Water Loss Performance Indicators

R. Liemberger *, K. Brothers, A. Lambert ***, R McKenzie****, A Rizzo*****, T Waldron******

* R Liemberger, Liemberger & Partners, Austria, roland@liemberger.cc

** K Brothers, Utility Services Branch, Ottawa, Canada, ken.brothers@ottawa.ca

*** A Lambert, ILMSS Ltd, UK allan.lambert@leaksuite.com

**** R McKenzie, WRP Pty Ltd, South Africa, www.wrp.co.za

***** A Rizzo, Rizzo Consultants Ltd., Malta, alex@rizzoconsultants

****** T Waldron, Wide Bay Water Corporation, Australia, TimW@widebaywater.qld.gov.au

Keywords: Performance Indicators; Apparent Losses; Real Losses

Introduction

The 2nd Edition of the IWA Manual of Best Practice, 'Performance Indicators for Water Supply Systems' (Alegre et al, 2006) updates the 1st Edition (Alegre et al, 2000). The changes include (but are not limited to) modification and extension of the overall number of PIs; changes to the reference numbers of some PIs; and removal of the Level 1 to 3 pre-classification of importance. The 2nd Edition also recommends that the choice of Performance Indicators for individual stakeholders should be based on an initial definition of demanding and realistic objectives.

The Vision Statement of the Water Loss Task Force (WLTF) is **'***to develop and promote international best practices and measurements in water loss management'*. The use of appropriate 'Best Practice' Performance Indicators for performance comparisons and target setting are clearly fundamental to achieving this objective.

The 2nd Edition recommendations relating to Water Loss performance indicators were not subject to prior discussion with members of the WLTF, so do not mention (or take due account of) several important recent developments in practical water loss management; such as the World Bank Institute Banding system, the ever-increasing importance of pressure management, and the positive evaluation and adoption of 1st Edition Performance Indicators in Australia, Malta[1] and South Africa, and by American Water Works Association.

The authors of this paper were invited by the current Chairman of the WLTF to review the new and revised material in the 2nd Edition of the PIs Report, and to present this paper at Water Loss 2007**.** This paper is the result of a long consultation process between the authors and in parts a compromise that was not easy to reach.

The conclusions differ in some respects from the material in the 2nd Edition of the IWA Manual and the authors hope that the WLTF will be involved in the preparation of a possible 3rd edition of the Best Practice manual. Until then, it might be a suitable option for the WLTF to publish an article in Water 21 based on the conclusions of this paper.

[1] Malta – although it is small, it is one of the most significant European examples of how major achievements in improving NRW management on a drought-stressed island have been recognised by the use of the best practice PIs in the 1st Edition. Previously, water losses were calculated in % of system input volume and per km mains – nothing could hardly have been more inappropriate for Malta.

The 2nd Edition of ‘Performance Indicators for Water Supply Systems’

Widening the experience on which recommendations are based

Of the 170 PIs listed in the 2nd Edition, Non-Revenue Water and its components account for 15 (9 Operational, 4 Water Resources, 2 Financial). The 2nd edition recommends that the choice of PIs for individual stakeholders should be based on ‘an initial definition of demanding and realistic objectives’. The objective of the Water Loss Task Force is to use ‘practical approaches’ to ‘develop and promote international best practices in water loss management’.

During the development of the 1st Edition (Alegre et al, 2000), there was comprehensive discussion and input from the Water Loss Task Force. However, during the development of the 2nd Edition, the Performance Indicators Task Force relied upon their own experiences in testing the 1st Edition methods (principally in Europe), and did not include (in relation to Water Loss PIs) the experiences of Water Loss Task Force members in introducing and applying the methods in many other industrialised countries as well as in low and middle income countries. Consequently, some aspects of the 2nd Edition are inconsistent with current practical approaches now endorsed by the Water Loss Task Force.

The differences in emphasis between this paper and the 2nd Edition can also be attributed to the fact that, for the Water Loss Task Force, use of Performance Indicators has moved on from being simply a calculation of appropriate meaningful PIs, to interpreting them and recommending appropriate actions - the World Bank Institute Banding System (of which, more later in the paper) is one of several such examples initiated by WLTF members. The emphasis of this paper can be summarised as follows:

- To continue to explain why expressing NRW and its components as % of system input volume can be very misleading (although the authors are aware that this is – unfortunately – still the most popular water loss PI)
- To reinforce the message from the 1st Edition that NRW expressed as a % of System Input Volume (Fi46 in the 2nd Edition) is a Financial PI which should definitely not be used as an Operational PI or for target setting
- To highlight the need of developing an effective Operational PI for Apparent Losses
- To show that the inclusion of pressure in Real Loss performance indicators and targets is essential
- To discuss the criticism of the Infrastructure Leakage Index (ILI) in the 2nd Edition.
- To provide guidelines for practical and effective PIs for Operational and Target Setting purposes

To assist interpretation of the contents of this paper, and emphasise the difference between ‘System Input Volume’ (which includes ‘Water Exported’) and ‘Water Supplied’ (which does not), a simplified IWA Standard Water Balance is shown in Figure 1 below.

<table>
<tr><td rowspan="2">Volume from own sources</td><td rowspan="6">System Input Volume</td><td colspan="4">Exported Water (part of Authorised Consumption)</td></tr>
<tr><td rowspan="5">Water Supplied</td><td colspan="3">Other Billed Authorised Consumption</td></tr>
<tr><td rowspan="4">Imported Water</td><td rowspan="4">Non-Revenue Water NRW</td><td colspan="2">Unbilled Authorised Conumption</td></tr>
<tr><td rowspan="2">Apparent Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Customer metering errors</td></tr>
<tr><td colspan="2">Real Losses</td></tr>
</table>

Figure 1: Simplified IWA Annual Water Balance

Why shouldn't NRW% by volume be used as an Operational PI?

The initial objective[2] of the Water Loss and Performance Indicators Task Forces, to develop a standard water balance which could be used for calculating both operational and financial PIs (and even some Water Resources PIs) was ambitious and has largely succeeded. However, experience shows that there are some traps for the unwary. The practice of expressing NRW, and components of NRW, as a % of either System Input Volume or a % of Water Supplied, is one such problem area.

The introductory section of the 2nd Edition of the PIs Manual (page 10) states 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).'***

Because consumption (including water exported) normally makes up a very substantial part of System Input Volume or Water Supplied for most systems and sub-systems, this severely compromises the use of %s by volume as a suitable PI for NRW and its components. However, because calculation of % by volume is traditional, and usually a simple 'first step', it can be found in the 1st and 2nd PIs Reports as a Financial PI for NRW, calculated as a % of System Input Volume.

This is not totally illogical for a crude Financial PI, as it represents the % of System Input Volume which is generating Revenue. However, it takes no account of the different valuations of components of NRW, nor the cost of operating the system. A better Financial PI for NRW is % by cost (Fi47 in the 2nd Edition), which calculates the cost of each of the three principal components of NRW (Unbilled Authorised Consumption, Apparent Losses and Real Losses) by attributing different monetary valuations (per m3) to each of these NRW components, and dividing by the operating cost of running the system.

However, the numerous problems that occur if %s by volume are used as Operational PIs for NRW and its components have been well documented internationally since the

[2] During the preparation of the 1st Edition of the IWA Best Practice Manual on Performance Indicators (1996-2000)

1980's, and extensively by members of the Water Loss Task Force. The problem is that the level of NRW is substantially influenced by the following (non-exhaustive list):

- whether the calculation uses, as the denominator, System Input Volume (which includes water exported) or Water Supplied (which does not)
- differences in consumption levels, and changes in consumption (e.g. by tariff increases)
- whether the Utility's customers have individual storage tanks, or are supplied by direct pressure (in the first case, customer meter under-registration will be much higher than the second case)
- the average supply time in systems with intermittent supply (which, unfortunately, is the rule rather than the exception in many systems in low income countries)
- the average pressure (wide variations between systems without pressure control in industrialised countries on the one hand and low(est) pressure systems in low and middle income countries on the other hand)

It is clearly evident from Figure 1 that, if water is exported from a system or sub-system, then for any given volume of NRW, the % NRW will be lower than in the case where no water is exported. The substantial influence of consumption on %NRW has been previously explained in other papers by the authors, but the influence of 'water exported' has not been previously highlighted. Two simple examples, based on actual case studies, and shown in Appendix 1.

Case Study 1 shows that, if NRW % by volume is to be used for any aspect of operational or target purposes, it must be expressed as % of Water Supplied, or in litres/connection/day, or as m3/km of mains/day. Case Study 2 demonstrates not only differences between NRW % of System Input Volume and NRW % of Water Supplied for a Utility with exports, but also how NRW % can increase when NRW volume decreases, in this case during a drought; expressing NRW in litres/service connection/day (or m3/km of mains/day for systems with connection density less than 20 per km of mains) avoids both problems in the Case Studies.

For almost 30 years, reputable working groups and National Organisations have been recommending against expressing NRW or its components as % of system input volume, for example:

- UK Report 26 (1979), Managing Leakage (1994), Economic Regulator (OFWAT) (1996)
- German DVGW W391 Guidelines (1986) and W392 Guidelines (May 2003)
- South African Bureau of Standards (1999)
- American Water Works Association (2003), for USA and Canada
- Malta Water Services Corporation and it's regulator (2003)
- Water Services Association of Australia (2003), regulators for the States of Queensland and Victoria (2004), and new National reporting standards (2007)
- World Bank Institute in its NRW Management training modules (2005) (except for policy dialogue)

Given this gradual international movement away from %s by volume, it comes as a surprise that the 2nd Edition:

- makes no criticism whatsoever of the many known anomalies and problems associated with use of NRW % by volume:

- states that ‘Fi46 (NRW as % of System Input Volume) is perhaps the most popular and easy way to assess water losses’ - but without any accompanying ‘Health Warning’
- promotes the use of Fi46 as the key PI objective in the example PI measurement system in Fig.3, page 58 of the 2nd Edition

In complete contrast to the 2nd Edition, a recent American Water Works Association Research Foundation study (AwwaRF, 2007) concluded that %s by volume - including %s by volume for NRW- were unsuitable for target setting for any of the following purposes:

Regulation, Environmental Protection, Contract Supervision, Financial Optimization, Operational Management.

This conclusion is endorsed by all of the authors of this paper. But perhaps the Water Loss Task Force needs to recognise that one of the reasons why % by volume continues to be incorrectly used as an operational PI and for setting targets is that ***the IWA Water Loss and Performance Indicator Task Forces have no recommended operational PI for NRW.*** This deficiency is considered and addressed in the Summary and Conclusions.

Apparent Losses: the need for a better Performance Indicator

From 1996 to 1999 the Water Losses Task Force was tasked to identify the best traditional PIs for Non-Revenue Water and Real Losses, and to develop improved PIs for these parameters. But similar objectives for Apparent Losses were not included in their terms of reference. Accordingly, in the 1st Edition of the PIs Manual (2000), the parameters selected for use in the Apparent Losses PI (and for Water Losses, = Real + Apparent Losses) were the same as the units used for the Real Losses PI, i.e. ’per service connection’ or ‘per km of mains’, depending upon system connection density.

The 2nd Edition states that ‘the field test and the experience of the Water Losses Task Force demonstrated that this was not a good option, and the use of percentages is now recommended’. Actually, 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’.

The WLTF is keenly aware of the need to develop an improved practical PI for Apparent Losses, and have actively been at work on this topic. The Apparent Loss Team members (12 members spanning 7 countries) have agreed that the % PI (both as a *% of System Input Volume* and as a *% of Water Supplied*) is a poor indicator, containing little valuable information that can be acted upon. A main reason for this is the complexity of the Apparent Losses issue:

- four components act upon Apparent Losses (under-registration, theft, billing errors and meter reading errors)
- systems without roof tanks provide an entirely different scenario from systems with roof tanks; customer meter under-registration is much greater where customers have private storage tanks (Lambert et al, 2002)
- the Apparent Losses volume can actually be negative due to the effect of jetting causing over-recording of single-jet and multi-jet meters

At this point in time the Team is working on an index which hosts, as a denominator, the concept of the **Maximum Acceptable Apparent Loss**, based primarily upon metering and direct/indirect supply considerations. The concept is similar to the ILI fro Real Losses, an approach that the team endorses. Pending completion of the development of this PI, the ‘least worst’ simple PIs for apparent losses are considered to be litres/service connection/day, or litres/metered property/day, or % of water supplied, or % of authorized consumption with the choice depending upon local circumstances.

Whatever the interim simple PI used, Apparent Losses from systems with customer storage tanks, and Apparent Losses from direct pressure systems, should not be compared directly with each other, but rather as two separate data sets. An if apparent losses are expressed as % of water supplied then the comparison of systems with very different leakage levels is also obviously troublesome.

Operational Performance Indicators for Real Losses

The best traditional performance indicators

The 2nd Edition again confirms previous conclusions of the Water Loss Task Force, regarding selection of the most appropriate traditional operational PI for Real losses:

- use ‘per service connection’ if connection density is 20/km of mains or more
- use ‘per km of mains’ if connection densities is less than 20/km of mains

In the 2nd Edition, the definitions of Real Losses PIs Op27 (per service connection) and Op28 (per km of mains) clearly specify this. However, in the main text (e.g. Table 21, Page 30, and page 31) the situation is unnecessarily confused by terms such as ‘Urban’, and ‘low service connection densities’ which have no specific meaning. These terms were avoided in the 1st edition, as some urban systems have low service connection densities[3].

Most distribution systems have service connection densities of 20 per km or more, and the 2nd edition reaffirms that Op27 (litres/service connection/day when the system is pressurised) is a much better operational performance indicator for Real Losses than any traditional percentage indicator. However, the limitations of Op27 (and Op28) are that:

- the allowance for density of connections is ‘either/or’, rather than allowing for actual density of connections
- the distance between the property line (or curb stop in North America) to the customer meters (or first point of consumption) is not taken into account
- the average pressure is not taken into account (on average, leak flow rates for large systems vary linearly with pressure)

For any individual system, the first two of these limitations effectively disappear, and Op27 (or Op28, if connection density is less than 20/km) have proved to be both practical and versatile for target setting and assessment of progress in Real Loss management. (AwwaRF, 2007). This is because:

- Real Losses can be reduced by pressure management (as well as by speed and quality of repairs, active leakage control and infrastructure management)
- if the system size is increasing, the performance indicator allows for this

However, for State, National and International comparisons all three parameters need to be taken into account, which is why the Infrastructure Leakage Index (ILI) was developed, to be used (where appropriate) in addition to the simpler PI of litres/service connection/day or m3/km of mains/day.

[3] This problem has also been recognised in Germany and the next revision of the W392 guidelines will most likely note use "urban" and "rural" anymore to differentiate between systems with different connection density

The Infrastructure Leakage Index (ILI)

The ILI is the dimensionless ratio of the Current Annual Real Losses (CARL) to the Unavoidable Annual Real Losses (UARL). UARL is calculated using an empirical formula (based on an auditable component analysis of Real Losses) which allows for mains length, number of service connections, average distance from property line (or curb stop) to customer meter (or first point of consumption) and average operating pressure.

The advantage of a performance indicator that includes a reasonably reliable estimate of the 'Unavoidable' Real Losses are obvious – it identifies not only what the current losses are, but also permits an initial estimate of the maximum potential for reduction in real losses at the current pressure.

The parameters used in the UARL formula were researched over a 4 year period, and the equation subject to sensitivity testing before being published (Lambert et al, 1999). It has proved to be robust in application, with many hundreds of ILIs having been calculated in numerous countries. In a very few cases, where there are virtually no unreported leaks and bursts due to local circumstances (so far such cases were reported from some water utilities in Australia, Austria and the Netherlands) lower annual Real Losses have been achieved, but for the great majority of Utilities worldwide, the UARL (corresponding to an ILI of 1.0) has proved to be an effective 'gold standard' for operational management of Real Losses in developed countries with good infrastructure condition. However, for many developing countries, ILIs for some systems are usually found to be in excess of 10, or in some cases even in excess of 100, so very low ILIs can be considered almost an impossible target for such systems.

The World Bank Institute Banding System.

Water Loss Task Force members who started to use the ILI quickly realised what a powerful PI it was for categorising operational performance in managing Real Losses in a wide variety of diverse international situations. But in the absence of widespread training programs for a new approach in what is essentially a conservative industry, an intermediate approach was also needed, which takes operating pressure into account.

Following earlier development of banding systems considered appropriate for South Africa, Australia and New Zealand, the World Bank Institute adopted and are promoting internationally a broader based Banding system (Liemberger et al, 2005) applicable to both developed and developing countries. This uses a matrix approach to identify a Technical Performance Category (Bands A to D) for a Utility's management of Real Losses, and guidance on the type of actions the Utility should be undertaking.

Figure 2 shows the WBI Target Matrix, which is expressed in terms of Litres/service connection/day, and average pressure. The values in the Matrix, in litres/connection/day, are based on the assumption that customer meters are located at the property line, with an average density of connections of 40 per km of mains. For meter locations and connection densities significantly different to these assumptions, users may wish to calculate the ILI and use it to identify the appropriate Band for the system under consideration.

Technical Performance Category		ILI	**Real Losses in Litres/Connection/Day** (when the system is pressurised); at an average pressure of:				
			10 m	**20 m**	**30 m**	**40 m**	**50 m**
Developed Countries	**A**	1 - 2		**< 50**	**< 75**	**< 100**	**< 125**
	B	2 - 4		**50 - 100**	**75 - 150**	**100 - 200**	**125 - 250**
	C	4 - 8		**100 - 200**	**150 - 300**	**200 - 400**	**250 - 500**
	D	> 8		**> 200**	**> 300**	**> 400**	**> 500**
Developing Countries	**A**	1 - 4	**< 50**	**< 100**	**< 150**	**< 200**	**< 250**
	B	4 - 8	**50 – 100**	**100 - 200**	**150 - 300**	**200 - 400**	**250 - 500**
	C	8 - 16	**100 - 200**	**200 - 400**	**300 - 600**	**400 - 800**	**500 - 1000**
	D	> 16	**> 200**	**> 400**	**> 600**	**> 800**	**> 1000**

Figure 2: Physical Loss Target Matrix (from WBI NRW Training Module 6: Performance Indicators)

It is sometimes queried why it was considered necessary to show the band limits in both litres/service connection/day and average pressure, rather than to simply use litres/service connection/day/metre of pressure. The reason is that the matrix approach demonstrates visually how reduction of excess pressures can reduce real losses.

The interpretation of Bands A to D is as follows:

- **A** Further loss reduction may be uneconomic unless there are shortages
- **B** Possibilities for further improvement
- **C** Poor leakage management, tolerable only if resources are plentiful and cheap
- **D** Very inefficient use of resources, indicative of poor maintenance and system condition in general

Pro-active National organisations (South African Water Resource Commission, Australian Water Services Association, New Zealand Water & Waste Association) had already introduced national banding systems prior to the publication of the WBI system, based on their own perceived country-specific requirements. The advantage of the WBI system is that it enables any Utility, in any country, to not only quickly assess and compare its performance using an international standard, but also to interpret the broad appropriate actions required to improve matters. This is an important step beyond the calculation of PIs and will, it is hoped, encourage Utilities to start to take action rather than fall into the trap of ‘paralysis by analysis’.

Comments on 2nd Edition criticisms of the ILI

The 2nd Edition of the PIs manual acknowledged that the ILI has great support, but also received 'a lot of criticism' in the field tests in which PI Task Force members were involved; most (if not all) of these seem to have been European projects. The 2nd Edition also states that 'in general, it *(the ILI)* seems to be supported by Water Losses Consultants'; this is true, as the WLTF contains many consultants who now regularly use the ILI, but there are also many WLTF Utility members (including the past, present and next WLTF Chairmen) who endorse and promote it .

No mention was in the 2nd Edition (2006) that the ILI had already been adopted and/or recommended by, for example:

- the South African Water Resources Commission (2000)
- the American Water Works Association (2003), for the USA and Canada
- Malta Water Services Corporation and its regulator (2002)
- the Water Services Association of Australia (2003), and the Regulator for the State of Victoria (2005)
- in calculating the Band Limits for the WBI Banding System (2005)

The first of the two main criticisms in the 2nd Edition of the PIs Report is that '*It is the only indicator in the whole IWA PI system that contains a judgement in itself and is based on an empirical expression (and for this reason does not fit all the PI requirements)'.* However, there are several other PIs in the 2nd Edition that do not meet all the PI requirements – notably all the %s by volume, and the two new Water Resources PIs for Real Losses (WR2 and WR3 which, like the ILI, contain 'a judgement' in empirical calculations of 'Annual Yield Capacity of Own Resources'). And the WLTF's proposed Apparent Losses PI, Maximum Acceptable Apparent Losses, will use a similar approach.

The second criticism of the ILI in the PIs Report is that '*Shortcomings relate to the meaning and confidence level when the variability of the operating pressure and/of the service connection length in the system is high (e.g. hilly regions, systems with significant daily pressure fluctuations, systems with apartment blocks and individual apartment meters.'*

Experiences of WLTF members who have been using confidence levels in Water Balance and PI calculations since 2001 show this criticism is not justified. Because in practice the largest error impacting Water Balance and PI calculations has consistently been the reliability of System Input Volume measurements and the estimates of Apparent Losses for (i) systems with customer storage tanks (neither of which are mentioned in the 2nd Edition Report) and (ii) utilities with a substantial volume of illegal consumption.

Practical techniques for assessing average pressure are in fact widely available and widely used by the WLTF members – and of course by other well run utilities. But the authors of this paper find it almost incomprehensible that the vast majority of Water Utilities take no systematic measurements of system pressure, given that pressure management is the foundation for effective management of leak flow rates, break frequency, some components of Apparent Losses, and infrastructure in general. Given the importance of pressure, Utilities must surely become more pro-active regarding pressure monitoring and management, rather than looking for reasons not to do so.

Reported problems with estimating average service pipe length were exacerbated by use in the 1st Edition of total service pipe lengths (main to meter) and an alternative formula for UARL. The original UARL formula (Lambert et al, 1999) uses number of service connections (main to meter), and length of pipe (property line to meter); this makes the criticism irrelevant for systems with meters close to the property line. The original correct approach is now included in the 2nd Edition definition of the ILI (Op29). For systems with meters distant from the property line, the 2nd Edition exaggerates the problem; users who doubt this are invited to contact authors Lambert, Liemberger or McKenzie for free software to test the implications of the accuracy of their calculations.

It should also be noted that Accuracy Bands recommended in the 2nd Edition (0-5%, 5-20%, 20-50% and >50%) are far too broad for effective Water Balance and PI calculations. If the Accuracy Bands recommended in the 2nd Edition are used, the criticisms relating to reliability of pressure and service pipe length would be irrelevant as all accuracies for all parameters would be assumed to be at the mid-points of one of the Bands (2.5%, or 12.5%, or 35%, or greater than 50%)

Summary and Conclusions

- This paper seeks 'to review the current Water Loss Task Force position on international best practice Performance Indicators for Water Utilities seeking to improve their management of Non-Revenue Water and its components', following publication of the PIs Report, 2nd Edition in 2006
- The following conclusions, for Operational and Target Setting purposes, draw upon the authors' WLTF experiences and international developments that were not considered as part of the development of the 2nd Edition.
- NRW and its components should always be presented in both volume and monetary terms, preferably with confidence limits, before performance indicators are calculated.
- % of System Input Volume is unsuitable for NRW or any of its components for a wide variety of reasons - notably the presence or absence of water exported, differences and changes in consumption, and presence or absence of customer storage tanks.
- More work will have to be done by the WLTF and its Apparent Losses Team before further recommendations on a PI or PIs for Apparent Losses can be made
- the best simple traditional Real Losses PIs are 'per service connection' or 'per km of mains' (depending upon connection density); they should be accompanied by an estimate of average pressure, and preferably with a calculation of ILI.
- the absence of an Operational and Target Setting PI for NRW needs to be remedied; while % of Water Supplied might be used initially for some minor components of NRW, it is not suitable for NRW as a whole, so the choice should logically be the PI that is selected for the largest component of NRW (normally Real Losses), and will therefore usually be either volume/service connection/day or volume/km of mains/day, depending upon density of connections.

References

Alegre H., et al. (2000) Performance Indicators for Water Supply Services. IWA Manual of Best Practice, 1st Edition. ISBN 900222272

Alegre H., et al. (2006) Performance Indicators for Water Supply Services. IWA Manual of Best Practice, 2nd Edition. ISBN 1843390515

American Water Works Association (AWWA) Water Loss Control Committee, 2003. Applying Worldwide Best Management Practices in Water Loss Control. AWWA Journal August 2003.

AWWA Research Foundation (2007): Evaluating Water Loss and Planning Loss Reduction Strategies. Report 1P-4.5C-91163-03/07-NH

Deutsche Vereinigung des Gas- und Wasserfaches (DVGW) (2003). W392 Guidelines: Network inspection and water losses: activities, procedures and assessments.

Lambert A. et al (1999). A Review of Performance Indicators for Real Losses from Water Supply Systems. AQUA, Dec 1999. ISSN 0003-7214

Liemberger R and McKenzie R. "Accuracy Limitations of the ILI: Is It an Appropriate Indicator for Developing Countries?" Conference Proceedings, IWA Leakage 2005 Conference in Halifax, Nova Scotia, Canada. (download from http://waterloss2007.com/Leakage2005.com/index.php)

Liemberger R. (2002): Do You Know How Misleading the Use of Wrong Performance Indicators can be? IWA Specialised Conference, Leakage Management - A Practical Approach, Cyprus, November 2002, Conference Proceedings, ISBN 9963875904 (download from www.liemberger.cc)

Seago C, McKenzie R., Liemberger R. (2005) International Benchmarking of Leakage from Water Reticulation Systems, Paper to Leakage 2005 Conference, Halifax, September 2005

South African Bureau of Standards Code of Practice: SABS 0306:1999 The management of potable water in distribution systems

Wide Bay Water Corporation and Queensland Environmental Protection Agency, (2005) Managing and Reducing Losses from Water Distribution Systems, Manual 10 – Executive Summary (ISBN 0724294988)

World Bank Institute (2005): NRW Training Module 6: Performance Indicators

WSAA Facts 2004. ISSN 1328-2751 Water Services Association of Australia

Appendix 1: Case Studies demonstrating problems with using NRW% by volume

Case Study 1: A Bulk Supply Utility serves 4 Distribution Utilities, via transmission mains which pass through each of the Distribution Utilities in sequence, with bulk export/import meters on the transmission mains at the boundary of each distribution Utility.

Each Distribution Utility has 25,000 service connections and 500 km of mains, and the Bulk Supply Utility has 500 km of transmission mains prior to the first export meter. The Water Balances and PIs are shown below.

Direction of flow in Transmission Main		>>>>>>>>	Meter	>>>>>>>>	Meter	>>>>>>>>	Meter	>>>>>>>>	Meter	>>>>>>>>
Water Balance Component	**Units**	**Bulk Supply Utility**		**Distribution Utility A**		**Distribution Utility B**		**Distribution Utility C**		**Distribution Utility D**
Water from own sources	**Ml/day**	**102**		**0**		**0**		**0**		**0**
Water Imported	**Ml/day**	**0**		**100**		**75**		**50**		**25**
System Input Volume SIV	**Ml/day**	**102**		**100**		**75**		**50**		**25**
Water Exported	**Ml/day**	**100**		**75**		**50**		**25**		**0**
Water Supplied WS	**Ml/day**	**2**		**25**		**25**		**25**		**25**
Other Billed Consumption	**Ml/day**	**0**		**20**		**20**		**20**		**20**
Non Revenue Water	**Ml/day**	**2**		**5**		**5**		**5**		**5**
	% of SIV	**2.0%**		**5.0%**		**6.7%**		**10.0%**		**20.0%**
	% of WS	**100.0%**		**20.0%**		**20.0%**		**20.0%**		**20.0%**
	l/conn/day			**200**		**200**		**200**		**200**
	m3/km/day	**4.0**		**10.0**		**10.0**		**10.0**		**10.0**

- NRW volume is the same for all four Distribution Utilities (5 Ml/day)
- But NRW as % of System Input Volume varies from 5% to 20% - due to exports
- NRW as % of Water Supplied is not influenced by differences in water exported
- But for operational or target purposes, preferable to use litres/connection/day (or m^3/km of mains/day for systems with less than 20 service connections/km of mains), or Infrastructure Leakage Index.

Case Study 2: An Australian Utility, exporting water to an adjacent Utility, and experiencing reduced consumption during a severe multi-year drought.

Simplified Water Balance for two successive years are shown below.:

	Year 1	Year 2	Year 1	Year 1	Year 2	Year 2
	Volumetric units		% of SIV	% of WS	% of SIV	% of WS
System Input Volume	255	198	100%	155%	100%	147%
Water Exported	79	63	31%	45%	32%	47%
Water Supplied	176	135	95%	100%	68%	100%
Other Billed Consumption	152	115	45%	86 %	58%	85%
Non-Revenue Water	**24**	**20**	**9%**	**14%**	**10%**	**15%**

- Year 1: % NRW is either **9%** or **14%,** depending on whether calculation is based on System Input Volume SIV (as in the IWA Financial PI) or Water Supplied (WS).
- Year 2: with restrictions on customers as drought severity increased, NRW was **reduced** from 24 units to 20 units; but due to reduced consumption, the % NRW **increased** to **10%** or **15%** (depending on whether SIV or WS was used).
- Fortunately, Water Services Association of Australia had ceased (in the early 1990's) to use %s by volume and moved to an IWA recommended operational PI (in this case the ILI, but litres/service connection/day would have equally well demonstrated the improved performance).