GUIDANCE NOTES ON APPARENT LOSSES AND WATER LOSS REDUCTION PLANNING

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The origins of these Guidance Notes related to draft Apparent Loss Guidance Notes created by a voluntary group of members of the IWA Water Loss Specialist Group (WLSG) between November 2007 and April 2010, which were not finalised, approved or published. The principal authors of the 2010 draft have now rewritten and updated these 2016 Guidance Notes in this revised easily updateable format; and they confirm that this document and its Appendices are their intellectual property.

Acknowledgements

These Guidance Notes on Apparent Losses had their origins in an unpublished draft developed in 2007 to 2010 by members of the IWA Water Loss Specialist Group. The preparation of this updated version was initiated by Michel Vermersch, Fatima Carteado and Alex Rizzo, and completed with substantial inputs from Edgar Johnson and Francisco Arregui. Allan Lambert assisted with editing, and provided the LEAKSSuite website as a facility for free web-based dissemination of the Guidance Notes and the 9 Appendices, which are available as individual papers.

The individual author (or combinations of authors) of the papers which constitute the Appendices are recognized in each individual Appendix.

Thanks also go to the members of the IWA Water Loss Specialist Group who contributed to the original 2010 draft. Those who could be contacted are named below, with their permission. It is hoped that they will gain satisfaction in seeing an eventual outcome from the initiative they started ten years ago.

The authors would also like to thank the multitude of Water Utility professionals who have contributed to the development of a better understanding of Apparent Losses, including those who have permitted their papers to be freely available to all on the LEAKSSuite website.

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Introduction

These Guidance Notes are intended to be an introduction to NRW practitioners to the process of identification and reduction of apparent losses. They provide basic – but sometimes innovative - answers to the aims defined by the Apparent Loss Initiative initiated by the IWA Water Loss Task Force (WLTF) in 2007. The WLTF has since become the IWA Water Loss Specialist Group (WLSG), and for simplicity, the term WLSG will be used in these Guidance Notes.

The Apparent Loss Initiative, Founding Document (November 2007), shows that the WLSG had been promoting an apparent loss (AL) reduction approach based on the reduction of four main AL components: meter under-registration, illegal consumption, meter reading errors and water accounting errors. The strategies aimed at reducing the four components have to be clearly defined and balanced to achieve the most cost effective programme, which reduces apparent losses to an economically, environmentally and socially acceptable level. Another objective was to reduce the existing gap between real losses and apparent losses in terms of knowledge and management.

The 2007 Founding Document aims were to:

- Define the various types of apparent losses that can be classified within the four components previously mentioned ;
- Define new indicators on apparent losses such as apparent loss index (ALI), minimum admissible level of loss for each AL component and minimum economical level of loss for each AL component;
- Give special emphasis on water under-registration and other metering issues;
- Investigate the minimum achievable level of loss for each type of apparent loss;
- Review current methods and techniques to reduce the various components of apparent loss to a minimum achievable level;
- Give recommendations to establish a cost effective programme to reduce AL to economically, environmentally and socially acceptable level;
- Give recommendations to get sustainable results

By late 2014, there was still relatively little good quality information on Apparent Losses freely available to practitioners, compared to extensive freely available papers and software on real losses management. Several of the principal authors of the 2006-2010 draft agreed an arrangement with the LEAKSSuite website to create a free-to-all Info-Hub on Apparent Losses, and to assist by making available their own papers, and others selected from other leading apparent loss specialists. As the number of papers and presentations on the Info-Hub, and the number of page views, grew rapidly, the principal authors of the 2006-2010 draft Guidance Notes on Apparent Losses decided, with the support of the LEAKSSuite website, to prepare an updated set of Guidance Notes.

Recognising that there is a regular flow of innovation and new papers in NRW Management, the format of these Guidance Notes is broadly based on the aims of the 2007 WLTF Founding document, but split into this main Guidance Notes document, with a series of 9 free-standing Appendices on specific topics, which can be readily updated in future years.

Following this **Introduction** to the Guidance Notes, **Section 1** considers broad issues relating to Apparent Losses within the context of the Annual Water Balance, including data reliability. Although Unbilled authorised consumption and Unpaid bills are not components of Apparent Losses, they need to be assessed and controlled within the framework of the Water Balance approach and the resulting action planning to bring Non-Revenue Water under control.

Section 2 considers the water audit component analysis and presents some guidelines and good practices. It presents some guidelines on populating the water balance with data to calculate or evaluate the Current Annual Apparent Losses CAAL and its components.

More detailed information to supplement Section 2 is provided in the following stand-alone papers, which are considered to be Appendices to the Guidance Notes:

- ***Appendix 1:*** Non-Revenue Water and Large Water Meter Calibration (Johnson)
- ***Appendix 2***: Non-Revenue Water and Unbilled Authorised Consumption (Vermersch, Carteado, Lambert)
- ***Appendix 3***: Customer Meter Errors (Arregui)
- ***Appendix 4***: Apparent Water Losses generated by Unauthorised Consumption (Carteado and Vermersch)
- ***Appendix 5:*** Non-Revenue Water and Errors throughout the Data Acquisition Process (Vermersch and Carteado)
- ***Appendix 6***: Non-Revenue Water and Revenue Collection Ratio: Review, Assessment and Recommendations (Carteado and Vermersch)

Section 3 considers Apparent Losses Performance Indicators, and the merits and deficiencies of different performance indicators for Non-Revenue Water, Apparent Losses, with some cross-reference to Real Losses performance indicators. It also considers components of Apparent Losses in detail, including attempts to define Unavoidable Annual Real Losses, Reference Annual Real Losses, and performance indicators for field and laboratory services, default value approaches and uncertainty.

Section 4 considers Action Planning and Dynamics of Apparent Losses, and 3 of the 5 sub-sections have their own separate weblink. The Appendices are:

- ***Appendix 7:*** An Action Planning Model to Control Non-Revenue Water (Vermersch & Rizzo)
- ***Appendix 8***: An Overall Dynamic Approach in Water Loss Reduction (Vermersch & Carteado}
- ***Appendix 9***: Change Management as an indispensable component when planning for NRW control (Vermersch & Rizzo)

Section 5 provides some elements related to the economics of apparent water losses.

Section 6 provides references and bibliography

Section 7 presents the authors’ profiles.

Abbreviations and Acronyms

AL	Apparent Loss
ALI	Apparent Loss Index
AMR	Automatic Meter Reading
AWWA	American Water Works Association
BCA	Benefit-Cost Analysis
BMC	Billed Metered Consumption
BMCR	Billed Metered Consumption Residential
BMCNR	Billed Metered Consumption Non Residential
BUC	Billed Unmetered Consumption
CAAL	Current Annual Apparent Loss
CAPEX	Capital Expenditure
CARL	Current Annual Real Loss
CBA	Cost-Benefit Analysis
CME	Customer Metering Error
CRA	Coefficient of Return of Anomalies
DMA	District Metered Area
EALL	Economic Apparent Loss Level
EIRR	Economic Internal Rate of Return
ELL	Economic Leakage Level
GIS	Geographical Information System
GNP	Gross National product
GPR	Ground Penetrating Radar
HIC	High Income Countries
ICF	Infrastructure Condition Factor
ILI	Infrastructure Leakage Index
IRR	Internal Rate of Return
IWA	International Water Association
KPI	Key Performance Indicator
LAMIC	Low and Middle Income Country
LPC	Leakage Performance Category
MAL	Migratory Attribute of Loss
NPV	Net Present Value
NRR	Natural Rate of Rise
NRW	Non-Revenue Water
O&M	Operation and Maintenance
OPEX	Operational Expenditure
PMA	Pressure Managed Area
PI	Performance Indicator
RAAL	Reference Annual Apparent Loss
RL	Real Loss
SIV	System Input Volume
SROI	Social Return on Investment
TF	Time Factor

UAAL	Unavoidable Annual Apparent Loss
UAC	Unbilled Authorised Consumption
UARL	Unavoidable Annual Real Loss
UFR	Unmetered Flow Reducer
VT	Visibility Threshold
WE	Water Exported
WI	Water Imported
WLCC	AWWA Water Loss Control Committee
WLSG	Water Loss Specialist Group of the IWA (current name)
WLTF	Water Loss Task Force of the IWA (former name)
WOS	Water from Own Sources
WS	Water Supplied

Table of Contents

List of Appendices

Available as separate documents at http://www.leakssuite.com/guidance-notes-app-loss/

List of Figures

List of Tables

1. WATER BALANCE AND APPARENT LOSSES

Summary

This chapter considers the definition of water balance, which is the usual foundation for any analysis of real and apparent losses in a water audit. A slightly modified breakdown of the apparent losses within an enhanced IWA standard water balance is proposed.

Stress is put on the reduction of uncertainty in the Water Balance calculations. Failure to consider these concepts usually leads to erroneous water audit and failure in the design of the action programs to reduce NRW.

1.1. Recommended Water Balance

The Water Balance of a water supply system is the basis for any NRW analysis related to both Real Losses and Apparent Losses in that system. The Water Balance is based on measurements and assessments of components of water produced, imported, exported, consumed or lost. The water balance used in this document and the related appendices, is shown in Fig.1.

<table>
<tr><td rowspan="6">Volume from Own Sources (corrected for known errors)</td><td rowspan="12">System Input Volume (corrected for known errors)</td><td rowspan="5">Authorised Consumption</td><td rowspan="3">Billed Authorised Consumption (includes Water Exported)</td><td rowspan="3">Revenue Water</td><td rowspan="2">Billed Metered Consumption</td><td>Billed Water Exported (corrected for known errors)</td><td></td></tr>
<tr><td>Billed Metered Consumption excluding Water Exported</td><td rowspan="11">Water Supplied</td></tr>
<tr><td colspan="2">Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td rowspan="9">Non-Revenue Water</td><td colspan="2">Unbilled Metered Consumption</td></tr>
<tr><td colspan="2">Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="7">Water Losses</td><td rowspan="4">Apparent (Commercial) Losses</td><td colspan="2">Unauthorised Consumption</td></tr>
<tr><td rowspan="6">Water Imported (corrected for known errors)</td><td colspan="2">Customer Metering Errors</td></tr>
<tr><td colspan="2">Errors in Estimate of Unmetered Consumption</td></tr>
<tr><td colspan="2">Errors throughout the Data Acquisition Process</td></tr>
<tr><td rowspan="3">Real (Physical) Losses</td><td colspan="2">Leakage on Transmission and Distribution Mains</td></tr>
<tr><td colspan="2">Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td colspan="2">Leakage on Service Connections up to point of customer metering</td></tr>
</table>

Figure 1 : Recommended Water Balance with focus on Apparent Losses

This water balance is consistent with the principles of the IWA water balance (Alegre et al, 2nd edition, 2006) and the AWWA water balance in the fourth Edition of the AWWA M36 Water Audit Manual (2016). Reasons for the enhancements of the original IWA Water balance published in 2000 are briefly explained in Section 1.2.

The Water Balance relates to a clearly defined water distribution system over a clearly defined period of time, generally one year in order to integrate seasonal variations.

Non-Revenue Water (NRW) volume is obtained by deducting Billed Authorised Consumption from System Input volume (or by deducting Billed Metered and Unmetered consumption from Water Supplied, in the case of Distribution Systems). NRW consists of three principal components - Unbilled Authorised Consumption (UAC), Apparent Losses (AL) and Real Losses (RL).

Unbilled authorised consumption (UAC) may include metered or unmetered items such as firefighting, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. UAC may also sometimes include gratuities to some categories of consumers: municipal or utility staff, utility premises, etc. These latter volumes may be unbilled and metered or unmetered according to local practices. The corresponding volumes are not part of water losses, but they are part of non-revenue water. These volumes may be optimised and savings are often possible. More information on UAC is provided in Section 1.3 and Appendix 2

Water Losses (WL) volume is obtained by deducting Unbilled Authorised Consumption from Non-Revenue Water. Systematic inaccuracies associated with production metering should be identified and corrected before bulk metered volumes are entered into the Water Balance; otherwise they will influence the calculated NRW and Water Losses volumes. Water Losses consist of two components: Apparent Losses (AL) and Real Losses (RL).

Apparent Losses (AL) , sometimes called commercial or non-physical losses, refers to volumes of authorised consumption that reach consumers, but are not billed They include unauthorised consumption, customer metering errors, errors in estimates of unmetered consumption, and errors throughout the Data Acquisition Process

Real Losses (RL) includes all the components of leakage in the water supply facilities: transmission and distribution mains, leakage and overflows at Utility storage tanks, and leakage on service connections up to the point of customer metering. They represent treated water lost from the water supply system which is neither consumed nor billed, and are also called physical losses

Splitting of Water Losses into Apparent Losses and Real Losses is usually not a simple matter, but for rational management it must be attempted. The basic formulas are:

- NRW = UAC + AL + RL
- Water Losses = NRW – UAC = AL + RL

This Guidance Note is mainly based on the assumption that many systems internationally will have significant excessive volumes of both Apparent and Real Losses, and that both components will require investigation at the same time over a multi-year time-scale. However, in well-managed direct pressure systems with low NRW, where Apparent Losses are clearly only a minor proportion of Water Losses, a default approach to estimating Apparent Losses is also outlined.

Water effectively consumed by the population includes both authorised consumption (billed and unbilled) and apparent losses. This point is to be emphasized because it would be erroneous, for instance, to base a water demand survey on the authorised metered consumption only.

1.2. Reasons for using the Water Balance format in Figure 1

The original version of the Standard IWA Water Balance ((Hirner & Lambert, 2000; Alegre et al, 2000) is shown in Figure 2.

System Input Volume	**Autorized consumption**	**Billed authorized consumption**	**Billed metered consumption (including water exported)**	**Revenue Water (or billed volumes)**
			Billed unmetered consumption	
		Unbilled authorized consumption	**Unbilled metered consumption**	**Non Revenue Water or (unbilled volumes)**
			Unbilled unmetered consumption	
	Water losses	**Apparent losses**	**Metering inaccuracies**	
			Unauthorized consumption	
		Real losses	**Transmission and distribution mains**	
			Overflow or leakage of storage tanks	
			Service connections to meter	

Figure 2: IWA Water Balance (source: Performance Indicators- first edition 2000)

The first Performance Indicators Report (Alegre et al, 2000) contained an additional diagram, which clearly identified ‘Water Supplied’ (equal to System Input Volume minus Water Exported) and numerous options and components for ‘System Input Volume’. These options and enhancements were rarely referred to in the early years after 2000 when the IWA Water Balance was being increasingly adopted as a basic international standard in many countries, but as more detailed calculations have become necessary, they have become increasingly relevant and important.

Fortunately, the original IWA Water Balance in Alegre et al (2000) wisely permitted small changes in the terms used in the Water Balance for good reasons, and many countries have included some minor country-specific changes (South African WSC; New Zealand WWA; American AWWA; German DVGW etc.). The reasons for the changes incorporated in the Figure 1 Water Balance used in this Guidance Note are as follows:

- More detail on bulk supply components of System Input Volume – Water Imported, Water from Own Sources, Water Exported, and Water Supplied are all clearly identified
- The need to try to identify and correct for systematic bulk metering errors before entering bulk supply volumes in the Water Balance; this helps to limit metering errors in Apparent Losses to Customer Metering errors, rather than also including Bulk Supply errors
- Water Supplied, shown separately, is essential for correct and unambiguous calculation of some performance indicators; this is now standard in several national Water Balances
- A more detailed breakdown of apparent loss components is provided, as recommended by the original IWA AL Initiative 2006 to 2010.
- Greater detail on water input and water exported components assists in developing water balances which are more orientated towards commercial and energy considerations

The differences in the four Apparent Losses components in Figure 1 allow for unmetered customers, and a breakdown of customer metering inaccuracies into the loss due to the water meters themselves (such as aging and cumulative throughput) and the management of the water meters (such as poor installation or poor meter reading practices). They can be briefly summarised:

- **Unauthorised consumption** refers to unregistered service connections and various types of fraud on the registered service connections (including public equipment).
- **Customer Metering Errors** refers to the errors generated by the water meters themselves but not by the management of the water meters
- **Errors in Estimates of unmetered consumption** refers to the errors generated by the estimates of unmetered consumption. This point is very important in the case of systems that are not metered or not fully metered.
- **Errors throughout the Data Acquisition Process** refers to the errors that may be generated at the various stage of the data acquisition process such as data capture, data transmittal, data processing, data manipulation, etc.

More detailed information on apparent losses (AL) are presented in Section 1.4, Sections 4.3 to 4.5 and Appendices 3 to 5.

Commercially-oriented Water Balance

The IWA water balance in Figure 1 is “technically-oriented” as it is based on the continuity of water flow (i.e. mass balance), but not “commercially-oriented” (i.e. taking into account the value or cost of the water). For instance, one point that is not taken into account is that the volume of water that is billed and not paid by the customers could be considered as a component of non-revenue water.

Some papers have already been produced on that topic (Jones R, 2007 and Whiting, 2008). This definition may lead to an alternative definition of NRW. NRW would consist of the four components: Real Losses, Apparent Losses, Unbilled Authorised Consumption and Unpaid Bills. This monetary balance would not provide a universal comparable benchmark as the price per unit volume varies between utilities and between countries. However, it could be useful for a utility's internal benchmarking requirements.

System Input Volume	Autorized consumption	Billed authorized consumption	Billed metered consumption (including water exported)	Revenue Water (or billed volumes)	Billed & Received
			Billed unmetered consumption		Billed & Not Received)
		Unbilled authorized consumption	Unbilled metered consumption	Non Revenue Water or (unbilled volumes)	
			Unbilled unmetered consumption		
	Water losses	Apparent losses	Metering inaccuracies		
			Unauthorized consumption		
		Real losses	Transmission and distribution mains		
			Overflow or leakage of storage tanks		
			Service connections to meter		

Figure 3 : Monetary Balance with indication of volume paid or not paid for.

It seems that the great advantage of the business-oriented water balance would be to promote complete water audits of the water utilities including both the operational and commercial side.

However, the authors of these AL Guidance Notes believe that it would be confusing - and not very effective - to work on water losses and unpaid bills in the same table. In particular, the period of time to take into account for the payment of the bills is not the same as the period of time considered to establish the volumetric water balance. It would create some troubles. In addition, different utilities have different water tariffs and it would be difficult to compare their business-oriented water balance.

Therefore, the water balance shown in Figure 3 is not recommended for universal application. However, it does emphasise the issue of the unpaid bills as a real problem. In some cases such as low-income areas, it is possible to reduce the NRW rate by sending bills to consumers who will never pay their bills: NRW will decrease but the revenue collection rate will decrease also and the outstanding debt will increase. The measure will be good for the standard water balance but not for the utility.

Finally, the traditional volumetric water balance is not supposed to solve all Utilities' problems. Any water audit should be based not only on the NRW rate but also on other indicators such as the Revenue Collection Ratio for instance (Alegre et al 2000). It is necessary to reduce NRW and increase Revenue Collection rates simultaneously[1]. Therefore, the authors have presented the methods to reduce unpaid bills and outstanding debts in Appendix 6.

1.3. Focusing on Unbilled Authorised Consumption (UAC)

Unbilled authorised consumption (UAC) is a NRW component but not a water loss component. However, it is not recommended to calculate the water balance without a good understanding and evaluation of the unbilled authorised consumption.

UAC may be classified into two categories:

- Water used for servicing or field operation: any Water Utility has to use water for its own operational needs.
- Water provided free of charge: the Water Utility may provide water free of charge to various consumers or categories of customers: some administrative or religious premises, its own

[1] This point needs to be carefully considered in the case of the performance-based contracts to reduce NRW. It is always possible to reduce NRW volumes by increasing the water billed. However, this would not be a good alternative for the utility if the additional water billed is not paid by the customers and generates no increase in the revenue collection ratio.

employees, etc. Such practice may be based either on habits and customs or on legal provisions. Whatever the causes, it needs to be listed and quantified.

Consumption free of charge is a concept that may be quite different according to the country, its law, its tradition or its culture. However, it is also important to list and quantify it in order to design the water balance. This point is developed in Appendix 2.

UNBILLED AUTHORISED CONSUMPTION			**Selected Examples**
1	**2**	**3**	**4**
Servicing (or field operation)	Tank cleaning	unmetered	Regular cleaning of service reservoirs
	Pipe cleaning	unmetered	Flushing of pipes to improve water quality in distribution 'dead ends'
	Discharge	unmetered	
	Hydrant tests	unmetered	Flow and pressure test at hydrants
	Water treatment devices	metered/ unmetered	Backwashing of filters
	Others	metered/ unmetered	Fire fighting
Consumption Free of charge	Utility staff	metered/ unmetered	Municipal/water authority housing
	Admin. Customers	metered/ unmetered	Government buildings
	Others	metered/ unmetered	

Table 1 : Examples of Unbilled Authorised Consumption (UAC)

1.4. Focusing on Apparent Losses (AL)

Apparent losses are classified according to the following categories: unauthorised consumption, customer metering errors, errors in estimates of unmetered consumption, and errors linked to the data acquisition process. Table 2 lists and describes different causes that may impact the level of apparent loss in each category

It is important to note that some components of apparent losses can be either positive or negative. For instance, a water meter may over register in some specific conditions; similarly, unmetered authorised consumption may be over-estimated or under-estimated.

This list clearly shows that measurement is the core issue in terms of apparent losses. Defective measurement generates apparent losses:

- meter error relates to water meter precision and uncertainty
- poor estimate of unmetered consumption relates to the lack of water meter on the service connections
- unauthorised consumption is generally not metered
- data handling errors are due to measurement errors at the various stage of the data acquisition process: data capture, data collection; data transmittance, data processing and manipulation.

APPARENT LOSSES			
1	**2**	**3**	Description
Unauthorised consumption	Registered customers	Meter by-pass	Unauthorised parallel, unmetered flow of water alongside the meter.
		Additional Unregistered connections	Case of double connection: one is registered, the other is not
		Disconnected customers illegally/unauthorised reconnected	Very frequent source of apparent loss in case of poor customer management: specially when disconnected connection are never checked
		Non-active customers illegally/unauthorised reconnected	As above
	Unregistered customers	Unregistered (illegal) connection	Also called illegal (or clandestine) connection
		Unregistered consumption in low income areas	
	Network equipment	Water theft from hydrants or other equipment	
Customer Metering Errors	Meter errors	Intrinsic errors	Error of indication of a water meter determined under reference conditions (ISO 4064: 2005)
		Aging	Change in the performance characteristics of the meter, due to the historic operational conditions of the meter.
		Inappropriate meter installation	Installation of a meter outside the limits of the reference conditions of the meter's pattern approval and/or the installation requirements stipulated by the manufacturer
		Inappropriate sizing	Incorrect matching of meter's specified flow range with the range of water demands associated with the particular user
		Impact of customer's in-house installation	Effect of the downstream-connected installation on the error of the metered volume passed through the meter. (E.g. storage tank etc.).
	Meter* management	Meter out of operation	Stopped meters
		Errors in meter reading	Error in reading of the meter display: incorrect reading of the value on the meter display.
		Invented meter reading	Intentionally incorrect reading of the value on the meter display.
Errors in estimates of unmetered consumption	Unmetered service connections	Misestimate of current unmetered connections	
	Meters out of operation	Misestimate in the case of meter out of operation	
Errors linked to Data Acquisition Process (data handling errors)	Data Capture	Measurement errors*	Related to the selection, sizing and calibration of meters
	Data Collection and Transmittance	Reading and signal path errors	Errors associated with the conversion of the data at various points along the pathway it is required to travel. Water meter lag
	Data Processing	Statistical errors	Errors associated with the lack of data validation processes
	Data Manipulation	Understanding errors	Misinterpretation of the data and its true meaning
	Application errors	Application errors	Incorrect application of the data and not using statistically representative samples.

(*) these errors may be also registered as errors linked to data acquisition system or handling errors

Table 2 : Apparent Losses (AL): Components and Causes

Therefore, the topic of the reliability of the measurement is essential for the establishment of water balances. This point is developed in the IWA manuals and guidelines and the important statements presented at the beginning of the IWA Performance Indicator manual need to be reminded hereafter (Alegre et al 2006)[2].

1.5. Reducing Uncertainty in the Water Balance

How reliable are volumes of Non-Revenue Water and its components, calculated from a Water Balance? The answer depends on many factors, and varies, but it can be assessed.

Each of the measured or assessed volumes entered in a Water Balance – including metered volumes - has random uncertainties caused by broad combinations of different factors; some are small, but others are large. Uncertainty is sometimes expressed in +/-% terms, and sometimes in +/- volume terms; both have their place in calculations, but ultimately it is the uncertainty in volume that needs to be quantified, so that it can be converted into financial or economic calculations.

In the first IWA Performance Indicators Report, (Alegre et al, 2000) it was:

- recommended that the quality of input data should be assessed in terms of 'reliability' and 'accuracy': as defined below, and proposed in the Banding system in Figures 3 and 4.
- considered that practice showed that, in general, data providers do not have detailed information on reliability and accuracy, but are able to provide informed guesses, if broad bands are adopted.
- the reliability of the source aims to account for uncertainties in how reliable the source of the data may be, i.e. the extent to which the data source yields consistent, stable, and uniform results over repeated observations or measurements under the same conditions each time.
- the accuracy of data aims to account for measurement errors in the acquisition of input data, i.e., the closeness of observations, computations and estimates to the true value as accepted as being true.

Reliability Band	Definition	Accuracy Band	Associated Uncertainty
***	Highly reliable data source: data based on sound records, procedures, investigations or analyses that are properly documented and recognised as the best available assessment method.	0 – 5%	Better than or equal to +/- 5%
		5 – 20%	Worse than +/- 5% but better than +/- 20%
**	Fairly reliable data source: worse than ***, but better than *	20 – 50%	Worse than +/- 20%, but better than +/- 50%
*	Unreliable data source: data based on extrapolation from limited reliable sample or on informed guesses.	> 50%	Worse than +/- 50%

Table 3 : Recommended data source reliability bands

Table 4 : Recommended accuracy bands

The general method presented in Figures 3 and 4 provide first estimates of accuracy and reliability, and are useful for initial assessment of the quality of the data input to the Water Balance, but they do not provide a methodology for calculating the uncertainty of a grouped data output, for example System Input, Water Supplied, Non-Revenue Water, Apparent Losses.

[2] Failure to consider these recommendations usually leads to erroneous water audit and failure in the design of the action planning to reduce NRW.

Accordingly, even when an individual data source is highly or fairly reliable, analyses that are more detailed need to be carried out in order to make sound decisions. Whatever the form of the balance the question of uncertainty needs to be properly assessed. The Water Balance cannot be used for planning purposes if the uncertainty of the various components is poor or unknown.

The first step in a more detailed analysis is to try to separate systematic errors (which are always positive, or always negative), from random errors (which have equal probability of being positive or negative). This topic is considered in more detail in Appendix 1, and the Water Balance in Figure 1 assumes that bulk metered volumes have been corrected for known systematic errors.

The Normal distribution is widely used for symmetrical probability distributions. It has a bell-shaped frequency curves with a single peak. Two quantities have to be specified: the mean μ, where the peak of the density occurs, and the standard deviation σ, which indicates the spread or girth of the bell curve. Different values of μ and σ yield different normal frequency curves and hence different normal distributions. The normal density can be actually specified by means of an equation. The height of the density at any value x is given by the equation:

$$\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}(\frac{x-\mu}{\sigma})} \qquad (1)$$

All Normal distributions share an important property, often referred to as the Empirical Rule that allows us to treat them in a uniform fashion.

- 68% of observations fall within +/- 1 standard deviation of the mean (67% confidence limit)
- 95% of observations fall within +/- 2 standard deviations of the mean (95% confidence limit)
- Almost all (99.7%) of values for a Normal distribution lie within +/- 3 standard deviations of the mean as can be seen in Figure 6.

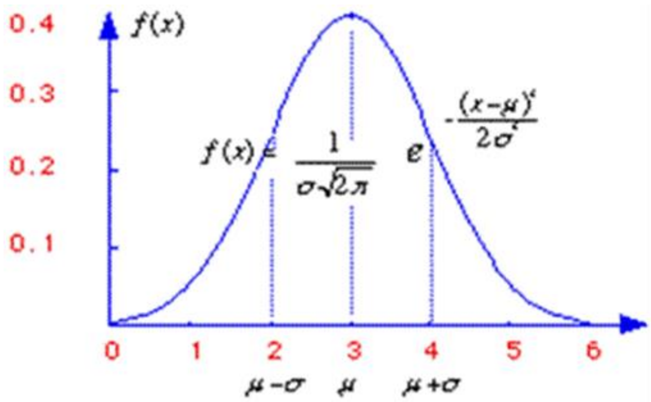

Figure 4 : Normal Distribution

For more than 20 years, some leakage specialists have been using the properties of the Normal distribution to assess 95% confidence limits for Water Balance components, by assigning +/- % uncertainties for random errors of individual data entry components, which are assumed to represent 95% confidence limits (+/- 2 standard deviations). An example is shown in Table 5.

	Volume (V) [m3/d]	95% Confidence Limits (CL)		Standard Deviation (SD) [=V x CL x 0.5]		Variance (Va) [= SD^2]
System Input Volume	300,000	+/- 2 %	→	3,000	→	9,000,000
Billed Author. Consumption	200,000	+/- 1 %	→	1,000	→	1,000,000
Non-Revenue Water	100,000	+/- 6 % [=SD/V/0.5]	←	3,162	←	10,000,000
Unbilled Author. Consumption	5,000	+/- 50 %	→	1,250	→	1,562,500
Water Losses	95,000	+/- 7 %	←	3,400	←	11,562,500
Commercial Losses	30,000	+/- 30 %	→	4,500	→	20,250,000
Real Losses	65,000	+/- 17 %	←	5,640	←	31,812,500

Table 5 : Building a Water Balance with 95% Confidence Limit (after Lambert & Liemberger)

This approach has given many important general insights into the relative importance of different Water Balance components, despite the drawback that there is no absolute method for assessing standard deviation of random uncertainty for some input components. For example, when bulk meters are tested in situ, the uncertainty of their volume output during the test cannot be less than the uncertainty of the method used for checking the bulk meter.

The calculated variance (equal to the standard deviation squared) for each data item is an integral part of the calculation, and is very useful for identifying priorities for where effort should be expended to improve the quality of the overall analysis – the components of the analysis with the largest variance are those that should be improved first.

However, it must be admitted that these attempts at a robust statistical approach have not been widely understood or adopted by practitioners who are unfamiliar with, and possibly intimidated by, Equation 1 and the use of specialist statistical terms.

In a recent attempt to de-mystify these calculations for wider use, Lambert (2016) explains how a user can set up their own water balance in basic IWA format on a spreadsheet (see Table 6), and then enter assessed uncertainty in +/-% and +/-volume, on a step-by-step basis. Specialist statistical terms are avoided, as are assumptions that % uncertainty is at the 95% confidence limit for water balance components where such estimates are not obtainable in practice.

	Water Balance Calculation	Data entry	Calculated	Assessment of Random Uncertainty and Priorities			
COLUMN	1	2	3	4	5	6	7
ROW	Component of Water Balance	Basis of calculation	Annual volume AV Mm^3	Random Uncertainty u +/-%	+/-U Mm^3		Priorities to reduce Uncertaint
A1	Treatment Works Y Output		5.000	2.0%		0.100	1
A2	Treatment Works Z Output		2.500	2.5%		0.063	4
A3	Standby Boreholes		0.500	6.0%		0.030	9
A	Water from Own Sources WOS	WOS = SUM of A1 to A3	8.000	1.5%	0.122		
B	Water Imported WI		4.000	2.0%		0.080	3
C	System Input Volume SIV	SIV = WOS + WI	12.000	1.2%	0.146		
D	Water Exported WE		2.000	2.0%		0.040	7
E	Water Supplied WS	WS = SIV - WE	10.000	1.5%	0.151		
F	Billed Metered Consumption: Residential BMCR		5.000	2.0%		0.100	1
G	Billed Metered Consumption: Non-Residential BMCNR		2.800	2.0%		0.056	6
H	Billed Metered Consumption BMC	BMC = BMCR + BMCNR	7.800	1.5%	0.115		
I	Billed Unmetered Consumption BUC		0.300	20.0%		0.060	5
J	Billed Metered and Unmetered Consumption	BMC + BUC	8.100	1.6%	0.129		
K	Non-Revenue Water NRW	NRW = WS - BMC - BUC	1.900	10.5%	0.199		
K	Non-Revenue Water NRW	NRW	1.900	10.5%	0.199		
L	Unbilled Authorised Consumption UAC	0.5% of BMC	0.039	20.0%		0.008	10
M	Water Losses WL	WL = NRW -UAC	1.861	10.7%	0.199		
N	Unauthorised Consumption UC	0.1% of BMC	0.008	20.0%		0.002	11
O	Customer Metering Errors CME	2.0% of BMC	0.156	20.0%		0.031	8
P	Apparent Losses AL	AL = UC + CME	0.164	19.1%	0.031		
Q	Real Losses RL	RL = WL - AL	1.697	11.9%	0.201		

Table 6 : Water Balance with uncertainty and priorities for action (Lambert, 2016)

Note that the priorities for further action to reduce uncertainty are based on uncertainty in +/-volume terms, not in +/-% terms. An overview of sequence of actions is as follows

- Customise the Water Balance components in the spreadsheet to be appropriate to your system
    - use Einstein's suggestion – as simple as possible but no simpler
- Calculate the Water Balance in the normal way
- Then enter +/-% uncertainty estimates as first step for initial calculations of uncertainty
- Multiply volume of input parameters by assessed +/-% uncertainty to get +/- volume uncertainty
- Prioritise activity to reduce uncertainty by ranking +/- volume uncertainty of inputs
- Do not show variance in the final spreadsheet – it confuses those unfamiliar with the term
- Calculate the ranking of priorities automatically in the spreadsheet, and show them clearly
- Use the spreadsheet for 'what-if' sensitivity testing

1.6. Water Balance Software

Many versions of water balance software have been developed since 2000. They are more or less simplified, and more or less customised for local circumstances and traditional terminology, but they should always follow the basic foundation principles of the IWA Water Balance.

The authors mention only the following list of free software, currently available on the web. This list is not exhaustive.

WB- Easy Calc, The Free Water Balance Software, by courtesy of Liemberger ad Partners

This multi-language software complies with IWA and World Bank recommendations.

A specific version has been developed for Brazilian context.

CheckCalcs. developed by ILMSS Ltd around 2003, over 700 copies distributed worldwide

Regularly updated to reflect developments in concepts since 2003. Numerous customised versions, some translated into several languages.
European versions now superceded by EurWB&PICalcs

EurWB&PICalcs: developed by ILMSS Ltd in 2015 to assist implementation of EU Reference document Good Practices on Leakage Management - (European Union, 2015)

This free software uses methods and recommendations in the EU Reference document, which is publicly available following an initiative sponsored by the European Commission (DG Environment), and is also approved by EurEau. This software is designed to be used in the 'Getting Started' methodology to provide a quick assessment of current leakage management and 'fit for purpose' leakage performance indicators for any European Utility system or sub-system, with quick simple sensitivity testing.

AWWA Free Water Audit Software, developed by the AWWA Water Loss Control Committee

This software complies with AWWA recommendations, which presents some specificities.

In addition, many Countries, States and individual experts have developed their own software.

References are listed in Section 6 of the Guidance Note

2. WATER AUDIT COMPONENT ANALYSIS AND BEST PRACTICES

Summary

This chapter presents some guidelines on populating the water balance with data to calculate or evaluate the Current Annual Apparent Losses CAAL and its components. More information is provided in the Appendices for each component of Apparent Losses. Unbilled authorised consumption and Unpaid bills are not components of Apparent Losses but they need to be assessed and controlled within the framework of the Water Balance approach and the resulting action planning to bring Non-Revenue Water under control.

2.1. Water Balance: Calculation of Non-Revenue Water volume

2.1.1. Calculating Non-Revenue Water Volume

The first step of any Water audit is to assemble bulk meter and customer consumption data (metered and unmetered), and establish a calculation of Non-Revenue Water NRW. The sequence of steps in Table 6 of Section 1, which allows uncertainties to be assessed, is listed below

Rows A: Define sources of water from 'Own Sources', and total of 'Water from Own Sources' WOS

Row B: Define volume(s) of Water Imported WI

Row C: System Input Volume SIV = Water from Own Sources WOS plus Water Imported WI

Row D: Define volume(s) of Water Exported WE

Row E: Water Supplied WS = System Input Volume SIV minus Water Exported WE

Rows F and G: Define Billed Metered Consumption, Residential and Non-Residential

Row H: Billed Metered Consumption = sum of Residential and Non-Residential components

Row I: Estimate or Assess Billed Unmetered Consumption

Row J: Billed Metered and Unmetered Consumption = sum of Billed Metered and Billed Unmetered

Row K: Non-Revenue Water NRW = Water Supplied– Billed Metered and Unmetered consumption

2.1.2. Good Practices for Calculating NRW from a Water Balance

Large Meters Calibration

Large water meters are used to measure system input volumes and more generally bulk supply such as treated water and imported and exported volumes. The confidence in the data provided by these meters is of paramount importance: it can be considered as a prerequisite for the establishment of the water balance and for the quality of the decision-making resulting from the water balance.

Systematic over registration of Water Supplied volume generates a fictitious increase in NRW and Water Losses that is neither a real loss nor an apparent loss but that could erroneously be considered as such. This may generate an over estimate of real or apparent losses. Alternatively, systematic under registration of Water Supplied would generate an under-estimate in NRW and Water Losses. In both cases, the errors may generate inappropriate decisions. The financial implications of these errors may be high. "Any programs, therefore which can determine and minimise the errors associated with these measurements on a sustainable basis will ultimately facilitate optimal decision-making and improve financial accountability" (Johnson, E H, 1999)

It is therefore essential to include the regular and comprehensive calibration of large water meters as part of sustainable water management practice. Every Water Utility should have an accredited approach to regularly calibrate and check its large meters. This point is very important as unfortunately, many Utilities have no accredited or reliable approach to calibrate their large bulk meters.

Meter Lag and Premature Calculations

In Water Balance calculations, it is not usually difficult to synchronise bulk meter readings to the start and finish dates of the annual water balance. However, for most systems it is not possible to read all customer meters on these two dates, unless there is a comprehensive automatic meter reading (AMR) system.

Residential and non-residential consumers are often read at different frequencies, between 1 month and one year, so after the last day of the 'Water Year', it may take several months more before all of the customer meter readings are available to cover calculation of metered consumption during the Water Year. The readings need to be adjusted to assess what the actual metered consumption was during the Water Year. Failure to carry out such 'meter lag' calculations can be a significant source of error.

Also, regulatory and media pressure to publish results means that Utilities sometimes have to complete the water balance before all the relevant data are available and customer meter reading and billing queries are resolved. 'Premature calculation' can also be an additional source of error even in fully metered systems.

Unmetered customers

Particular difficulty is experienced in completing the water balance with reasonable accuracy where a significant proportion of customers are not metered. Authorised Billed Unmetered Consumption in such cases should be derived

- from sample metering of statistically representative individual service connections of various categories and sub-categories and/or
- by measurement of total flows into discrete areas of uniform customer profile.

In the latter method, subtraction of leakage volume from total input is necessary, leakage being determined by analysis of the sub-components of minimum night flows, adjusting for diurnal pressure variation as appropriate using the Night-Day Factor (Lambert, 2016).

2.2. Water Balance: Calculation of Water Losses

Non-Revenue Water consists of Unbilled Authorised Consumption and Water Losses (which is the sum of Apparent and Real Losses).

The sequence of steps for calculation of Water Losses in Table 6 of Section 1, which allows uncertainties to be assessed, is listed below

Row K: Non-Revenue Water NRW has been previously assessed from steps A to K

Row L: Assess Unbilled Authorised Consumption UAC

Row M: Water Losses WL = NRW minus Unbilled Authorised Consumption UAC

Unbilled authorised consumption (UAC) is part of NRW but not part of apparent loss, so it needs to be measured or assessed in order to proceed with the water balance. Underestimating or neglecting UAC in any top-down or bottom-up approach would lead to overestimated values of Water Losses. In addition, the value of UAC needs to be optimized for obvious financial reasons.

Appendix 2 provides useful information on a wide range of components of Unbilled Authorised Consumption, some of which may be metered. Guidance is given on estimate unmetered components of UAC, together with examples of standard or default values used in various countries.

2.3. Splitting Water Losses into Apparent and Real Losses

2.3.1. Top-down and bottom-up approaches

There are two general approaches for splitting Water Losses into Apparent Losses and Real Losses:

In the **top-down** approach, a first estimate is made of the Current Annual Apparent Losses CAAL, preferably based on a % of billed metered consumption. This is shown in Rows M to P of Table 6 of Section 1. The Current Annual Real Losses CARL are then calculated as

Current Annual Real Losses CARL = Water Losses – Current Annual Apparent Losses CAAL

In the **bottom-up** approach, the CARL is evaluated from analysis of measured minimum night flows (MNF) and Night-Day Factor. CAAL is calculated by the formula CAAL = Water Losses – CARL

In practice, the top-down approach is often based on an approximation of the apparent losses.

The bottom-up approach is not always applicable or may require a large investment (to install DMAs for instance), Also, the interpretation of the leakage component of the measured minimum night flows can be difficult, especially for unmetered properties, and there needs to be a further adjustment for variation of average zone pressure over 24 hour periods (the Night-Day Factor NDF).

When it is possible to use both methods, it is possible to check if the calculations are consistent or not, but defining the exact boundary between real and apparent loss can be a significant issue for some utilities. The volumes that are consumed by the customers at a very low flowrate are not registered by their meters. These volumes are apparent losses (under-metering). However, when the real losses are extrapolated from the Minimum Night Flow value there is a risk for these apparent losses to be registered as a large part of the real losses. There is also a risk for these losses to be accounted-for twice, as both real losses and apparent losses. This possibility must be taken into consideration during the establishment of the balance.

2.3.2. Direct evaluation of Apparent Losses – Component analyses

Whatever the approach is, there is a need for a direct evaluation of the apparent losses. Therefore, the authors recommend developing methods and guidance in order to directly measure or estimate each component of the apparent losses. As these measurements and estimates are assembled, it should gradually become clearer whether Apparent Losses (or any particular component of Apparent Losses) are sufficiently large to require management attention. As Apparent Losses represent water that is consumed but not paid for, they can quite readily be converted to financial equivalent loss of income to the Utility using the retail price of water, so the judgement needs to be based on both volume and retail price of water.

Checking the figures of the water balance will be easier if each component of the real and apparent losses is estimated directly, rather than deducting CAAL for the estimation of CARL or vice versa. Then, it will be possible to check the consistency of the figures.

In order to measure or estimate the various apparent losses it is necessary to consider two steps:

- Analysis of the customer database
- Field surveys: estimating AL without field survey would be unreliable.

The audit of the customer database (even when it is a poor database) enables detection of anomalies and discrepancies. It is a prerequisite in order to define any further field survey.

These Guidance Notes recommends the use of all three approaches: Top Down, Bottom Up and Component Analysis.

2.4. Apparent Losses - Evaluation and Component Analysis

2.4.1 Methods for quantifying each Apparent Losses component

In the case of apparent losses, field surveys and laboratory experimentation or measurements are necessary to quantify each component of the apparent loss.

At a very preliminary stage, Current Annual Real Losses CAAL may be assessed through a benchmarking approach. However, because there are so many parameters, confirmation from field surveys is needed before any meaningful strategies can be developed.

Table 7 provides selected examples of the numerous causes for apparent losses. They are classified by categories and subcategories, together with recommended methods for evaluating their magnitude.

The objective of classification by subcategories and cases is to show the number of sampling and field or laboratory surveys that are necessary to cover the whole topic. For instance:

- field surveys related to domestic consumers will differ from those related to large customers
- laboratory survey on aging (or the deterioration meter's measurement error) will not be truly representative if these meters were incorrectly installed
-

Categories of AL	**Subcategories of AL**	**Cases**	**CAAL** **Method for evaluation**	**UAAL applicability**
Unauthorised consumption	Registered customers	Meter by-pass and other fraud	Sampling and Field surveys	Yes (but difficult)
		Additional Unregistered connections	Sampling and Field surveys	Yes (but difficult)
		Disconnected customers illegally reconnected	Sampling and Targeted Field surveys	Yes (but difficult)
		Non-active customers illegally reconnected	Sampling and Targeted Field surveys	Yes (but difficult)
	Unregistered customers	Unregistered (illegal) connection	Sampling and Field surveys	Yes (but difficult)
		Unregistered consumption in low income areas	Sampling and Field surveys	Yes (but difficult)
	Network equipment	Water theft from hydrants or other equipment	Sampling and Field surveys	Yes (but difficult)
Metering Errors	Meter errors (small consumers)	Aging	Sampling /Customer. Profile / Meter Errors graph.	Yes (but difficult)
		Inappropriate meter installation	Sampling and field meter tests	No
		Impact of customer's in-house installation	Sampling / Census / Lab. Tests	Yes (but difficult)

	Meter errors (large meters)	Meter Aging	Sampling /Customer. Profile / Meter Errors graph.	No
		Meter Oversizing	Sampling /Customer. Profile / Meter Errors	Yes (but difficult)
		Inappropriate meter installation	Sampling and field meter tests	Yes (but difficult)
		Impact of customer's in-house installation (domestic tanks for instance)	Sampling / Census / Lab. And Field Tests	Yes (but difficult)
	Meter management	Meter out of operation	Sampling and Meter tests	No
		Errors in meter reading	Computer analysis / Field check	No
		Invented meter reading	Computer and Field check	No
Misestimate of unmetered consumption	Small consumers		Sampling and Field Surveys	Yes (but difficult)
	Large consumers		Meters must be installed	No
Errors throughout Data Acquisition Process	System Input and Water Supplied	Error in bulk metering	Calibration procedures (protocol of calibration)	No
		Error in data capture and transmittance	Technical audit	No
	Errors in customer metering	Manual or semi manual Meter reading	Sampling and Field survey	No
		Automatic Meter reading	Technical audit	No
	Data processing errors	Billing system errors	Billing system and procedures audit	No
		Errors in other data manipulation	Customer management and procedures audit	No

Table 7 : Categories of Apparent Losses, and recommended methods for their evaluation

The fourth column describes the methods that can be used to evaluate the losses: mainly, technical audit, laboratory sampling survey or field sampling surveys.

In the case of sampling surveys, the extrapolation will be considered as valid only when the sampling procedure is valid. The confidence limits of the CAAL values relate to the choice of the sampling procedures.

The only interest of the last column 5 is to show in which cases there is an unavoidable level of loss but in fact, the quantification is not very useful as shown in the next section.

2.4.2. Field and laboratory surveys: sample and/or pilot areas

It is unwise to assess CAAL using the limited data available from some types of periodical corporate reports, as is sometimes done for NRW percentage calculations of water input or for the total loss per km and per day. CAAL can only be determined from appropriate field surveys.

The specific studies that are needed to achieve the audit should be carried out in pilot zones or, preferably, on samples of pipes, customers, meters, etc. What are the advantages and drawbacks of each option?

- Pilot areas and samples must be selected such that the results obtained may be realistically extrapolated. The sampling approach is generally more appropriate in that respect if the samples have been properly defined and based on a scientific statistical approach.
- When a single pilot area is selected, the results generally cannot be extrapolated since this pilot area does not represent the whole of the city. It is generally necessary to select several pilot areas representing the various parts of the city and based on urbanism and social criteria.
- The other advantage of the sampling approach is that it is more appropriate than the pilot area approach because it enables assessment of individual various components of the apparent loss as described in Table 7.

Examples:

- The multi-use investigation or census of the consumers, in well-defined zones, in order to detect the technical and administrative anomalies, and in particular the possible fraud;
- The passage of meter samples on the test bench to study their behaviour and to determine their useful lifespan,
- Data-logging to determine the customer consumption profiles (i.e. demand patterns),
- Tests on new types of meters,

2.4.3. Examples of field and laboratory surveys: sample and/or pilot areas

Unauthorised consumption and other customer anomalies

A mini pilot census will provide a first indication on the importance of possible fraud and other anomalies, which could exist between the field reality and the technical and customer's databases.

- The investigations will cover 3% to 5% of the customers, who will be selected according to their geographical locations, their categories, and their social conditions. It is also recommended to carry out investigations that are more specific:
    - On samples of customers with zero or abnormally low consumptions and
    - On samples of customers that are supposed to have been cut-off or having terminated their contract.

It is recommended to ensure that the following ratios are calculated:

- Percentage of inactive clients, illegal consumption / total number of inactive customers visited
- Percentage of non-registered customers / total number of customers visited
- Percentage fraud on the water meters / total number of meters visited
- Percentage of anomalies found in the field with respect to the data on the existing files

At the end of the pilot study, it will be possible to define the most appropriate type of investigation to be operated through the action plan:

- Exhaustive census
- Partially localised census
- Targeted investigations on one or more different types of anomaly

Billing losses

In addition to the unauthorised consumption (illegal service connections or frauds), billing losses may be the result of different causes:

- Incorrect tariff application,
- Meter reading errors or absence of reading,
- Billing corrections – or discounts for example - not taken into account.

The customer services management must rely on clear procedures that are regularly audited at the different levels of the personnel concerned: installation of a meter, meter reading, back office and front office, bill delivery etc. The errors and the anomalies must be the subject of detailed investigations that will sometimes call into question, and improve, the procedures.

Concerning the meter reading procedures, the following points must be the subject of a specific analysis, or even an audit:

- Quantity of unread meters (why? and since when?);
- Critical analysis of the meter reading;
- Control on unread meters (second reading, inspection etc.);
- Quantity of estimated bills;
- Factors used for the estimation.

Under measurement

The errors by under measurement are most often found in:

- The over sizing of the meters;
- The ageing of the meters that leads to a progressive deterioration of their error of measurement.

It will be necessary to conduct several types of analysis

- Structure of meter fleet and detection of the large customers: it is frequently the case that 3% to 4% of the customers consume more than 50% of the total consumption;
- Verification via the customer database of the probability of the over sizing of the large customer meters;
- Verification of samples of meters using data loggers;
- Definition of the consumption profiles for each type of customer;
- Laboratory testing to establish error graphs of meters samples of different ages and volume usage.

2.5. Default values approach

In some countries, "default values" for apparent loss item have been defined by the national water organisations or regulators. Any claim greater than the default value requires validated Utility specific data [3].

No doubt, this approach may provide assistance in terms of global strategy especially with respect to regulation and tariff setting. No doubt also that the approach is valid if the reservation about the claim is strictly followed (which requires appropriate surveys).

However, the incautious use of default value within the water balance may have a negative and misleading impact. If the true value is far above the default value, it may lead to a significant over estimation of the real loss.

The reliance on default values – unless they are set very low - instils less confidence in the results produced. Any Water Utility should have its own realistic and practical approach to assess its own levels of apparent losses. The direct estimation of the AL components should include an appropriate evaluation of their uncertainty as shown in Table 6.

2.6. Dealing with unauthorised consumption

This section lists the various kinds of unauthorised consumption: non-registered consumers, unauthorised consumption of registered customers and other types of water theft. It presents the various ways to quantify the loss, to reduce it and to get it under control.

The level of unauthorised consumption is not only the consequence of poverty, dishonesty or cultural aspects: it also often results from the laxity of the Water Utility and its poor strategy in terms of social involvement and communication. Relevant solutions are also outlined in the Appendix 4.

- General census in pilot areas or in sampled areas, including detection of anomalies
- Partial targeted (focused) field surveys in selected areas or fields
- "Walk the line" and "Walk the book" exercises
- Targeted investigations based on preliminary analysis of the database
- Comparison to other utilities customer's databases (electricity, telephone, taxes, etc.).
- "High risk" consumer's method
- Self-reporting (or denunciation) under an amnesty process.
- Community participation in the fight against illegal connections and frauds.
- Customers' observatory
- Mapping (GIS) analysis.
- Detection of illegal connections in the case of large consumers.
- Ground penetrating radar (GPR) to detect illegal connections

[3] In Australia for instance, in 2011, default values are the following:

- 0.5% of water supplied (input water less bulk exports) for Unbilled Authorised Consumption
- 2.0% of Metered Consumption for Under-Registration of customers' meters,
- 0.1% of water supplied for Unauthorised Consumption

If a Water Utility uses values greater than the above defaults, sufficient data must be provided to satisfy an auditor as to the accuracy of those values used. As a minimum the following must be provided *(for meters)*, a profile of the meter fleet, including age and type and the sampling regime used to determine accuracy

2.7. Dealing with customer metering errors

Customer metering errors are the consequence of meter accuracy or uncertainty. They generally lead to under registration, under metering and finally under billing. The term Metering Errors has been preferred because it is both a technical term (error graph of the meter) and a common term that anyone should understand. In addition, meter error does not always lead to under-registration: it may also lead to over registration.

Appendix 3 considers the meter itself, including the selection of the meter, its ageing process, its usage and its installation. The various methods to review and assess the metering error and to reduce it are presented. However, please note that the meter reading issue is also treated in Appendix 5 regarding data acquisition processes.

In the review and assessment stage, the stress is put on the definition of the customer's consumption profile. There is a variety of types of water meters, which may be used in various contexts. Some are good, others are not; but the best meter in the world may generate a large error if it does not fit the consumption profile of the consumer. This point is often under estimated in some poorly managed utilities.

When the level of metering losses is high, various types of actions would be required to reduce losses. They will be selected in accordance with the results of the review and assessment survey.

These would require a massive (extensive) replacement programme, a specific or targeted replacement programme and meter resizing programmes. These solutions are briefly described below.

- **Specific meter replacement programme for large customers**

The number of large consumers is generally fewer than the number of small residential consumers, but their consumption may represent a significant part of the total water consumption and, consequently, a significant part of the Utility's income. These meters must always be treated as a priority. Considering that oversized meters generates under registration, large meter resizing programs generally provides significant reduction in NRW and increase in financial input.

- **Massive (extensive) domestic meter replacement programme**[4]

When losses in residential consumption are high, it is necessary to carry out a massive meter replacement programme. It is based on the results of the ageing surveys. This survey will shows that the replacement of the meters installed before Year "n" is highly cost effective and that the rate of return on investment will be high. All the meters installed before Year "n" will be systematically replaced[5].

Many utilities carry out massive replacement programmes instead of using a more selective approach because it is simpler and more cost effective. However, the targeted meter replacement may be carried out in some cases.

- **Targeted meter replacement programme**

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[4] Massive replacement programmes need to be associated to some other actions:

- It would be of little benefit to replace an old oversized meter by a new oversized meter
- It is also an opportunity to correct meter installations when the initial installations did not comply with particular international or national standards.

It can also be considered as an opportunity to use the latest generation of meters incorporating recent technological advancements

[5] Instead of using the date of installation as an ageing criterion, it is also possible to use the accumulated volume that has flowed through the meter since it has been installed for instance replacing all the meters that have registered more than 3000 m^3.

Generally, water utilities use a large range of meters, in terms of technology and brand. These various meters do not have the same life expectancy: the optimum replacement period may not be the same. This need to be taken in consideration and following strategy may be considered as more efficient than implementing a massive replacement programme only based on the date of installation of the meter for instance.

Targeted replacement program may be based on one criterion only or on a multi-criteria analysis:

- Brand or type criteria : replacing brand or type that present the higher rate of loss, or shorter life expectancy
- Technology: replacing volumetric meters in areas where velocity meters are proved to be more convenient,
- Metrological class: class C may be reserved to some category of users only
- Category of consumers
- Range of consumption: for instance replacing a meter when the consumption is lower than 5 m^3/month is not a priority when the Utility bills a minimum rate of 10 m^3/month.
- Resizing programme

The case of the large consumers has been considered as a priority. However, resizing programmes may also be necessary for small consumers. The incorrect Installation of ¾”(20 mm) meters, 1” (25 mm) meters or 1 ½ (37 mm)for a small domestic consumer can incur high losses when actually a ½” (12 mm) meter might be sufficient. Replacing the oversized water meters is a prerequisite either in the frame of a targeted replacement programme or in the frame of a massive replacement programme.

2.8. Dealing with Errors on Data Acquisition Process

The reliability of the water balance and the related strategic decision rely on the confidence limit of the assessment and measures that are carried out to establish the water balance. Errors associated with the acquisition of data are sometimes much significant than any other type of errors. Errors in data can be introduced at all stages of the data acquisition process. For instance, there is no need to have a recent fleet of excellent water meters if the meter reading process is not reliable.

Appendix 5 shows the various sources of errors and how to minimise these errors. A special section is devoted to meter reading procedures. Aspects of data transfer such as the SCADA systems and more recently, the Automatic Meter Reading are also reviewed and assessed. .

2.9. Dealing with Errors in Estimates of Unmetered Consumption

Two different cases need to be considered:

(i) A small number of service connections are not metered

This occurs when all the customers are metered and some meters are out of order. In that case, Utilities should have specific procedures: for instance, they should bill the same amount as during the same period last year. It does not create big issues when the procedures are correctly implemented (but it is necessary to check that they are).

Some devices are usually not metered. In that case, the consumption needs to be assessed. Appendix 2 provides some procedures to assess the volumes consumed.

(ii) Many service connections are not metered, which happens in countries where the decision to install meters has been made recently. Unmetered consumers are billed based on a flat rate, which may be varied with size or value of the property.

In that case, one method consists in comparing the consumption of metered consumers and unmetered consumers. The rate will depend on the type of water supply: continuous or intermittent. The over consumption of the unmetered consumers will be considered as an apparent loss (consumed but unbilled).

2.10. Dealing with Unpaid Bills

Unpaid bills and outstanding debts are not an apparent loss, and should not be included in the water balance, which is a volumetric calculation, but there is no doubt that they generate real financial losses. “Unpaid bills” and “outstanding debts” are very real issues that need to be addressed under certain circumstances where this has been identified as a problem.

Another reason to include the problem of the unpaid bills in the AL Guidance Notes is that in many utilities, unpaid bills are a significant source of apparent losses. Sometimes, consumers who are disconnected for non-payment reconnect their house connection illegally and become illegal consumers. In that case, the Utility is losing twice: through outstanding debts and through apparent losses.

Unpaid Bills can also be considered as an important component to be addressed in an action plan. NRW and Revenue Collection cannot always be considered as completely independent issues: it can be relatively easy to reduce apparent losses by issuing bills to customers in low-income areas for instance but it is much more difficult to get the payment of these bills from bad payers and defrauders. Cost benefit analysis of apparent loss reduction should be based on collected revenue and not only on billed revenue. To improve the financial health of a water utility it is recommended to work at the same time on reducing NRW rate and increasing Revenue Collection Ratio.

Appendix 6 lists some approaches and solutions to address this issue either in the frame of current operation or corrective actions. Emphasis is placed upon payment and revenue collection procedures that need to be adapted to the local technical and cultural background as well as on the customer information system (CIS) that is an essential tool with respect to revenue collection but also to apparent loss control.

References are listed in Section 6 of the Guidance Note

3. APPARENT LOSSES INDICATORS

Summary
This chapter commences with a brief overview of the evolution of Real Losses performance Indicators, from the recommendations of the 1st IWA Performance Indicators Report (Alegre et al, 2000) to the 'Fit for Purpose' recommendations in the 2015 EU Reference document on Good Practices in Leakage Management. It is then explained why the 2000 and 2006 recommendations for Apparent Losses Performance Indicators lead the IWA Water Loss Task Force to set up an Apparent Losses Group in 2007 to look at better approaches, leading eventually to the recommendations in this Guidance Note.

Developing a Performance Indicator for apparent losses is a challenge due to the multiple and complex nature of apparent losses and the need for considering technical, human and social aspects. Considering the diverse nature of the apparent losses, it is clear that detailed component analysis needs to be undertaken. The concept of Unavoidable Annual Level of Apparent Loss (UAAL) has necessarily been replaced by the concept of Reference Level of Apparent Loss (RAAL). A simple calculation method for RAAL has been defined together with an Apparent Losses Index ALI. The Chapter confirms that percentage of System Input Volume and percentage of Water Supplied should not be used as KPIs for NRW and its components.

3.1. Evolution of Real Losses Performance Indicators 2000 to 2015

Much has been done and written during the last fifteen years to analyse, monitor and control real losses, and to understand how best to use the Key Performance Indicators (KPIs) recommended in the 1st and subsequent IWA Performance Indicators Report (Alegre et al 2000 onwards). It is useful to briefly review the changing perceptions of Real Losses KPIs that have occurred during that period,

3.1.1. Real Losses Management Overview

The assessment and management of Real Losses contains so many elements that it is useful to consider the simplified overview shown in Figure 5.

Suppose that the area of the large outer rectangle represents the Current Annual Real Losses (CARL) volume, calculated from the water balance for a specific system. As the system ages, there is a tendency for a natural rate of rise of Real Losses through new leaks and bursts, some of which will not be reported to the Utility. This tendency can be controlled and managed by an appropriate combination of all four of the primary components of Real Losses Management) the four arrows). The extent to which each of these four activities is carried out will determine whether the CARL volume increases, decreases or remains relatively constant from year to year.

This diagram is often called the'4-Component Approach' and the process is often called 'Squeezing the Box'. In the case of an inadequate leakage management policy for any one or more of the constraining policies, the arrows will move outwards and the box will expand as CARL increases. This is why, for the purposes of this Guidance Note on Apparent Losses it will be referred to as the 'Real Losses Dynamic Scheme'.

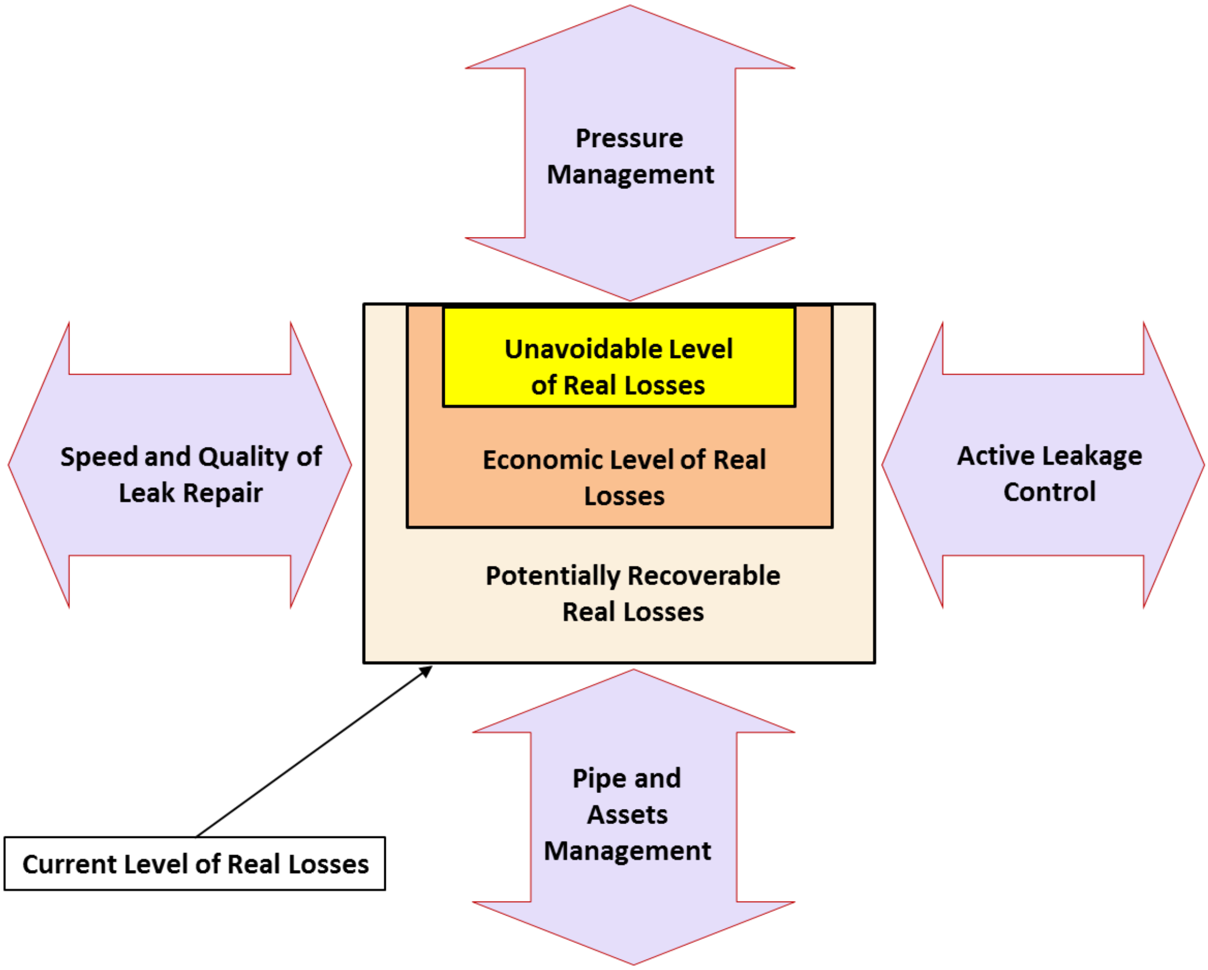


Figure 5 : Real Losses Dynamic Scheme (Four Component Approach), 2001

For each of the four activities, there should logically be an economic level of investment and activity, which would imply an Economic Annual Real Losses (EARL), provisionally shown as the intermediate box, when the cost of further reducing CARL would be higher than the benefit of achieving the additional reduction. However, calculation or assessment of EARL depends upon many parameters in addition to the financial value per m^3 placed on the Real Losses. Depending upon local circumstances and practice, the value placed on Real Losses may be very low – perhaps marginal chemicals and minimal power cost only – or very high, for bulk supplies, environmental and social costs, deferred capital costs etc.

Pressure management interacts with the other components by influencing leak flow rates, repair frequencies on mains and services, and extensions or reductions of asset life. Whereas early (pre-2000) assessments of EARL were based mainly on assessing the economic frequency of active leakage control at current pressure, many leakage practitioners now consider that EARL cannot rationally be assessed without considering the many beneficial influences of pressure management options.

Real Losses cannot be eliminated totally. The lowest technically achievable annual volume of Real Losses for well-maintained and well-managed systems at any specified average pressure is the Unavoidable Annual Real Losses (UARL), represented by the smallest rectangle in Fig. 5. System-specific values of UARL can be calculated using the following equation developed by the 1st IWA Water Losses Task Force (Lambert et al, 1999), based on auditable component analysis.

UARL (litres/day) = (18*Lm + 0.8*Nc + 25*Lp) * P

where Lm = mains length (km)
Nc = number of service connections (main to property line)
Lp = underground service pipe length (km), property line to meter
P = average pressure (metres)
For more information on the ILI and UARL see http://www.leakssuite.com/concepts/uarl-and-ili/

The difference between the UARL (small rectangle) and the Current Annual Real Losses (CARL) is the potentially recoverable Real Losses at the current pressure. The ratio CARL/UARL is the non-dimensional Infrastructure Leakage Index (ILI).

3.1.2. Real Losses KPI Recommendations by IWA, 2000 to 2016

The 1st IWA Water Loss Task Force (Lambert et al 1999) developed the UARL and ILI for international comparisons of technical performance comparisons of Real Losses, because the traditional Real Losses performance indicators used in the 1990's - % of System Input Volume, m^3/km mains/day, litres/service connection/day, and litres/billed property/day - were clearly demonstrated to be inadequate for technical performance comparisons.

The components of the UARL equation can be used to show that for well-managed systems with an ILI close to 1.0 (CARL÷ UARL), more than half the Real Losses volume would be likely to occur on service connections if service connection density exceeds around 20 per km of mains. The IWA performance Indicators Report 2006 included the following recommendations for Real Losses performance indicators for Operational Purposes.

- Litres/connection/day: this is a better operational PI than the traditional % indicator. Density of connections is an important factor affecting leakage volume.
  - but use m^3/km mains/day where density of connections is very low, and mains length becomes a dominating explanatory factor
- ILI aims to allow for other factors (service connection density, service connection length and average system pressure) not related to the physical condition of the network that significantly affect the leakage volume. Technical achievable low-level annual real losses are equal to the best estimate of so called Unavoidable Average Real Losses, UARL.
- %s of System Input Volume should not be used for assessing the efficiency of management of distribution systems, infrastructure condition or Real Losses

However, after 2006 practitioners began to realise that these PIs might be suitable for one Operational Purpose but not necessarily for all Operational Purposes.

Recommendations of the 2015 EU Reference Document 'Good Practices on Leakage Management' on 'Fit for Purpose' KPIs for Real Losses, shown in Table 8 below, have categorised suitability of different KPIs for Real Losses according to the Operational purpose they are used for.

OBJECTIVE	GOOD PRACTICE PERFORMANCE INDICATOR FOR LEAKAGE, FIT FOR PURPOSE						
	Volume per year	litres/ service connection	m^3/km mains	litres/ billed property	% of System Input Volume	% of Water Supplied	Infrastructure Leakage Index, with Pressure
SET TARGETS AND TRACK PERFORMANCE, FOR AN INDIVIDUAL SYSTEM	YES, for large systems	YES*	YES*	YES (UK)	NO	NO	Only if all justifiable pressure management completed
TECHNICAL PERFORMANCE COMPARISONS OF DIFFERENT SYSTEMS	NO	NO	NO	NO	NO	NO	YES
DRAW GENERAL CONCLUSIONS FROM SINGLE OR MULTIPLE SYSTEMS	NO	NO	NO	NO	NO	NO	YES, together with other context factors
* Choose services connection density > 20/km; if not, choose mains; or base choice on country custom and practice							

Table 8 : Fit for Purpose Performance Indicators for Real Losses

After ILIs have been calculated, they can be assigned to Leakage Performance Categories A to D, first introduced by Liemberger (2005) and since split into A1 and A2, B1 and B2 etc. as shown in Table 9. LPC bandwidths for Low and Middle Income countries are twice as large as for High Income countries. Recommended actions are then suggested for each LPC range,

Low and Middle Income Countries ILI range	High Income Countries ILI range	Leakage Performance Category LPC	Calculated ILI for this System	General Description of LPCs A to D (LPC limits for Low and Middle Income Countries are double those for High Income Countries)
Less than 3	< 1.5	A1		Further loss reduction may be uneconomic unless there are shortages; careful analysis needed to identify cost-effective improvement
3 to < 4	1.5 to < 2	A2		
4 to < 6	2 to < 3	B1		Potential for marked improvements; consider pressure management, better active leakage control practices, and better network maintenance
6 to < 8	3 to < 4	B2		
8 to < 12	4 to < 6	C1		Poor leakage record; tolerable only if water is plentiful and cheap; even then, analyze level and nature of leakage and intensify leakage reduction efforts
12 to < 16	6 to < 8	C2		
16 to < 24	8 to <12	D1		Very inefficient use of resources; leakage reduction programs imperative and high priority
24 or more	12 or more	D2		

Recommend Actions for each LPC range	A	B	C	D
Investigate pressure management options	Yes	Yes	Yes	
Investigate speed and quality of repairs	Yes	Yes	Yes	
Check economic intervention frequency	Yes	Yes		
Introduce/improve active leakage control	Yes	Yes	Yes	
Identify options for improved maintenance		Yes	Yes	
Assess Economic Leakage Level	Yes	Yes		
Review burst frequencies		Yes	Yes	
Review asset management policy		Yes	Yes	Yes
Deal with deficiencies in manpower, training and communications			Yes	Yes
5-year plan to achieve next lowest band			Yes	Yes
Fundamental peer review of all activities				Yes

Table 9 : Leakage Performance Categories (LPC) based on ILI, and use of LPCs to prioritise actions

Some countries using these LPCs have preferred to use descriptive terms rather than letters. For example, the EU Reference document (2015) uses Very Low/Low for A1 and A2, then Moderate/High/Very High for B, C and D.
For more details, see http://www.leakssuite.com/concepts/uarl-and-ili/ .

Since the introduction of UARL and ILI in 1999, ILIs have been calculated for thousands of systems internationally, and have helped in identifying and targeting excessive Real Losses in numerous countries and Utilities, leading to large sustained reduction in Real Losses.

It is technically possible to achieve UARL but it is not usually economically viable unless water is very expensive or very scarce. There are limited ranges of situations in which validated calculated ILIs less than 1.0 (CARL less than UARL) can occur.,
For examples see http://www.leakssuite.com/global-ilis/ for Austria and Denmark.

- Very small stand-alone systems (less than 3000 service connections)
- Low (less than 40 metres) or Very Low (less than 30 metres) average pressure with a high proportion of flexible pipes

Or of course, high uncertainty associated with the calculation of very low CARL (see Section 1).

3.2. Evolution of Apparent Losses Performance Indicators 2000 to 2016

3.2.1. Apparent Losses KPI Recommendations by IWA, 2000 to 2006

The first IWA performance Indicators Report (Alegre et al, 2000) recommended that the Operational Indicator for Apparent Losses should use the same units as the recommended KPI for authorised consumption, m^3/service connection/year.

However, in the second Edition (2006), the recommendation for Apparent Losses KPI had changed to

- Apparent Losses volume as a % of Water Supplied, for distribution systems
- Apparent Losses volume as a % of System Input Volume for Bulk Supply Systems.

The IWA Water Loss Task Force was not made aware of, or invited to comment on, this change of Apparent Losses KPI recommendation before it was published, and many regarded it as a backward step, as the problems with using % of System Input Volume or % of Water Supplied as KPIs for NRW and NRW components were already well known. In addition, the second Edition in 2006 specifically stated that *'Performance indicators are typically expressed as a ratio between variables (...) the use of denominators of variables which may vary substantially from one year to another (...) should be avoided (e.g. Annual consumption, that may be affected by weather or other external reasons).'*

A paper by a group of senior members of the Water Loss Task Force (Liemberger et al, 2007) recognised the need for a better KPI for Apparent Losses, but admitted that 'there is no consensus on the best international operational PI for Apparent Losses, not even within the Water Loss Task Force. Personal views tend to be influenced by personal experiences, depending upon the relative proportions of 'unauthorised consumption' and 'customer metering errors''. Accordingly, an Apparent Losses Group of the Task Force was created and asked to address this problem.

3.2.2 Apparent Losses Management Overview

The Apparent Losses Group of the WLTF produced the Dynamic Scheme diagram of the principal components of Apparent Losses (Rizzo et al, 2007) shown in Figure 6, based on the approach that it is possible to define several management concepts for AL similar to those already defined for RL

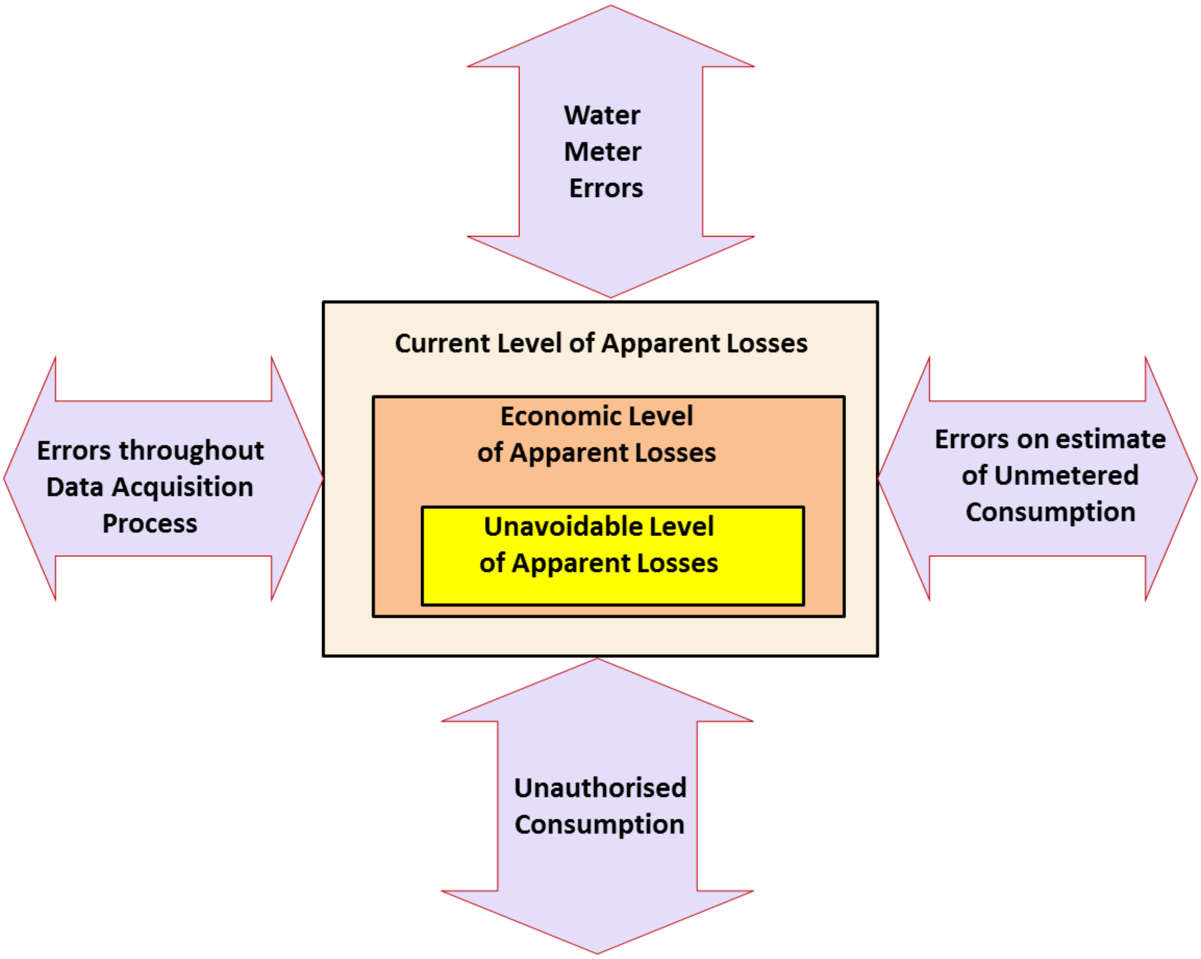


Figure 6 : The Apparent Loss Dynamic Scheme

CAAL, Current Annual Apparent Loss similar to CARL, Current Annual Real Loss

UAAL, Unavoidable Annual Level of Apparent Losses similar to UARL, Unavoidable Annual Level of Real Losses
EALL, Economical Apparent Loss Level similar to ELL, Economical Level of Leakage
And ALI Apparent Loss Index, similar to ILI, Infrastructure leakage index

Although this approach seems reasonably structured, it is rather difficult to implement because the nature of the apparent losses is very different to that of real losses.

- Real Losses are volumes of water lost from the Utility system and not paid for, through leaks of different frequencies, flow rates and durations
- Apparent Losses are volumes of water consumed through different types of activity such as under-metering or water theft, but not paid for.
- Technical factors dominate in the case of Real Losses whereas human and social factors are dominant in the case of Apparent Losses.

In the case of the Real Losses Dynamic Scheme, the arrows refer to four categories of actions that can be used to control frequencies, flow rates and duration of the leaks. Whereas in the case of the Apparent Losses Dynamic Scheme, each arrow refers to a category of causes, and for each cause, there is a wider variety of corrective actions that can be implemented.

For Customer Metering Losses. Technical and human factors include the following:

1. Make (Brand) and Type of meter
2. Metrological class
3. Historical application

4. Meter age (or date of installation, or reading index value)
5. Sizing procedures
6. Installation procedures
7. Customer consumption (demand) profiles
8. Category rating of large customers
9. Customers data base structure
10. Water quality
11. Water pressure of service
12. Discontinuous supply status (i.e. partly pressurised system)
13. Quality of meter reading data
14. Occurrence of meter frauds
15. Domestic installations (in-house leakage, domestic tanks, etc.)
16. Contractor-usage meter enforcement practices
17. Meter reading procedures
18. Retail price of water

For Unauthorised Consumption (frauds)

1. Gross National Product (GNP)
2. Water charges and household's income
3. Local legislation and regulation: laxity, impunity, right to disconnect, fines and penalties.
4. Political or/and social aspects
5. Human resource policy and staff salaries in the Water Utility
6. Corruption
7. Reliability and updating of customers` database (data available)
8. Active/Inactive customers

Quantifying these multiple human and social factors and expressing them as equations is even more complex than developing a UARL formula for Real Losses based on technical factors for leak frequency, flow rates and average durations for nine different categories of leaks on three different parts of the infrastructure system.

3.2.3. Apparent Losses as a percentage of authorized billed consumption

Referring to the case of the real losses which is well known, comparing various utilities on the basis of the AL indicator as a percentage of the Input Volume would be as meaningless as comparing various utilities on the basis of their real loss as a percentage of the water supplied. In the case of real losses this incoherence has been noted and analysed worldwide; it has led to the definition of the ILI, which introduces system-specific parameters relating to the mains length, number and length of service connections (main to meter) and operating pressure of each individual system. As far as real losses are concerned, various utilities may be compared based on their ILI but not based on their real loss calculated as a percentage of the volumes supplied to the system.

The Apparent Loss Initiative Team has implemented a similar approach in terms of apparent loss, trying to develop an ALI, Apparent Loss Index.

Due to this complex nature - represented by the four arrows of the AL dynamic scheme - the level of apparent loss is not directly linked to the number of service connections or the mains length (first proposal) nor to the value of the volume supplied to the network (second proposal). Nevertheless, it is directly linked to the billed consumption. Therefore, it is proposed to calculate an AL Indicator as a percentage of the authorized billed consumption.

Apparent Loss as a percentage of the authorised billed consumption, excluding water exported
This approach is rather logical, as the genuine (or real) consumption of the customers is the sum of the authorised billed consumption and the apparent losses themselves

In such an approach, the factors that are not related to the customer and meter management are removed (the real loss for instance) and the value of the ALI only refers to the customer and meter management of the utility and the other components of Apparent Losses shown as arrows in Figure 6..

Some may object to the fact that the AL Initiative recommends the use of the percentage in the case of the apparent losses whilst it has been so strongly advised not to use it in the case of the real loss. The reason is that the context is quite different.

- For the main categories of Apparent Losses, it is established testing practice to express metering errors as a percentage of registered metered consumption and reductions in Apparent Losses generally become increases in metered consumption, as their sum is the total consumption.
- For Real Losses expressed as a % of System Input Volume or a % of Water Supplied, reductions in Real Losses do not generally migrate to become increases in total consumption (and vice versa)

3.2.4. The challenge of Unavoidable Annual Apparent Losses (UAAL)

Considering the numerous components of apparent losses, is it possible to define an "unavoidable level of apparent loss"? This was attempted, with the direct assistance of the member of the 1st Water Loss Task Force who had been most closely involved in developing the UARL equation, but it was eventually recognised as impractical to create an equation with so many diverse parameters, for practical application.

A positive outcome of this collaboration was, however, that a possible solution could be to refer to a 'Reference' Annual Apparent Loss Level' (RAAL), against which actual performance could be judged. This would acknowledge that unavoidability is not an absolute concept, as it always depends on some external factors or parameters.

RAAL would also omit the word 'Unavoidable' in the UARL, which has been a topic for criticism by some. These criticisms were listed and responded to in Liemberger et al, (2007)**.** There is no 'perfect' word, but the UARL equation is now so widely used internationally that attempts to make minor changes to the coefficients in the UARL equation, or change 'Unavoidable' to some other term (such as Minimum Achievable Annual Physical Losses MAAPL for the same UARL equation) that some (but not all) may consider marginally better, would be likely to confuse, rather than inform the topic of International comparisons.

3.3 Reference Annual Apparent Losses (RAAL)

3.3.1. Selecting Appropriate Units and figures for RAAL

For Apparent Losses, the concept of Unavoidable Annual Apparent Loss UARL has necessarily been replaced by the concept of Reference Annual Apparent Loss, RAAL, for reasons previously described. It is next necessary to decide on appropriate units for RAAL, then to set a value of RAAL that represents a realistic overall sum of the individual components of RAAL.

As previously stated in Section 3.2.1, in 2007 there was no consensus within the Water Loss Task Force on the 'best' KPI for Apparent Losses, other than that it should definitely not be % of System Input Volume or % of Water Supplied. Apparent losses per service connection, or per household, or per km of mains, all have their supporters, and there are points for and against each of these depending on local circumstances. Therefore, a different approach has been proposed: defining a reference figure based on the experience of some well-managed utilities internationally, where some of the authors have worked.

A fresh look at the problem recognises that any part of the volume of Apparent Losses identified by a Utility's investigation is already being consumed (but not paid for). That volume will probably still be consumed afterwards, but paid for, most likely as part of authorised metered consumption (which excludes Water Exported).

No AL component can be reduced to zero, which is rather easy to demonstrate. However, in well-managed utilities, each component is minimized.

- Water Metering Loss is minimised through an appropriate meter maintenance and meter replacement policy based on economic considerations.
- Unauthorized Consumption is minimised through proper customer management actions and procedures.
- Mis-estimate of unmetered consumption is minimised through the installation of meters on all service connections and proper maintenance of the meters.
- Errors throughout data acquisition process are reduced through proper maintenance of the metering equipment, and data collection and transmission equipment.

The management of these well managed "reference utilities" considers that:

- the metering loss may be reduced to 4% of the authorised metered consumption*
- the unauthorised consumption is less than 1% of the authorised consumption
- the other kinds of apparent losses are under control and negligible.

Based on that reference it is possible to adopt the following formula:

RAAL = 5% x Billed Authorised Metered Consumption, excluding Water Exported*

(Expressed as a volume)

In which 5% is taken as a default value until actual historic records can demonstrate otherwise.

(*) Therefore, this formula is not applicable to the unmetered customers when many or most of the customers are not metered.

Comments:

Comments received concerning the use of this definition for RAAL include the following:

- Some consultants consider that it is not possible to achieve only 4% metering losses; based on their experience the metering error is generally between 6% and 8%, even with effective management.

- Some utilities claim they have metering error less than 4% – or that they are negligible – because they replace their meters very frequently (e.g. every 4 years),[6]

- [6] In a 2002 IWA International Report on Water Losses in 22 countries [http://173.254.28.127/~leakssui/wp-content/uploads/2012/11/2002_IntRepWaterLossesManTechniquesIWABerlin-2002N.pdf], 7 Northern European Utilities claimed zero for UAC and Apparent Losses, 9 claimed less than 2%, and 17 claimed 5% or less of billed metered consumption.
- Australia: all WSAA Companies during the 10-year millennium drought were extremely keen to identify every component of their NRW. They were the first Utilities group to agree (around 2008) to set formal (rather than informal) defaults for the auditors for the National Water Council Returns, as 2% of Water Supplied – but because ILIs were so low, close to 1.0, this was not too far from 2% of Billed Metered Consumption. Meters are permitted to over-record when they are new.
- Austrian OVGW W63 Sept 2009: Water losses in water supply systems. Assessment, Evaluation and Measures for Water Loss Reduction, states that 'Experience has shown that with correct dimensioning, correct installation and maintenance within the legal required calibration intervals for customer meters, apparent losses have to be estimated at round about 0,5% *(of billed and unbilled metered and unmetered consumption).* In rare cases larger losses should be justifiable
- German DVGW Sept 2015 draft revision of W392 Guideline states: Without concrete valuation, no apparent losses should be assumed (QVS = 0). Apparent losses above 0.5% of water consumption (QVS >0.005 x QA) has to be justified in detail.
- Danish ILIs, published by DANVA, with most ILIs less than 1: all 36 Utilities claimed zero for Customer Meter under-registration. See LeaksSuite Global ILIs for Denmark.
- 2015 EU Reference document uses defaults of 2% of Billed Metered Consumption (excluding Water Exported) for under-metering in direct supply systems, 5% for systems with roof storage tanks (mainly Malta, Cyprus). 0.5% for UAC, 0.2% for UC.

- Other practitioners say that metering errors are negligible because they are permitted to use a particular type of meter set to over-record when new, or that under measurement at low flow rates is compensated by over measurement at nominal rates (generally it is not demonstrated)
- Other members say that the lowest economically achievable level of unauthorised consumption cannot be the same in Low & Middle Income Countries as in High Income countries; they are probably right.

Many of these remarks make sense, especially if we were to use the term 'unavoidable' for Apparent Losses. However, these criticisms are not valid anymore if the RAAL is only considered as a Reference value, which is known to be achievable as some Utilities have achieved or bettered it.

In some countries with direct pressure systems (Australia, Denmark, Germany for example), default values lower than the RAAL are recommended and used in Water Balance calculations. In others, where roof storage tanks in properties result in persistent low flows through the meters, the RAAL of 5% of authorised metered consumption (excluding Water Exported) may not be achievable.

3.3.2. The Apparent Losses Index ALI

Once the RAAL has been calculated as a volume, the Apparent Losses Index ALI is:
ALI = CAAL/RAAL

In many countries around the world, the ALI is very high, because the management of the meter fleet is poor and the number of unregistered consumption is high. ALIs higher than 5 frequently occur.

However, when the management of the meters and customers is under control, the ALI may be lower than 1. In such cases, it is important to check that the default values that have been used are valid and supported by appropriate field and lab surveys.

In the case presented in Figure 6 (Chapter1):

- The RAAL is 5% of Billed Metered Consumption BMC = 0.05 x 7.8 = 0.39 Mm^3
- The Current Annual Apparent Losses CAAL are 0.164 Mm^3
- The Apparent Losses Index ALI = 0.164/0.39 = 0. 42

ALI lower than 1.0 In the same way that an ILI lower that 1.0 can occur in some circumstances (Lambert et al 2014), an ALI lower than 1.0 can also occur and be accepted if .

- Validation of the volume components of RAAL has been sufficient to justify the calculation of ALI, or
- It has been recently validated that the use of defaults lower than an RAAL of 5% of Billed Metered Consumption are justified.
- New metering techniques are used
- However, if only a limited or cursory check on RAAL components has been done, further control and monitoring is required especially if no measures were previously put in place to reduce this value to less than unity.

Unmetered customers. In some countries, utilities measure all customers, but in others (e.g. New Zealand), many Utilities do not meter non-residential customers. The ALI approach is not appropriate when a large percentage of customers are unmetered. In such situations, expressing Apparent Losses as '% of Water Supplied' or 'per service connection' would discriminate against fully metered Utilities. Accordingly, '% by volume of metered consumption (excluding Water Exported)' was recommended as an appropriate Operational PI in the Water New Zealand Water Loss Guidelines (NZWWA 2010).

3.3.3. Apparent Losses Performance Indicators, Fit for Purpose

Table 10 below summarises the Authors' suggestions for Apparent Losses 'Fit for Purpose' PIs, in a similar format to Table 9 for Real losses, which appears in Section 2 of this Guidance Note.

OBJECTIVE	GOOD PRACTICE PERFORMANCE INDICATORS FOR APPARENT LOSSES FIT FOR PURPOSE								
	COMPONENT OF APPARENT LOSSES	CURRENT ANNUAL APPARENT LOSSES CAAL			CAAL as % of billed metered consumption, exc. water exported	litres/ billed property	litres/ service connection	% of System Input Volume	% of Water Supplied
		Volume	Value/m³	Value					
SET ECONOMIC TARGETS AND TRACK PERFORMANCE, FOR AN INDIVIDUAL SYSTEM	CUSTOMER METER ERRORS	YES	YES	YES	YES	YES	YES	NO	NO
	UNAUTHORISED CONSUMPTION	YES	YES	YES	YES	YES	YES	NO	NO
TECHNICAL PERFORMANCE COMPARISONS OF DIFFERENT SYSTEMS	APPARENT LOSSES	NO	NO	NO	YES: APPARENT LOSSES INDEX ALI = CAAL%/5%	N0	NO	NO	NO
FINANCIAL PERFORMANCE COMPARISONS OF DIFFERENT SYSTEMS	APPARENT LOSSES	YES	YES	YES: CAAL VALUE / RUNNING COSTS	NO	N0	NO	NO	NO

Table 10 : Fit for Purpose Performance Indicators for Apparent Losses and Components

Targets for individual components of Apparent Losses for an individual system should preferably be based on economic principles. Tracking of progress (or deterioration) for that system against its targets can be carried out in several different units (but not percentages of System Input Volume or Water Supplied), as shown in Table 10.

For technical performance comparisons of Apparent Losses management between different systems, the Apparent Losses Index ALI is the only Apparent Losses PI, which is designed for that purpose.

For Financial performance comparisons of Apparent Losses management between different systems, the 1st Performance Indicators Manual (Alegre et al, 2000) proposed that Non-Revenue Water component volumes should be valued (Apparent Losses at retail unit price, Real Losses at an appropriate value/m^3) ; then added and expressed as a % of annual running costs.

Table 9 and Table 10 show that Real Losses and Apparent Losses expressed as percentages by volume (of either System Input Volume or Water Supplied) are not 'Fit for Purpose' Performance Indicators. This means that %s by volume are also unsuitable as a PI for Non-Revenue Water as a whole. For further information on that topic, see the Info-hub 'KPIs Fit for Purpose' at http://www.leakssuite.com/kpis-fit-for-purpose/

3.3.4 ALI Performance Categories

Some 5 years after the ILI concept was first published, many hundreds of calculations of ILI for individual systems were available, and a classification of Leakage Performance Categories based on ILI was proposed. This has since been improved, and the current A1 to D2 Leakage Performance Categories are shown in Table 2.

The authors considered the merits of proposing a similar Table of ALI Performance Categories for international application, but decided not to do so in these Guidance Notes on Apparent Losses. The reasons for this decision are as follows:

- Volume components of RAAL are readily converted to monetary terms for calculation of economic meter replacement policies (the major RAAL component), and Economic Annual Apparent Losses (EALL)
- A large validated data base of international ALI values, on which to base the class limits and descriptions, is not yet available
- A premature attempt to categorise ILIs in 2003 in one country is now considered to be too generous, but being the first published Table, it has been widely circulated. It is now problematic to try to withdraw it or state openly that it should no longer be used.
- Should different ranges be used for High Income Countries (HICs) and Low and Middle Income Countries (LAMIC), as in the Real Losses Leakage Performance Categories?

- There are well performing utilities in LAMICs and poorly performing utilities in HICs.

In Figure 7 the Authors have assembled an initial chart of 25 validated international ALI values from 23 countries, derived mostly from published data. Note that each vertical bar represents an individual Utility, not a representative ALI for the named country.

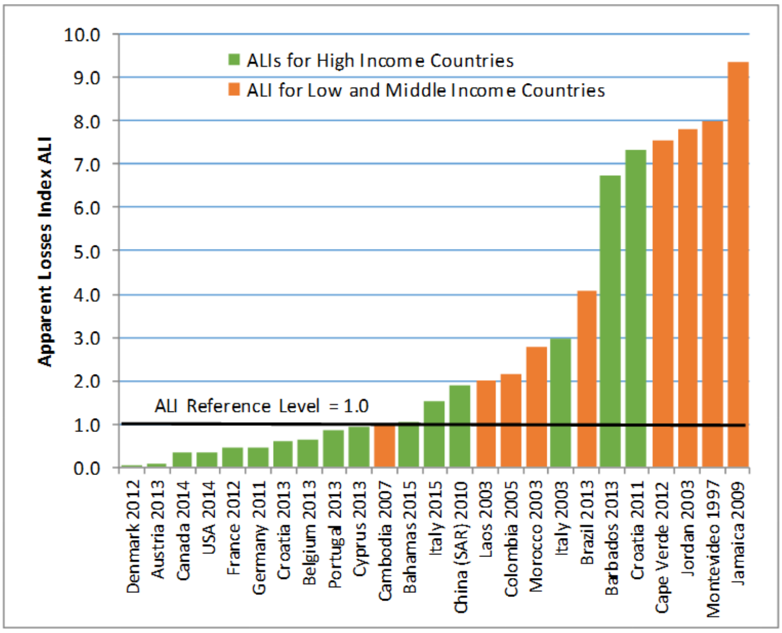


Figure 7 : Some International Value of Apparent Losses Index ALI

It can be noted that, in this small sample of ALIs:

- Most of the Utilities in High Income Countries were achieving ALIs less than the Reference value of 1.0, but there are also Utilities in HICS with ALIs significantly greater than 1.0
- Most of the Utilities in Low and Middle Income Countries had ALIs greater than 2.0; the level of unauthorised water consumption is very high in many LAMICs due to different economical and cultural backgrounds.
- However, this should not be used as a justification or excuse for poor performance; the LAMIC Utility with an ALI of 1.0 sets an example for others to follow, and the better performing Croatian Utility (ALI = 0.6) is categorised as being close to the HIC/LAMIC boundary.
- The five highest ALI values in the sample were all preliminary surveys, in both HICs and LAMICs, which identified significant opportunities for improvement

Readers of these Guidance Notes with reliably calculated ALIs are invited to contact Author M.Vermersch by e-mail. With a larger set of validated ALIs, the topic of ALI Performance Categories will be revisited in the next review of the Guidance Notes, or considered in detail in an Additional Appendix.

3.4. Operational Indicators by field of activity

The monitoring of specific "operational indicators" or "metric indicators" by field of activity is also important. Some operational indicators that are used by many practitioners are mentioned below:

Meter management:

- Percentage of unmetered connections.
- Percentage of meters out of operation.
- Percentage of poorly installed meters.
- Percentage of obsolete meters by diameter.
- Indicator on meter over sizing, etc.
- Number of flowmeter replaced per year (OP8)
- Breakdown of meters by brand (make), type, diameter, date of installation, reading index value.
- Customer meter reading efficiency (OP36)
- Domestic customer meter reading efficiency (OP37)
- Percentage of active meters (OP38)
- Percentage of non-metered water (OP39)
- Density of water meters (n°/connection) (Ph11)
- Time interval for meter installation (QD24)
- Etc.

Customer management:

- Percentage of active and inactive connections.
- Percentage of connections disconnected for non-payment.
- Number of frauds detected by meter readers.
- Etc.

3.5. Unmetered customers and the case of utilities that do not use water meters

Consumers with unregistered or unmetered connections are not motivated to save water. Generally, this generates over consumption (or wastage); should that be considered as apparent loss?

When there is no water meter, it is clear that the boundaries between “water consumption”, “apparent losses” or “internal wastage” are difficult to define. Most of the members in the AL Initiative agreed that over consumption and wastage due to lack of metering should not be considered as apparent loss. In fact, it seems that the concept of apparent loss cannot be applied to utilities that do not use meters.

This statement is not completely satisfactory. It is true that the ALI is rather meaningless when there are no meters installed and read. In that case, the problem is not the ALI but the establishment of the “Revenue Water Column” of the Water Balance itself. In similar cases, the real billed consumption can be estimated based on field measurement campaign and the difference between the estimated billed volume and the estimated billed consumption is considered as an apparent loss that could be reduced through an appropriate metering policy.

It is interesting to note that the problem of calculating the volumes that generate revenue may also exist when consumption is metered. Revenue Water is generally based on the billed volumes. However, the volumes billed are different from the volumes consumed for the following reasons:

- There is no meter and the consumption is based on flat rates which sometimes are not related to volumes (surface of the premises, taxes etc.)
- There is a meter and the volumes billed are different from the volumes consumed depending on the tariff structure. For instance, the Utility charges a minimum rate of $10m^3$/month even if the customer consumes less.

These comments show that the establishment of the water balance is very difficult when the customers are not fully metered (misestimate of unmetered consumption). In that case, the ALI concept cannot be applied because the different values are estimated with a very poor precision.

References are listed in Section 6 of the Guidance Note

4. ACTION PLANNING AND DYNAMICS OF LOSSES

Summary

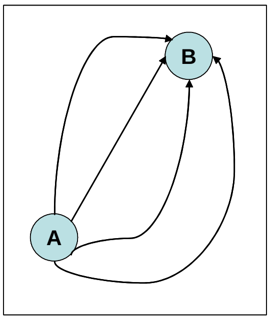
This Section provides some guidance on the design and implementation of action planning to control non-revenue water. In Chapter 2, the authors have described various methods to reduce the various components of the apparent losses but experience shows that reducing apparent losses only cannot be a good and sustainable solution.

The "dynamics of loss", the principles of which are outlined in this chapter, shows that various actions should be implemented simultaneously and in a coordinated manner in order to get significant and sustainable results.

More detailed descriptions and analyses are provided in Appendices 7, 8 and 9.

4.1. Action Planning: a 3-Dimension Approach

The concept of water balance of a water supply system is currently well known and commonly used to assess both real and apparent losses. Nevertheless, the balance only gives a picture of the situation in terms of Revenue and Non-Revenue Water (NRW) during a specific period of time, generally one year.



Action planning to reduce and control NRW is about how the water balance (A) will gradually change when an action plan is carried out, and finally reach a new equilibrium represented by a new-targeted water balance (B). Many ways may be envisaged to meet the target: the action plan will follow the best one.

A complete action plan consists of a full range of actions to get the various components of the water balance under control.

The action plan is successful when it complies with two conditions:

(i) The target indicators are met and

(ii) The results are sustainable

Progression from the initial water balance (A) to the targeted one (B) requires considerable analysis and simulations. Experience shows that many plans have failed due to inadequate assessment of the initial situation and to a poor or wrong estimate of the impact of the forecasted actions. Section 4.2 provides some guidelines to avoid these failures.

The scheme in Figure 8 shows that Water Loss control projects need to be considered in three dimensions: change management, project management and operational management. Sub-optimal results are achieved if the three dimensions are not considered together.

- The **operational dimension** looks at the creation of a current and targeted water balance for the water utility. It defines the technical and operational activities that are required to progress from the current to the targeted water balance, and clarifies the corresponding resource requirements.
- The **project management dimension**. Professional project management requires a project champion, a committed team, quantified objectives, time scheduling, resource commitment, and adequate tools and techniques for the project to be successful.

- The **change management dimension**. This dimension looks at the readiness or willingness of the water utility to address NRW project issues, such as institutional and stakeholders' support, a clear mandate, and an established project strategy. Many action plans have failed for having ignored the essential change management dimension, the study of which should always be considered as a prerequisite for a NRW reduction program.

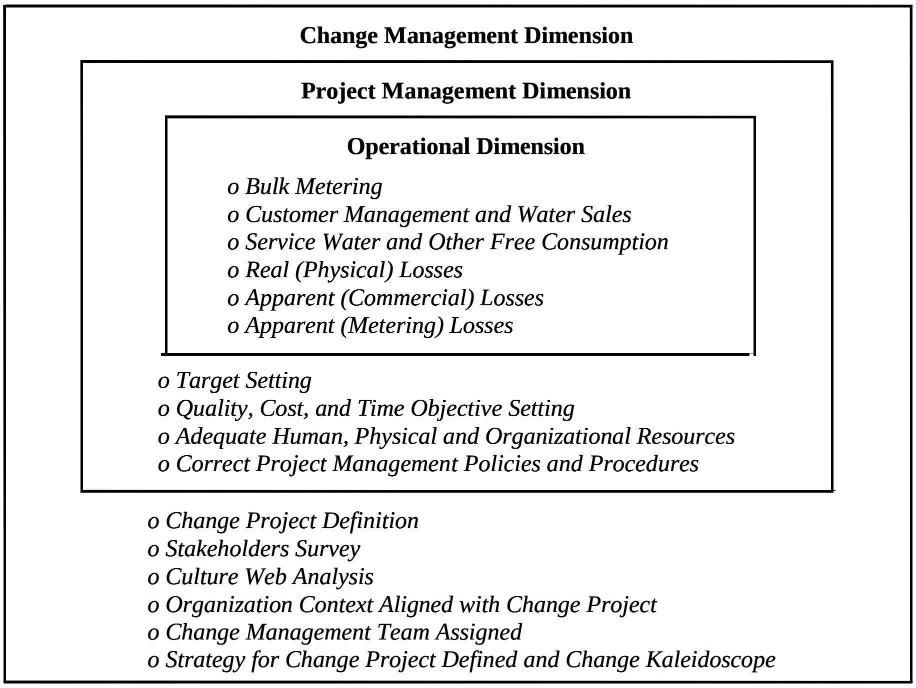


Figure 8 : NRW Control as a 3-Dimension Structure

4.2. Dynamics of Losses

Main causes of failure in action planning

In any water supply system, there is a natural entropic tendency to disorder, incorrect estimates and possibly some mis-information: if nothing is done, there will be an accelerated propagation of leaks and occurrences of defective water meters as well as the accumulation of out-of-date information in the customers' database for instance.

Therefore, the value of the network efficiency at any moment is the combined result of the natural deterioration of the installations and the procedures that have been put in place since their creation by the technical and customer services sections to fight this deterioration.

To counter this natural tendency it is necessary to understand what the causes of this deterioration process are, and to carry out appropriate actions to minimise the negative effect of these causes. This may either be: (i) appropriate procedures to keep the network efficiency at its current value or (ii) an appropriate action programme to meet specific and improved efficiency targets. In the first case we call it an Operational and Maintenance Program (O&M); in the second case, it is called the action plan (or program) and it includes many components such as the targets, list of the actions to carry out to meet the target, human and material resources, budget, time schedule, etc.

There are many reasons why an action plan may fail, for example if there are no improvements in the water loss indicators, if the improvements are less than scheduled, if the improvements do not meet the time schedule, if capital cost is much higher than scheduled, if the results are not sustainable, etc.

The following are some of the main causes for failure: the time schedule is not controlled; the possible returns of the anomalies have not been quantified; and potential interactions between the various kinds of losses have been underestimated. These considerations have resulted in the proposal for some new concepts and indicators that are defined and commented hereafter.

Time Factor (TF) and Visibility Threshold (VT)

The Time Factor for one specific action is the period of time that it takes from the implementation of the action until the moment it affects the water loss indicator. The Visibility Threshold is the moment when the impact of the action becomes noticeable (inflection on the water loss graph).

How many detected and repaired anomalies will there be before there is a visible impact on the value of losses and relevant performance indicators? Sometimes the utility management fails to complete the project and abandons it even before the target threshold is achieved. This is unfortunate as it is only after the detection threshold has been reached, that there will be an accelerated improvement due to a “snowball effect" that will eventually ensure the success of the project.

Some examples related to various types of losses are given as follows:

Example 1 : It is common that reducing real losses leads to reducing water input into the surveyed areas. This is true, but in a large distribution network, repairing some small leaks may be insufficient to affect the volume of water input. The visibility threshold on the water input will only be met when the volumes saved are sufficiently large to affect the volume supplied. This is one of the major benefits of district-metered areas (DMA) and pressure-managed areas (PMAs): the smaller the area, the easier it is to demonstrate the impact of the intervention. The visibility threshold is met sooner in a PMA or DMA than in the entire utility service area (see Figures 9 and 10). The same approach may be applied to the various categories of apparent losses, such as under-metering and unauthorised consumption.

Example (ii) Suppose the water utility has decided to renew a part of the consumers’ meters because the error (under metering, thus under billing) is increasing by 0.5 % annually, i.e. more than 5% in a 10-year period. This action should lead to some calculable increase in the water sales. What is the visibility threshold and how long does it take to reach it? It is a precision matter. In addition, it may be difficult to appreciate the visibility threshold when the meters are read once a year or when there are important seasonal and yearly variations in the consumer’s consumption.

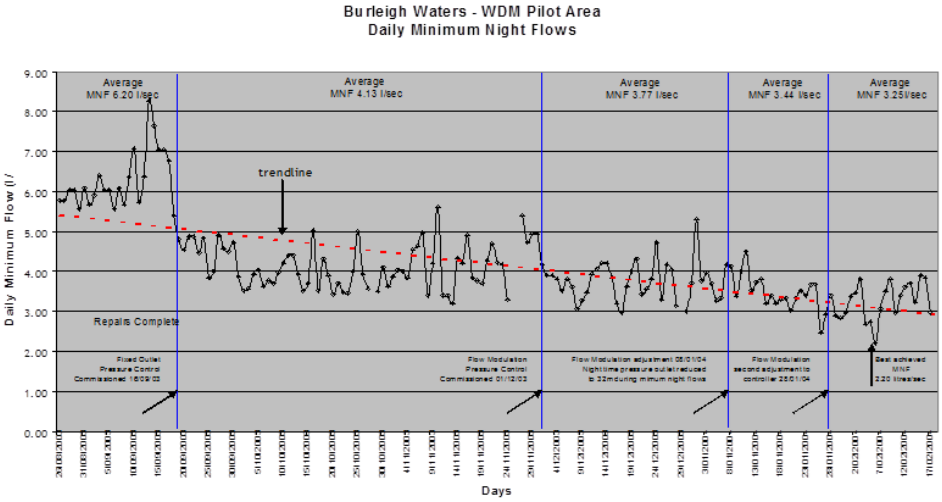


Figure 9 : Influence of pressure management and leak detection on minimum night flow in a Gold Coast PMA

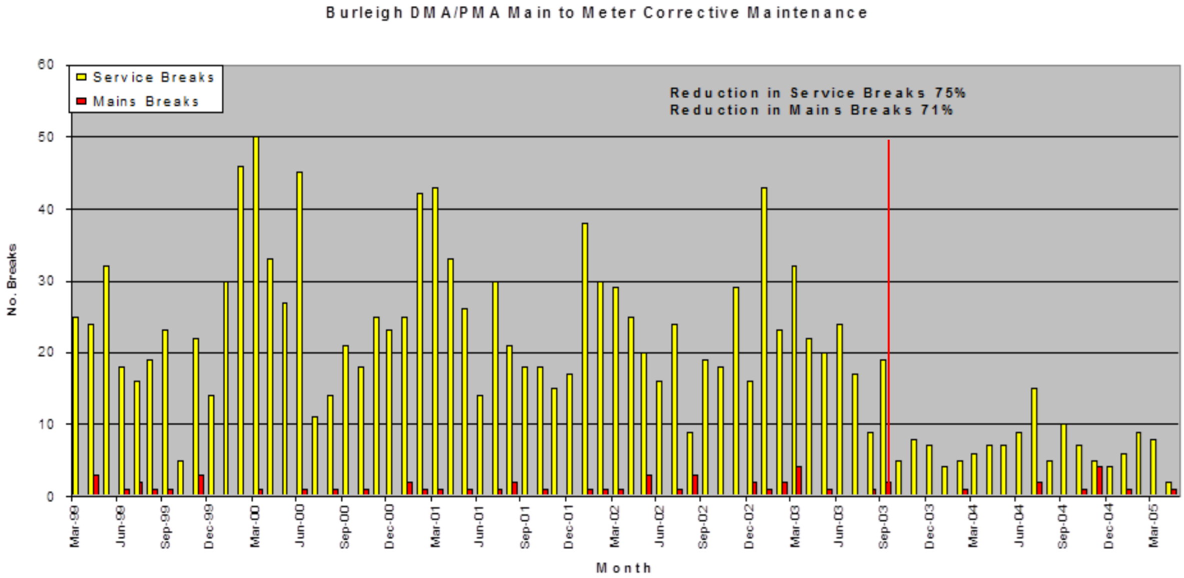


Figure 10 : Influence of pressure management on monthly repairs on services (yellow) and mains (red)

With respect to water leakage, the impact can be appreciated by the review and assessment of the minimum night flow and the monthly repair frequencies. With respect to apparent losses, it may be more difficult due to the frequency of meter reading.

The visibility threshold for each action will also depend on the rate of return of the anomalies. In the case of a complex action plan involving various actions, the visibility threshold of the plan will also depend on possible interactions between the various components of the plan.

The Coefficient of Return of Anomalies (CRA)

The name is self-explanatory and applies to both real and apparent losses. When one hundred anomalies are corrected in the period of the action plan, what number of similar new anomalies will occur due to the natural deterioration process? The CRA is an indicator that can be calculated as a percentage. The following examples are considered:

(i) After having detected and repaired many leaks in the distribution network, new leaks will appear during the next months. Implementing annual active leak detection in the same areas, the CRA may be 1 (100%), less than 1 or more than 1. When it is 1 or more than 1, the visibility threshold on the water input figures may never be reached. The policy then requires reviewing: pressure control or pipe renewal might be more effective. In the case of real losses, the present concept of CRA covers the existing concepts of Natural Rate of Rise (NRR) and Infrastructure Condition Factor (ICF) (Fantozzi and Lambert 2005, Lambert and Lalonde 2005)

(ii) In the case of the meter replacement campaign, the utility may decide to replace 5% of the meters every year because the errors are increasing by 0.5% every year. However, you need to remember that meters that have not been replaced that year (i.e. 95%) are continuing to lose 0.5% a year. It is easy to calculate the CRA for under metering and the minimum number of meters required to reduce the total loss due to under metering.

(iii) The detection and regularisation of unauthorised connections can be matched by the occurrence of a similar number of new unauthorised connections. When the Utility disconnects 100 customers for fraud or non-payment, how many disconnected customers will reconnect their connection illegally? The CRA needs to be assessed to know what is the global impact of the actions and, obviously, to take appropriate corrective actions at the management level.

These examples show that there are obvious relationships between the Coefficient of Return of Anomalies (CRA), the Visibility Threshold (VT): the highest the CRA, the longer the TF and more remote the VT.

The Migratory Attribute of Losses (MAL)

Any action may have side effects and these effects need to be forecast and taken into account in the design of the action plan.

When a volume of water is saved through a leak detection campaign, one part leads to a reduction of the water input and another portion may be lost through other leaks or apparent losses.

This concept applies for instance to the automatic transformation of real losses into apparent losses under certain circumstances. If the leak repair creates pressure increase and new leaks or if the water saved from the leak repair campaign is used to supply some inadequately served and metered areas, the visibility threshold on production will be higher, or may never be met. Some consumers will transform a part of the water saved into apparent losses through unmetered additional consumption. This is what is called the "migratory nature of the loss".

This concept is of paramount importance because if some MAL phenomenon occurs, it completely distorts the former TF, VT and CRA analyses and the final target may never be reached.

Overall Dynamic Scheme

In the following diagram, the central ellipse represents the water loss and it is divided into two parts; the real loss and the apparent loss.

In order to reduce the real loss four categories of actions are possible and may be implemented together or separately: fast burst repair, pressure control, active leak detection and pipe replacement.

In order to reduce the apparent loss there are also four categories of actions which are linked to the various categories of apparent losses: unauthorised consumption, meter errors, misestimate of the unmetered consumption and errors linked to the data acquisition process.

In fact, Fig.11 (Dynamics of Water Losses) is a combination of Fig.5 (Real Losses Dynamic Scheme) and Fig 6. (Apparent Losses Dynamic Scheme) In addition, some real losses may be transformed into apparent losses and vice versa under certain circumstances.

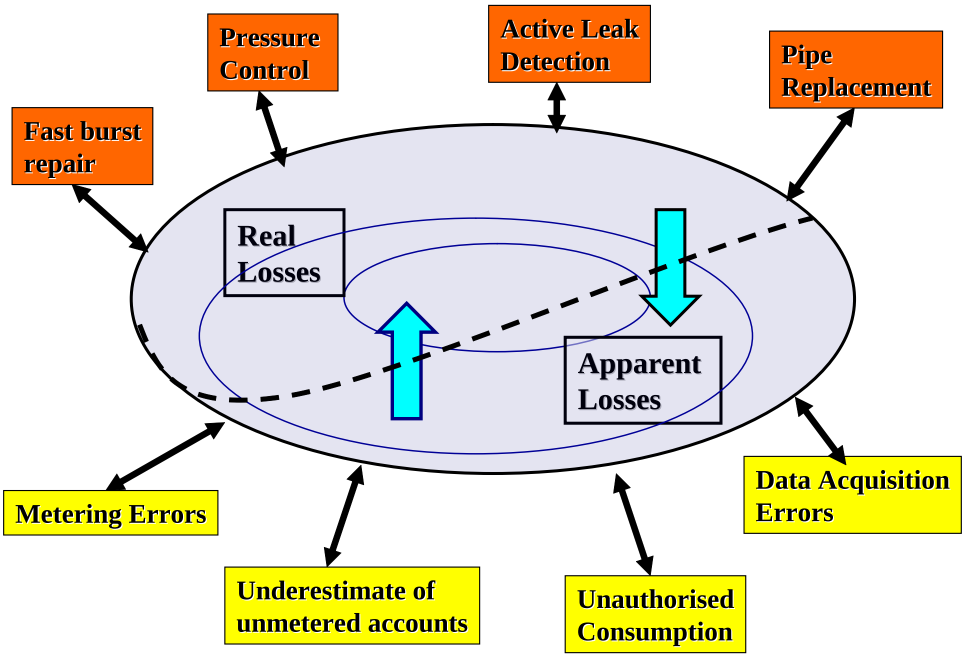


Figure 11 : Dynamics of Water Losses

The 10 (ten) arrows are the basis of what is called the dynamics of loss. Not considering them in the elaboration of an action program to reduce the losses may lead to failure.

These arrows are 2-way arrows; it means that implementing the action lead to loss reduction but not implementing it may lead to loss increase.

Some simple examples:

- The utility commences leak detection is a system with intermittent supply, but does not achieve continuous supply. Any reductions in leak flow rates serve to extend the hours that the system is pressurised, so the savings are lost in additional leakage volume and some apparent losses.
- The utility implements an effective leak detection programs but does not get the apparent loss under control: the increase in apparent losses may compensate the decrease in real loss. The NRW value may remain the same.
- The utility implements an effective meter replacement policy but does not control the unauthorised use: the increase in the unauthorised uses may compensate the decrease in metering losses.
- The utility implements an effective leak detection campaign to reduce water shortage and provide more water to the customers: unmetered customers will consume more water and will continue to pay flat rates. The increase of apparent loss by misestimate of the unmetered consumption may compensate, or partly compensate, the decrease in real losses. This can be a particular problem in LAMIC countries with many customers not metered, high level of unauthorised use, and limited resources leading to intermittent supply

These examples shows that a global approach involving all categories of losses should always be implemented. It is recommended to build a model to simulate the dynamic evolution of the losses when going from the current level of loss to the targeted one.

More about Dynamics of Water Losses is provided in Appendix 9.

4.3. The Operational Dimension

The Seven Components of the Operational Dimension

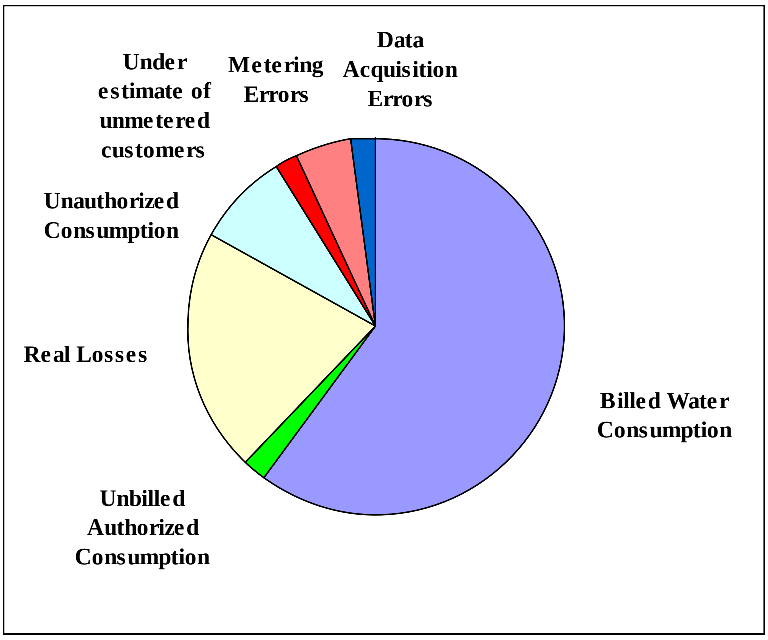


Figure 12 : Water Balance shown as a pie chart

Figure 12 is a pie chart representation of the water balance and suggests what the various components of an operational action plan should be:

1. Bulk Metering to define Water Supplied' (the whole circle)
2. Billed consumption (water sales)
3. Unbilled authorized consumption
4. Real Losses
5. Metering errors
6. Unauthorized consumption (Apparent Losses)
7. Data acquisition errors (Apparent Loss)

Based on the dynamics of losses, any action plan should include these various components to take into account any possible interaction between the various categories of losses.

Getting apparent losses under control

Table 11 focuses on apparent losses and shows a range of actions that may be implemented to get apparent losses under control. Some of them are described with more precision in the appendices.

Categories of AL	**Subcategories of AL**	**Cases**	**Type of Actions**
Errors throughout Data Acquisition Process	System Input and Water Supplied	Error in bulk metering	Establishment of calibration protocol Calibration procedures Large meter replacement
		Error in data capture and transmittance	Technical Audit Repair or replacement
	Errors in customer metering	Manual or semi manual Meter reading	Audit of the meter reading procedure Use of handheld computers
		Automatic Meter reading	Technical audit Installation of an AMR system
	Data processing errors	Billing system errors	Billing system and procedures audit Improvement of the existing billing system Purchase of a new billing system
		Errors in other data manipulation	Specific audits
Metering Errors	Meter errors (small consumers)	Aging	Definition of the aging curve Meter Replacement policy Use of UMR (unmetered flow reducers)

		Inappropriate meter installation	Define standard procedures Training Replacement of non-standard installation
		Impact of customer's in-house installation	Carry out laboratory survey Select most adapted meters Use of UFR
	Meter errors (large meters)	Meter Aging	Definition of the aging curve Meter Replacement policy
		Meter Oversizing	Establish Customer’s consumption patterns Check the size Replace meters when oversized
		Inappropriate meter installation	Define standard procedures Training Replacement of non-standard installation
		Impact of customer's in-house installation (domestic tanks for instance)	Carry out laboratory survey Select most adapted meters Use of UFR
	Meter management	Meter out of operation	Define detection and fast repair procedure
Unauthorised consumption	Registered customers	Meter by-pass and other frauds	Customer database survey Targeted field survey
		Additional Unregistered connections	Customer database survey Targeted field survey
		Disconnected customers illegally reconnected	Customer database survey Targeted field survey
		Non-active customers illegally reconnected	Customer database survey Targeted field survey
	Unregistered customers	Unregistered (illegal) connection	GIS approach Field survey
		Unregistered consumption in low income areas	Multi-purpose approach including social and communication components

	Network equipment	Water theft on hydrants or other equipment	Install more secure equipment Develop security procedure Specific supply procedures
Misestimate of unmetered consumption	Small consumers		Water meters to be installed Sampling surveys for unmetered connections
	Large consumers		Water meters to be installed

Table 11 : List of Actions to reduce Apparent Losses (non-exhaustive)

4.4. The Project Dimension

As any project, any NRW reduction program needs to meet the following conditions to be successful i.e. to meet the target in terms of NRW in a given period of time.

- Objectives and targets
- Project manager
- Detailed time-schedule
- Human resources
- Material
- Progress monitoring
- Results monitoring

The success implies:

- Genuine Project Management that implies the assignment of a Project Manager (Coordinator)
- Tight coordination of the actors through an effective Project Steering Committee
- Conscientious Management of the Change
- Best use of the Human Resources, Material Resources and Financial Resources as scheduled when the program is designed.

The project may fail for the following reasons:

- Poor design of the plan
- The dynamics approach has not been surveyed
- No coordination between the components
- No coordination between the investments
- Poor involvement of the management
- Difficulties under estimated
- T factor under estimated
- Considering that each department is autonomous

More details are provided in Appendix7.

4.5. The Change Management Dimension

The Change Management Dimension is the one that take into consideration the sustainability of the results of the plan when the plan has been successful.

The change is about the people, both the utility staff and the customers. Some tools are described in the Appendices such as the following:

- **The organisation chart**. All departments should be involved in the NRW reduction process.

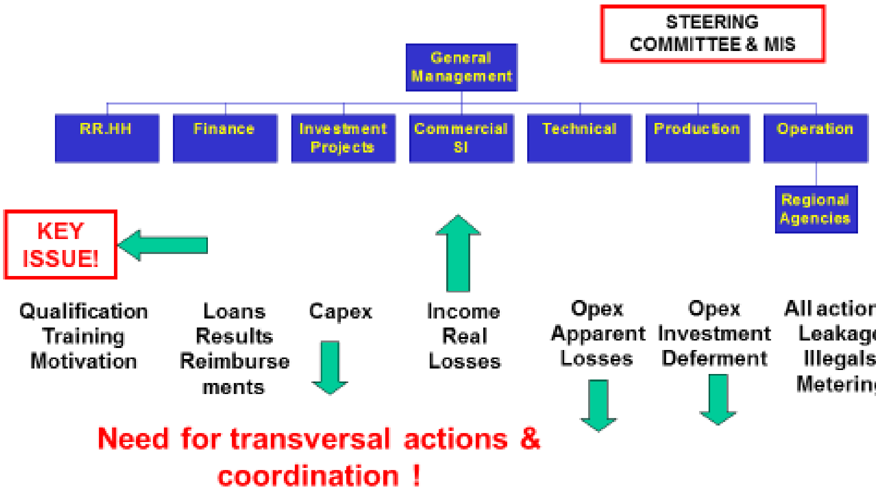


Figure 13 : Corporate organisation chart related to NRW control

- **The Culture Web** that define the symbols, routine and paradigms that are the basis of the Corporate Culture

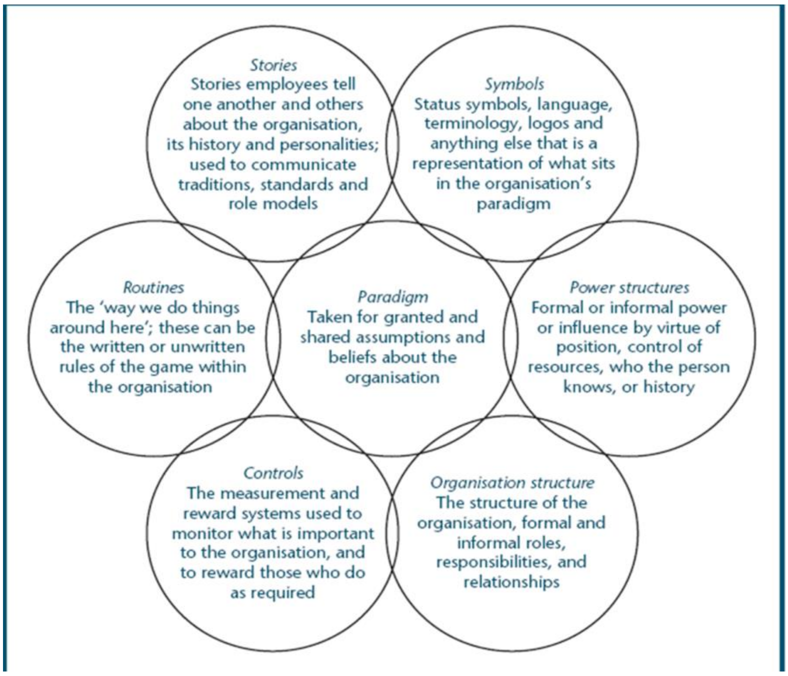


Figure 14 : Corporate Culture Web (Balogun et al, 1999)

- **The stakeholder grid** that defines the position of the various stakeholders involved in the NRW reduction process.

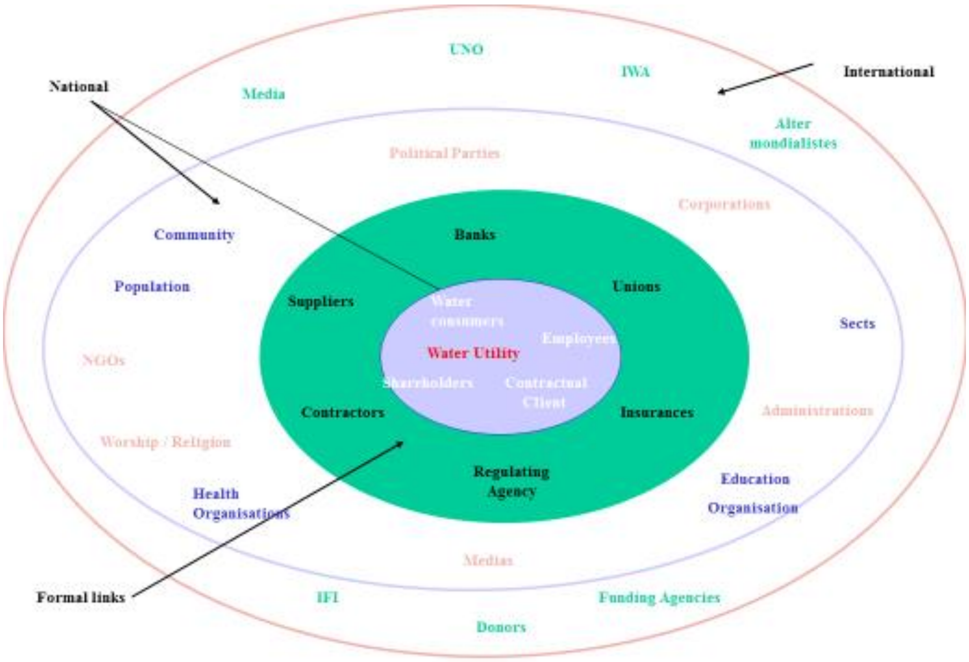


Figure 15 : Stakeholder's grid (Source: Alexandre Braïlowsky)

- The **Change kaleidoscope** that defines the detailed needs in terms of change

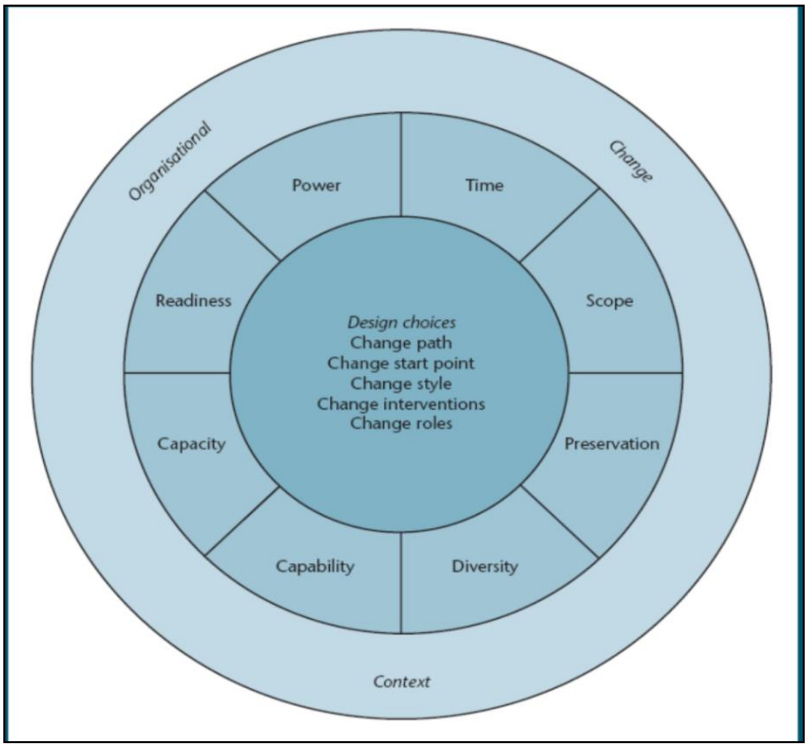


Figure 16 : Kaleidoscope of Change (Balogun et al, 1999)

It includes:

- The Broader Strategic Context (external ring): Why would the organization want to change?
- The Change Context (medium ring): Aspects of culture, competences and situation that should be considered when studying the change process
- The Design choices (inner ring): The range of options that a change agent chooses from when selecting an appropriate change approach.

Finally, – last but not least - the Change Management Dimension should include:

- Internal and External Communication Programs
- Community Participation Programs[7]

More about Change Management is provided in Appendices 7 and 8.

References are listed in Section 6 of the Guidance Note

[7] As emphasized in several sections, the fight against apparent losses is not only an engineering matter. Social sciences and humanities are also involved.

5. ECONOMICS OF APPARENT LOSSES

This section presents some basic economic and financial principles that can be used when preparing an apparent losses reduction programme or more generally a NRW reduction program.
There is a special focus on the cost-benefit analysis (CBA) that enables definition of the economic level of loss for any component of apparent losses.
The authors also focus on two items that need to be considered in any apparent loss programme, namely:
- optimizing the level of data required for effective analysis
- optimizing the water meter replacement frequency.

5.1. Principles

As for any project, the economics of any NRW reduction project has to consider:

- Quantified objectives in terms of NRW indicators
- Capital expenditures (Capex)
- Operational expenditures (Opex)
- Revenue simulation
- Viability (EIRR, Economic Internal Rate of Return, or Payback period)

Generally:

- Financial savings on real losses are estimated at marginal cost of bulk supply or production (whichever is the greater), plus distribution marginal costs
- Financial savings on apparent losses are estimated at the current water charge (tariff)

However, there are exceptions

- Water shortage. In case of actual or predicted water shortage, volumes saved on real losses may be sold to the customers and then they will be estimated at current water charges (tariff)
- In case of severe drought for instance, previous uneconomic solutions generally become economic compared with options of intermittent supply or running out of water..

5.2. Cost-Benefit Analysis (CBA)

The cost-benefit analysis is the basis for the economics and the selection of any actions to reduce losses. It is useful to review the CBA principles.

General
Cost–benefit analysis (CBA) – sometimes called benefit–cost analysis (BCA) - is a systematic approach to estimating the strengths and weaknesses of alternatives that satisfy transactions, activities or functional requirements for a business. This technique is used to determine options that provide the best approach for the adoption and practice in terms of benefits in labour, time and cost savings etc. The CBA is also defined as a systematic process for calculating and comparing benefits and costs of a project, decision orgovernment policy. (Wikipedia)
Broadly, CBA has two purposes:

- To determine if it is a sound investment/decision (justification/feasibility),

- To provide a basis for comparing projects. It involves comparing the total expected cost of each option against the total expected benefits, to see whether the benefits outweigh the costs, and by how much.

Theory
Cost–benefit analysis is often used to appraise the desirability of a given policy. It is an analysis of the expected balance of benefits and costs, including an account of foregone alternatives and the status quo. CBA helps predict whether the benefits of a policy outweigh its costs, and by how much relative to other alternatives (i.e. one can rank alternate policies in terms of the cost–benefit ratio). Generally, accurate cost–benefit analysis identifies choices that increase welfare from a utilitarian perspective. An analyst using CBA should recognize that perfect appraisal of all present and future costs and benefits is difficult, and while CBA can offer a well-educated estimate of the best alternative, perfection in terms of economic efficiency and social welfare are not guaranteed (according to Wikipedia)

Process
The following is a list of steps that comprise a generic cost–benefit analysis.[6]

1. List alternative projects/programs.
2. List stakeholders.
3. Select measurement(s) and measure all cost/benefit elements.
4. Predict outcome of cost and benefits over relevant time period.
5. Convert all costs and benefits into a common currency.
6. Apply discount rate.
7. Calculate net present value of project options.
8. Perform sensitivity analysis.
9. Adopt recommended choice.

Evaluation
CBA attempts to measure the positive or negative consequences of a project, which may include:

1. Effects on users or participants
2. Effects on non-users or non-participants
3. Externality effects
4. Option value or other social benefits.

Accuracy
The value of a cost–benefit analysis depends on the accuracy of the individual cost and benefit estimates.

Implementation
The CBA approach can be used in following cases for instance:

- Comparing several alternatives to reduce a category of real or apparent loss
- Comparing the use of different equipment with different cost and efficiency
- Comparing several action programs

Comments

- In a given situation, the action plan to reduce and control NRW generally consists of various elementary actions to get every component of NRW under control. The best plan in terms of cost benefit analysis is the one that gathers the best elementary solutions in terms of CBA. However, it is always useful to consider the eventuality of some interactions between the actions as demonstrated in §4.2 (Dynamics of losses).
- The CBA of the overall program is not always the sum of the CBA of its components: it is sometimes necessary to include some investments that generate no immediate direct benefit such as the installation of bulk meters or other system to get reliable data. These investments are essential for the operation, maintenance and sustainability of the overall project.

5.3. Economic Apparent Loss Level (EALL)

The value of apparent losses can be reduced to an economic threshold beyond a level that is not economically viable to address. This economic threshold is determined by establishing the optimal level of investment in data required to achieve commensurate lower level of non-revenue water.

The economic level of apparent loss on a given project is the level for which the financial savings gained from the project (present value of the inflows) equals the financial expenses (present value of the outflows) incurred by the project.

In fact, this approach is similar to the approach used for cost-benefit analysis. When the financial savings are higher than the financial expenses the project is financially feasible and when the financial savings are lower, it is not. It is then possible to use the classical financial indicators such as the internal rate of return (IRR) or Net Present Value (NPV) for medium to long-term benefits, or the period of return for more immediate benefits, to compare various projects or various solutions together.

This definition of the EALL implies various consequences:

- The EALL may be calculated in volume or in volume per connection: it is the volume of apparent loss that corresponds to the financial equilibrium described above.
- The value of the EALL will differ for each type of apparent loss. In the frame of a global project each component of the apparent loss need to be considered separately.
- For a given type of apparent loss, the EALL value will depend on the methods and techniques used to reduce the loss.
- The EALL value may change over time depending on the evolution of the techniques

Other important statements and findings

- The different kinds of apparent losses are generally not linked and it is possible to have specific actions according to the loss category
- In most cases, the return on investment in apparent losses reduction project is very short and the calculation is simple: an example on meter replacement is given below in § 5.6.1.
- Some investments are very expensive but they have a multi-purpose impact that needs to be considered globally for example installation of an AMR system.
- The EALL is a financial concept but in some cases social impact needs to be considered in the frame of a more sophisticated Social Return on Investment (SROI)

Is it possible to calculate absolute EALL that would be valid as a worldwide reference?

- The members of the 2010 AL initiative considered this point and concluded that it is not possible to calculate such reference values.
- Clearly, the EALL value depends on the method that is used for regularising the related kind of apparent loss. The IRR may be effective with one method and ineffective with another method, or under different background (see example in § 5.6.3)
- Cultural background has a big impact: the cost of reducing water theft is some developing areas is much higher than the cost in developed countries where the problem has already been addressed, as the standard of living is much higher.
- The technical background has a big impact too, as detecting metering losses and unauthorised consumption is much easier when an automatic meter reading (AMR) system has already been installed.

5.4. Calculating EALL by type of apparent loss

The feasibility of calculating EALL for each type of loss is provisionally undertaken in Table 7. There are different types of apparent losses: Apparent Loss a, Apparent Loss b, … AL Loss x.

Obviously, the necessary condition for EALL loss x being calculated is that CAAL loss x itself can be quantified.

The following table indicates for each type of apparent loss:

- the method to calculate the CAAL
- the applicability of the UAAL concept
- the feasibility of calculating the EALL

Collection of information for a given utility and a given project are usually made through a well-designed multi-purpose field survey.

The EALL calculation is done through the analysis of the preliminary field - or laboratory – sample surveys that are recommended to evaluate the CAALs. Each time one given method is tested to regularise the situation it is possible to compare "cost and benefit in present value" or the "rate of return of the investment (IRR)".

The accuracy and reliability of the calculated EALL depends on the size of the sample and its possibility to be extrapolated with a sufficient level of confidence.

<table>
<tr><th colspan="3">APPARENT LOSSES</th><th>CAAL Method for evaluation</th><th>UAAL applicability</th><th>EALL applicability</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td rowspan="7">Metering inaccuracy</td><td rowspan="3">Meter errors (small consumers)</td><td>Aging</td><td>Sampling /Customer. Profile / Meter Errors graph.</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td>Inappropriate meter installation</td><td>Sampling and field meter tests</td><td>No</td><td>Yes</td></tr>
<tr><td>Impact of customer's in-house installation (presence or absence of storage tank)</td><td>Sampling / Census / Lab. Tests</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td rowspan="4">Meter errors (large meters)</td><td>Aging</td><td>Sampling /Customer. Profile / Meter Errors graph.</td><td>No</td><td>Yes</td></tr>
<tr><td>Oversizing</td><td>Sampling /Customer. Profile / Meter Errors graph.</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td>Inappropriate meter installation</td><td>Sampling and field meter tests</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td>Impact of customer's in-house installation (presence or absence of storage tank)</td><td>Sampling / Census / Lab. And Field Tests</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td rowspan="3">Meter Management</td><td rowspan="3"></td><td>Meter out of operation</td><td>Sampling and Meter tests</td><td>No</td><td>n.a.</td></tr>
<tr><td>Errors in meter reading</td><td>Computer analysis / Field check</td><td>No</td><td>n.a.</td></tr>
<tr><td>Invented meter reading</td><td>Computer analysis / Field check</td><td>No</td><td>n.a.</td></tr>
<tr><td rowspan="7">Unauthorised consumption</td><td rowspan="4">Registered customers</td><td>Meter by-pass</td><td>Sampling and Field surveys</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td>Additional Unregistered connections</td><td>Sampling and Field surveys</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td>Disconnected customers illegally reconnected</td><td>Sampling and Targeted Field surveys</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td>Non-active customers illegally reconnected</td><td>Sampling and Targeted Field surveys</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td rowspan="2">Unregistered customers</td><td>Unregistered (illegal) connection</td><td>Sampling and Field surveys</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td>Unregistered consumption in low income areas</td><td>Sampling and Field surveys</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td>Network equipment</td><td>Water theft on hydrants or other equipment</td><td>Sampling and Field surveys</td><td>Yes (but difficult)</td><td>Yes</td></tr>
<tr><td>Data acquisition process</td><td>Billing system errors</td><td>Billing system errors</td><td>Billing system and procedures audit</td><td>No</td><td>n.a.</td></tr>
</table>

n.a. = not applicable

Table 12 : Apparent Losses - Calculation - UALL & EALL Applicability

5.5. Optimizing the level of data; economic threshold

When there is a paucity of data to establish the various indicators required to formulate related water loss control strategies, there is a general tendency to rely on default values and assumptions. This reliance on assumed values instils less confidence in the results produced, which tend to be a high-level strategic nature.

The management of apparent and real losses is not a precise science and deriving very specific values from high-level strategic data should be qualified with a statement as to its reliability and a caution as to its applicability. The use of assumed data and default values has the potential to introduce errors of commission (doing the wrong things), omission (failure to do the right things) and disordering (doing things out of an optimal sequence).

The management of apparent and real water losses requires a significant investment in data management and if this is not undertaken at the outset of a project there is greater risk that the strategies and measures selected may not achieve the optimal results.

The level of investment in data, or level of data, is categorised according to its availability, quality and quantity. A particular type of data can be evaluated in terms of whether it is available or not, as well as when it is available (i.e. timeliness), does it relay meaning, is it accurate, is it relevant, is it complete, and how detailed is it?

The level of data available to a water organisation is directly related to the amount invested in the capture, collection, transmittal, processing, manipulation, representation and application of the data. The cost of these data comprises both fixed costs, which do not change as the amount of data changes, and variable costs, which are related to the quantity of data. Transmission costs are established from the application of a tariff to the time taken to transmit the data is an example of variable costs relating to the quantity of data.

Cost of data = K_1 * Level of Data (L_{od}) where K_1 is a constant

The efficiency of a water organisation or its infrastructure components would be expected to be lower in data deficient situations while in data "rich" situations, higher efficiency would be expected. The proviso for this assumption is that the data is substantially error free after quality control, ideally fit for purpose and usefully applied to make optimal decisions.

The relationship between the level of data and cost of inefficiencies follows the law of diminishing returns, i.e. efficiency improves at a lower rate as the data improves i.e.

Cost of inefficiencies = K_2 / Level of Data (L_{od}) where K_2 is a constant

The sum of these costs represents the total cost of data to the water authority, i.e.

Total Cost = Cost of Data + Cost of Inefficiencies

$$C_d = K_1 L_{od} + K_2 / L_{od}$$

The relationship can be depicted by the generalized graph in Figure 33, which shows that the optimal level of data corresponds to the minimum total cost.

The minimum value of C_d can be established through differentiation and equating the result to zero, which indicates the slope of the Total Cost Curve is horizontal, i.e.

$$\delta C_d: / \delta L_{od} = K_1 - K_2 L_{od}^{-2} = 0$$

Therefore, the optimal $L_{od} = (K_2 / K_1)^{0.5}$

To be practically applicable this generalised theoretical relationship requires modification through the inclusion of other factors that influence the costs of inefficiency and data. These other factors are identified for the organisation as a whole or a specific infrastructure component.

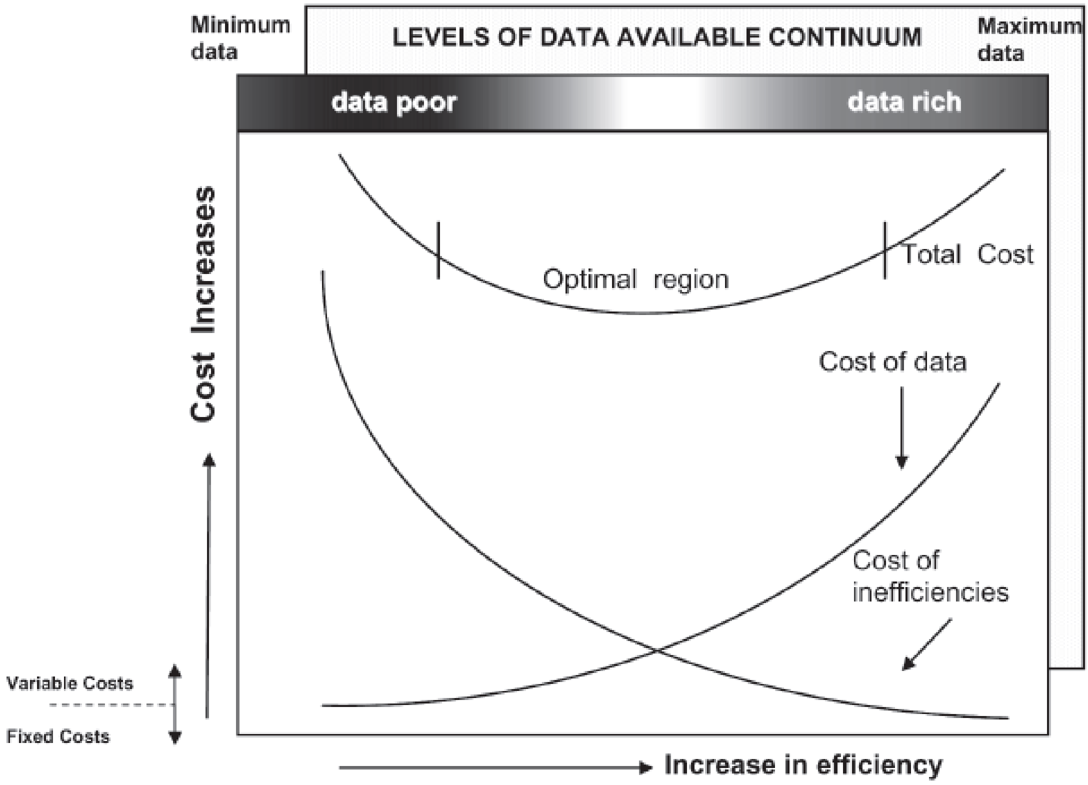


Figure 17 : Optimizing level of data - economic threshold (Johnson EH, 2009)

Case study:
A key assumption made in the theory used to determine the economic threshold for a particular water authority is that there is a negative relationship between the amount of non-revenue water (NRW) and the level of data (L_{od}), i.e. the higher the level of NRW the lower the L_{od}. This general relationship was tested with data from a sample of fifteen small towns in Australia collected for the period 1 July 2003 to 30 June 2004 (Johnson, 2009).

The important finding from considering the results of this sample was that there is a negative relationship between the NRW and the L_{od}. Even though this negative trend is slight, it identified the "weakness" of this relationship was due rather to a low level of data and the lack of associated overt measures in addressing the high levels of NRW.

5.6. Examples of CBA Analyses applied to NRW reduction programs

Optimizing Water Meter Replacement Period

The following case has been studied in Macao in 1998.
The blue curve is the ageing curve of a structured sample of domestic meters (1/2"), which was obtained through lab and field surveys. The red curve shows what the variations of the water sales will be if the meters are replaced every 4 years.

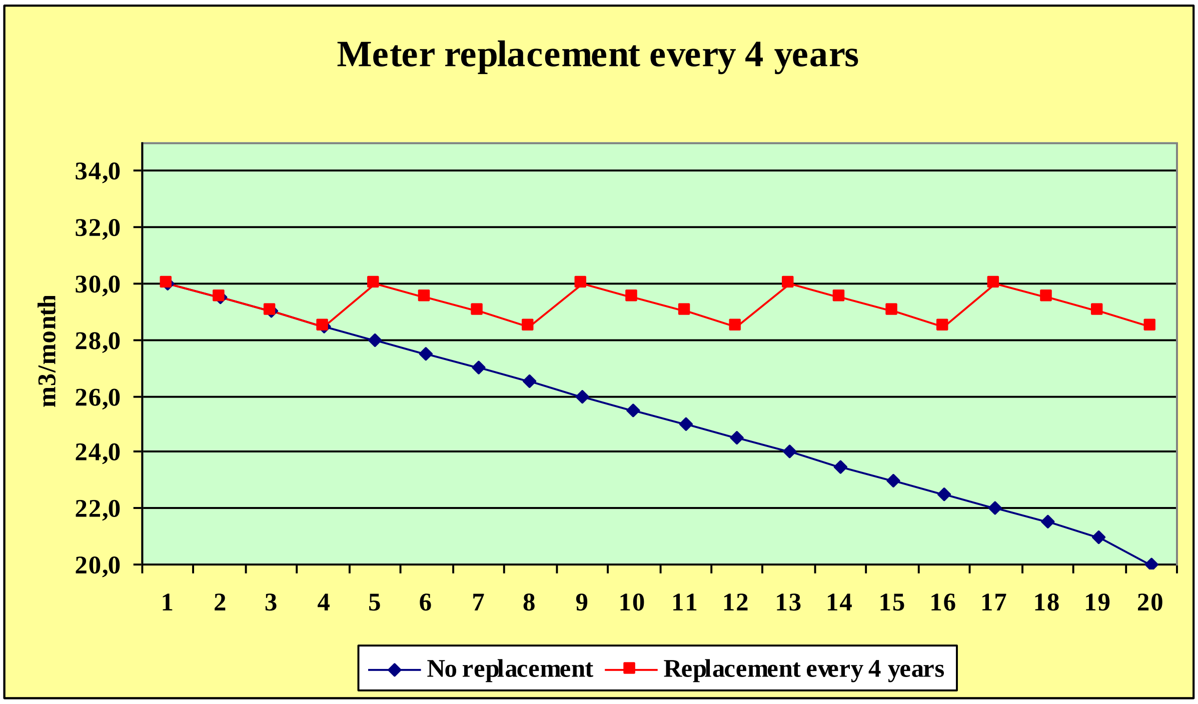


Figure 18 : Aging curve of residential water meter and replacement on a 4-Year basis in Macao (Vermersch M, Carteado F 2008)

The CBA has been implemented for various meter replacement periods from 2 to 20 years: for each time from 2 to 20 years. The y-axis of the graph represents the sum of the annual cost in local currencies (purchasing cost of the new meter and the manpower cost) minus the billing increase due to the meter replacement. The Utility decided to replace the meters every 6/7 years instead of every 10 years under the previous policy. This resulted in a dramatic decrease in the apparent losses due to undermetering.

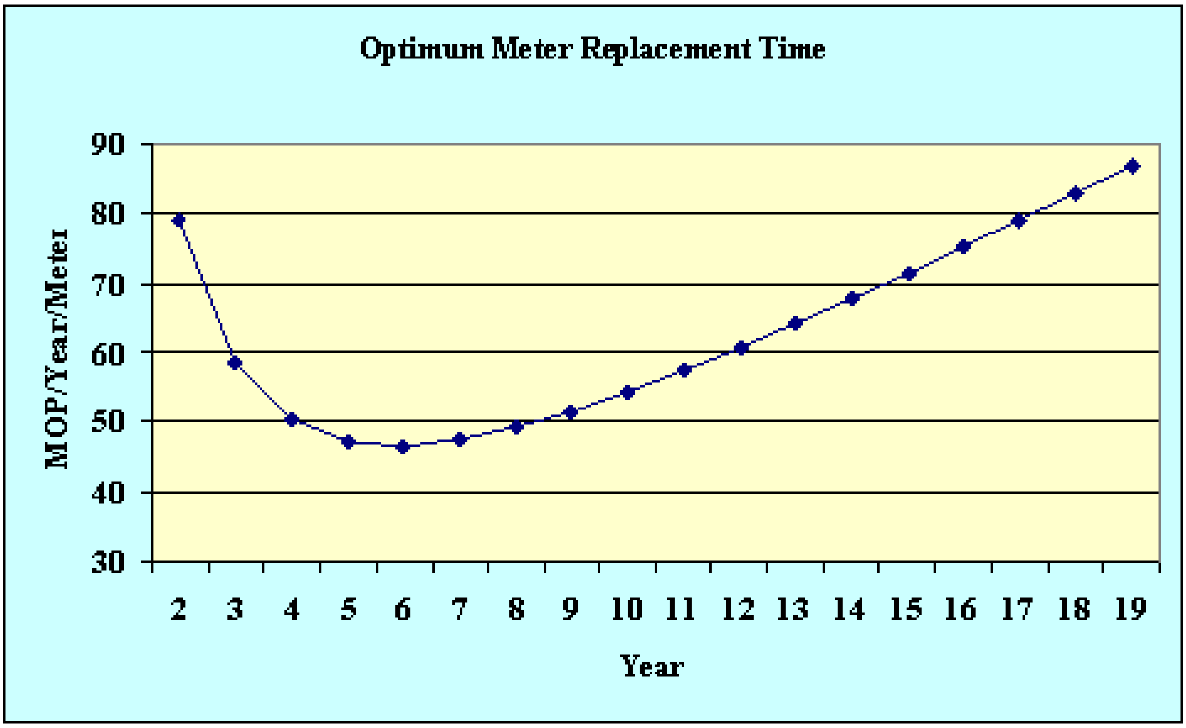


Figure 19 : Optimum Meter Replacement Time in Macao (Vermersch, Carteado, 2008)

The optimum period to replace water meters depends on several factors:

- The Ageing Curve of the meter and the conditions of installation and service.
- The Water Charges (Tariff)
- The Purchasing Cost of the meter
- The Replacement Cost (manpower for instance)

The optimum period may vary based on:

- significant changes in the economical background (water tariff, costs)
- new metering technologies

The optimum period may be different in the various districts of a given city based on service conditions.

Finally, the calculation of the optimum replacement period should be carried out for each specific case. For example, the replacement frequency of meters for industrial customers is generally higher than the frequency used for residential customers because industrial tariff are generally higher.

References are listed in Section 6 of the Guidance Note

6. REFERENCES AND BIBLIOGRAPHY

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The specific references mentioned in each Section of the Guidance Notes are shown in Sections 6.1.1 to 6.1.5 below, in the order in which they first appear in that Section.

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These references can be found by accessing the individual Appendices using the weblinks shown in the Table below.

APPENDIX	TITLE	MOST RECENT ISSUE	WEBLINK
1	Non-Revenue Water and Large Water Meter Calibration	**15 Sep 2016**	Paper AppLoss 2016H
2	Non-Revenue Water and Unbilled Authorised Consumption	**15 Sep 2016**	Paper AppLoss 2016G
3	Customer Metering Errors	**15 Sep 2016**	Paper AppLoss 2016J
4	Apparent Water Losses generated by Unauthorised Consumption – Assessment and Corrective Actions	**15 Sep 2016**	Paper AppLoss 2016B
5	Non-Revenue Water and Errors throughout the Data Acquisition Process	**15 Sep 2016**	Paper AppLoss 2016K
6	Non-Revenue Water and Revenue Collection Ratio: Review, Assessment and Recommendations	**15 Sep 2016**	Paper AppLoss 2016A
7	An Action Planning Model to Control Non-Revenue Water	**15 Sep 2016**	Paper AppLoss 2007R
8	An Overall Dynamic Approach in Water Loss Reduction	**15 Sep 2016**	Paper AppLoss 2010N
9	Change Management as an Indispensable Component when Planning for NRW Control	**15 Sep 2016**	Paper AppLoss 2009F

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7. AUTHORS' PROFILES

Michel Vermersch

Michel Vermersch is an expert in the management of water, sanitation and electricity utilities, as well as in corporate engineering for water and wastewater services. He is also a recognized specialist in the diagnostics of network yields and in reducing water and energy losses.

Michel has worked for over 50 years in the urban water sector in Europe (8 countries), Africa (26), Asia (13), Latin America (10), the Middle East (3) and Australia. After working for 15 years in Water Utilities for the Suez group early in his career, he focused during the following ten years on the study of water supply systems.

Based on this experience at both the practical and theoretical levels, he has specialized in the past 20 years in providing technical assistance to water utilities all around the world. He has developed specific expertise in reducing technical and commercial/apparent water losses. He has implemented more than 60 urban programs to reduce water losses, particularly in Sao Paulo, Buenos Aires, Macau, Phnom Penh and Chongqing. Michel has been one of the leaders of the IWA Working Group on commercial/apparent losses (*Apparent Loss Initiative*). He has been a lecturer on NRW for the UNESCO-IHE in Delft and, presently, for the International Executive Master "Water For All" at the AgroParisTech Engref Institute in Montpellier (France).

Fatima Carteado

Fatima CARTEADO holds a Master's degree in Urban Utility Management from the University of Loughborough (UK) and a civil engineering degree from the Polytechnic School of the Federal University of Bahia (Brazil). Her 30 years of experience make her an expert in the water sector and the management of utility companies. She has headed projects in technical assistance and customer management for public and private operators but has also carried out more specialized appraisal work on reducing non-revenue water and implementing quality plans on this issue.

After holding various positions of responsibility for a dozen years with the water utility department of the state of Bahia (Brazil), she has carried out various technical assistance assignments - particularly in Africa - on behalf of the Overseas Development Association (ODA), run by the British Government. Then, she has worked in many developed and developing countries in Africa, Asia, America and Europe. For the last 10 years, she has run her own consulting office in Salvador (Brazil) and worked on many NRW projects around the world. She is also a NRW lecturer for the International Executive Master OPT (Water for All) at the AgroParisTech Institute in Montpellier (France).

Alex Rizzo

Dr. Ing. Alex Rizzo: Main fields are in vocational education & training, small business strategy, alternative technologies and integrated water resource management, with some 30 publications to date. Alex has been responsible for the implementation of a number of national technology-based projects over the years, such as the efficiency enhancement of the national potable water infrastructure. Alex presently acts as Head of University College at the Malta College of Arts, Science & Technology (MCAST), and was previously its Director for the Institute of Applied Sciences.

Alex's key areas of expertise are in water loss strategies and integrated water resource management; vocational education/training; and business strategy. His key professional achievement is the implementation of a national water loss control strategy in Malta, resulting in a leakage reduction from an ILI (Infrastructure Leakage Index) of 10 to an ILI of below 3, with a national leakage reduced from 3,000m3/Hour to 600m3/Hr. Alex holds the following affiliations: Fellow of the Chartered Institution of Water and Environmental Management and a Chartered Water/Environmental Manager; Fellow of the Institution of Engineering and Technology and a Chartered Engineer; Fellow of the Chartered Management Institute and a Chartered Manager.

Edgar H Johnson

Edgar Johnson is a professional engineer with more than 35 years of international experience in water management. His education combines a Doctor of Technology (Water Engineering) with a commerce degree, providing him with unique insight into the full range of utility system practices.

He has contributed to the development of national standards and guidelines associated with water loss management, efficiency and metering and published more than 30 articles/papers/research books related to the field. His experience includes the successful development and implementation of projects during the severe droughts and water shortages throughout Southern Africa and Asia in the 1980's through to 2000, as well as during the millennium drought in Australia (2001-2009).

His involvement with the International Water Association's (IWA) Water Loss Specialist Group included leadership of its non-revenue-water apparent loss (AL) initiative and he currently provides related papers for inclusion on the LEAKSSuite website.

Francisco Arregui

Francisco (Paco) Arregui is an industrial engineer holding a PhD degree with specialization in urban hydraulics. His PhD dissertation dealt with new strategies for water meter management. Following this, for more than 20 years, he has worked as an associate professor, researcher and consultant on urban hydraulics and water metering projects. His work involves cooperation with different international water companies in highly specialized projects aimed to reduce commercial losses. He has also been an active member of IWA Water Loss Specialist Group since 2004.

His expertise in urban hydraulics includes the following areas: water meter optimization and management, residential water demand characterization, water demand management strategies, software development (water meter management tools, water demand characterization, water hammer calculation …) and statistical analysis of inflows to water distribution systems. Francisco is the main author of IWA's book "Integrated water meter management" which is a comprehensive reference providing technical information on water meter technologies and strategies to improve water meter management.

Allan Lambert

Allan has over 50 years' UK and international water industry experience, split equally between Water Resources/Hydrology, and NRW management, in more than 40 countries. A Past President of British Hydrological Society, and special advisor on water resources and leakage to House of Commons Environment Committee in the 1995-1996 UK drought, he developed Component Analysis (Background & Bursts Estimates) when Technical Secretary to the UK National Leakage Control Initiative (1992-1994). He chaired the 1st IWA Water Loss Task Force (1995-1999) which developed the Best Practice IWA Water Balance and Performance Indicators. A Fellow of IWA and C.I.W.E.M, he has researched benefits of pressure management for almost 20 years, and is recognised as a leading international authority in leakage management.

In 2013, Allan converted his LEAKSSuite website into a non-commercial source of easily accessible free information on effective water leakage and pressure management. In 2015, with several leading Apparent Losses experts he created an Info-Hub on Apparent Losses where these Guidance Notes and 9 Appendices, and numerous other papers on Apparent Losses are available to all, free of charge http://www.leakssuite.com/apparent-losses/outreach-app-loss/ .