.28084 ft
Volume large	million m^3	million gallons (US)	1 million m^3 = 264.172 million US gallon
Volume small	m^3	gallons (US)	1 m^3 = 264.179 US gallon
Volume	m^3	ft^3	1 m^3 = 35.31467 ft^3
Volume	Acre-feet	m^3	1 acre foot = 1233.4818 m^3
Volume	Acre-feet	ft^3	1 acre foot = 43560 ft^3
Volume	Acre-feet	US gallons	1 acre foot = 325 851.06 US gallons
Volume	m^3	Acre-feet	1 m^3 = 0.000810713

METRIC TO IMPERIAL

Description	Metric	Imperial	Factor/notes
Pressure	Metres	lb/in^2	1 m = 1.4223 lb/in^2
Default pressure	50 m	71.115 lb/in^2	= 50 * 1.4223
Length of mains	Km	mile	1 km = 0.621371 miles
Length underground pipe	M	ft	1 m = 3.2808 ft
Volume large	million m^3	million gallons (Imp)	1 million m^3 = 219.97 million Imp. gallon
Volume small	m^3	gallons (Imp)	1 m^3 = 219.97 Imp. gallon