Recommendations for Initial Non-Revenue Water Assessment

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Abstract: The paper suggests a simple methodology for initial Non-Revenue Water (NRW) assessment which can be applied prior to a detailed water audit. The performance indicator suggested is NRW expressed in litres per service connection per day.

In addition to this performance indicator, the average pressure has to be determined and with this information a first assessment of the water utilities NRW management performance can be made by using the International NRW Assessment Matrix.

Introduction

After a decade of work done by the IWA Water Loss Task force (WLTF) and the dissemination of results at conferences around the world, water sector professionals, key decision makers and International Funding Institutions (like the World Bank) very often still use Non-Revenue Water expressed as percentage of system input volume as the only water loss performance indicator and too often base multimillion Dollar investment decisions on this misleading indicator.

Part of the problem is the lack of understanding of the importance of the water balance and the associated lack of know-how of how to do a first basic NRW assessment without having the luxury of a detailed water audit. The other problem is that IWA and the WLTF initially overlooked the need for a simple NRW performance indicator.

Water Audit and Water Balance

Twenty years ago, NRW management was more based on a process of 'guesstimation' than on precise science. This has changed dramatically in many industrialized countries, kick-started by the regulatory pressure on UK water companies to cut leakage. Yet, despite some encouraging success stories, most water supply systems worldwide continue to have high levels of water losses.

Part of the problem was the lack of a meaningful standard approach to defining and quantifying the components of NRW. Surprisingly few Low And Middle Income Countries (LAMIC) have a national standard terminology and standard water balance calculation …and even then, they all differ from each other!

Being aware of the problem of different water balance formats, methods and water loss performance indicators, the IWA decided in the late 1990's that a standard international water balance structure and terminology was required. This standard format has meanwhile been adopted (with or without modifications) by national associations in a number of countries.

Preparing a baseline to establish current levels of water losses (by carrying out a water audit that leads to a water balance) is the first – critical - step for any utility wanting to reduce water losses. A water balance is a prerequisite for designing a NRW reduction strategy. Strangely enough, it is a step often overlooked in the development of urban water supply projects. A standard template[1] and terminology for categorizing and quantifying NRW, based on the initial version of the International Water Association (IWA) but using the "Commercial Losses" instead of "Apparent Losses" and "Physical Losses" instead of "Real Losses", as preferred by the World Bank, is shown below. Definitions of all terms can be found in Appendix 1.

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Commercial Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Metering Inaccuracies and Data Handling Errors</td></tr>
<tr><td rowspan="3">Physical Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to Point of Customer Metering</td></tr>
</table>

Figure 1: The International Water Balance

The components of the water balance can be measured, estimated or calculated using a number of techniques. Whilst ideally many of the important components are measured, the reality unfortunately is often very different and in many cases utilities simply do not have a water balance – and only the total volume of NRW is known.

Before planning NRW reduction activities ideally at least a quick water audit should be undertaken to establish an initial water balance. This would involve the following steps:

1. Determination of the annual system input volume. This can be simple if system input is fully metered and good records are kept or may require temporary measurements and extrapolations in cases with non or only partially metered system input
2. Determination of all elements of authorized consumption. This will require analysis and quantification of the unmetered elements
3. Estimation of commercial losses. Average customer meter accuracy will have to be determined by bench and in-situ meter testing and theft of water has to be estimated, for example based on detailed house-to-house survey in problem areas. The magnitude of meter reading, data handling and

[1] Similar water balance templates have become (or are becoming) national reporting standards in a growing number of countries (for example, Australia, Canada, Germany, New Zealand, South Africa) and in the United States in selected states (for example, Texas and California), and they are promoted by the American Water Works Association (AWWA) Water Loss Control Committee.

billing errors can be estimated based on a thorough process analysis and analysis of billing data.

4. After having done the first three steps, the volume of physical losses can simply be calculated. Since a lot of estimates had to be made in these first three steps, the accuracy of the leakage volume is often problematic and flow and pressure measurements in hydraulically discrete parts of the system have to be made so that the actual level of leakage can be calculated and compared to the results of the top-down water balance.

In addition to this volumetric assessment, the length of the distribution system and the number of service connections has to be determined; pressure and supply time measurements have to be carried out so that the average pressure and average supply time can be determined. Only then all water loss performance indicators can be calculated in a satisfactory manner.

Table 1: Water Loss Performance Indicators

	Performance Indicator
Non-Revenue Water	Litres/connection/day (w.s.p.)[2]
Commercial Losses	% of Authorized Consumptions Litres/connection/day
Physical Losses	Infrastructure Leakage Index (ILI) Litres/connection/day (w.s.p.)

If it is impossible to carry out a water audit (lack of time, funds or know-how) at least an **Initial NRW Assessment** should be done and the NRW performance indicator, volume of NRW in litres per connection per day, calculated and compared to the **International NRW Assessment Matrix** (Figure 2).

Initial NRW assessment

Only four key numbers have to be known for an Initial NRW Assessment:

1. Daily volume of NRW
2. Average supply time (in case of intermittent supply)
3. Average pressure
4. Number of service connections

[2] w.s.p. stands for "when the system is pressurized". The indicator must be calculated for continuous supply, this meand when a simple calculation of the volume of NRW per connection is 500 litres per day at a supply time of 12 hours per days, the performance indicator would be: 500 / 12h x 24h = 1,000. Only then the indicator can be compared to a system with continuous supply

Daily volume of NRW

The daily volume of NRW is the difference between the average daily system input volume (usually the annual average) and the average daily billed consumption.

Since the main component of NRW is nearly always the volume of physical losses, and physical losses increase proportional to the supply time, the volume of NRW must be adjusted to reflect the 24/7 volume of NRW, the volume of NRW that would occur if the system, in its present condition, would be supplied on a continuous (24/7) basis. For example: if the average supply time is 18 hours per day, the actual volume of NRW must be divided by 18 and multiplied by 24h to derive the theoretical volume of NRW (w.s.p.). This corrected volume is then used to calculate the NRW performance indicator.

Average supply time (in case of intermittent supply)

If the system is not supplied on a continuous basis, the average supply time must be calculated. Identify areas which different supply times, determine the approximate number of service connections of each area and calculate a weighted average supply time using the number of connections as weighting factor. The water utility will normally be able to calculate the average supply time.

Average pressure

The average pressure in a certain point is the 24 hour average. Pressures have therefore be measured several times a day – ideally recorded (in at least 15 minutes intervals) with electronic pressure loggers. Identify areas with different pressure characteristics, measure pressures and calculate average pressure for each area, determine the approximate number of service connections of each area and calculate a weighted average pressure using the number of connections as weighting factor.

Pressures are often crossly over- or underestimated by water utilities:

- Overestimated pressure: if the output pressure of a pumping station is used
- Underestimated: when pressure information is based on measurements which were all taken during peak supply hours (=daytime) and no information on night pressures was taken into account.

Number of service connections

The number of service connections is very often not equal to the number of customers. Only in cases where each customer is supplied by an individual service connection the number of connections equals the number of customers. But in most cases the number of (physical) connections is less than the number of customers. Therefore the approximate number of service connections must be estimated based on the average number of customers per service connection.

Use of the International NRW Assessment Matrix

Calculate NRW in litres per connection per day by simply dividing the 24/7 volume of NRW[3] by the number of service connections. Together with calculated average pressure, determine the NRW performance category with the International NRW Assessment Matrix.

NRW Management Performance category		**Non-Revenue Water in Litres/connection/day** when the system is pressurized at an average pressure of:				
		10 m	**20 m**	**30 m**	**40 m**	**50 m**
High Income Countries	**A1**		**< 50**	**< 65**	**< 75**	**< 85**
	A2		**50-100**	**65-125**	**75-150**	**85-175**
	B		**100-200**	**125-250**	**150-300**	**175-350**
	C		**200-350**	**250-450**	**300-550**	**350-650**
	D		**> 350**	**> 450**	**> 550**	**> 650**
Low and Middle Income Countries	**A1**	**<55**	**<80**	**<105**	**<130**	**< 155**
	A2	**55-110**	**80-160**	**105-210**	**130-260**	**155-310**
	B	**110-220**	**160-320**	**210-420**	**260-520**	**310-620**
	C	**220-400**	**320-600**	**420-800**	**520-1000**	**620-1200**
	D	**> 400**	**> 600**	**> 800**	**> 1000**	**> 1200**

Figure 2: International NRW Assessment Matrix

- **Category A1:** World class NRW management performance; the potential for further NRW reductions is small unless there is still potential for pressure reduction or accuracy improvement of large customer meters
- **Category A2:** Further NRW reduction may be uneconomic unless there are water shortages or very high water tariffs; a detailed water audit is required to identify cost-effective improvements
- **Category B:** Potential for marked improvements; establish a water balance to quantify the components of NRW; consider pressure management, better active leakage control practices, and better network maintenance; improve customer meter management, review meter reading, data handling and billing processed and identify improvement potentials
- **Category C:** Poor NRW record; tolerable only if water is plentiful and cheap; even then, analyze level and causes of NRW and intensify NRW reduction efforts
- **Category D:** Highly inefficient; a comprehensive NRW reduction program is imperative and high-priority

[3] The “24/7l” volume is the volume of NRW for a continuous (24/7) supply situation

Development of the International NRW Assessment Matrix

This part of the paper shows how the International NRW Assessment Matrix was developed and which assumptions and simplifications were made. It is based on the simple physical loss matrix which was published in 2005[4] that provides some insights into typical values for different situations. This approach can be used to classify the leakage levels for utilities in developed and developing countries into four categories:

- **Category A:** Further loss reduction may be uneconomic unless there are shortages; careful analysis needed to identify cost-effective improvement
- **Category B:** Potential for marked improvements; consider pressure management; better active leakage control practices, and better network maintenance
- **Category C:** Poor leakage record; tolerable only if water is plentiful and cheap; even then, analyze level and nature of leakage and intensify leakage reduction efforts
- **Category D:** Highly inefficient; leakage reduction programs imperative and high-priority

Technical performance category		ILI	**Real Losses in Litres/connection/day** when the system is pressurized at an average pressure of:				
			10 m[5]	**20 m**	**30 m**	**40 m**	**50 m**
High Income 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**
LAMIC	**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**	**500–1,000**
	D	**> 16**	**> 200**	**> 400**	**> 600**	**> 800**	**> 1,000**

Figure 3: Physical Loss Assessment Matrix

Based on discussions between Allan Lambert with the Australian Water Industry, this Matrix has meanwhile been modified to take best performing utilities into account (the "A" category has been split into A1 and A2 (Figure 4). The new category definitions are:

[4] R Liemberger and R. McKenzie, "Accuracy Limitations of the ILI: Is It an Appropriate Indicator for Developing Countries?" Conference Proceedings, IWA Leakage 2005 Conference in Halifax, Nova Scotia, Canada; *This matrix is sometimes referred to as the "WBI Banding System"*

[5] m = meters

- **Category A1:** World class leakage management performance; the potential for further physical loss reductions is small unless there is still potential for pressure reductions
- **Category A2:** Further loss reduction may be uneconomic unless there are shortages; careful analysis needed to identify cost-effective improvement

Technical performance category		ILI	**Real Losses in Litres/connection/day** when the system is pressurized at an average pressure of:				
			10 m	**20 m**	**30 m**	**40 m**	**50 m**
High Income countries	**A1**	**< 1.5**		**< 25**	**< 40**	**< 50**	**< 60**
	A2	**1.5 - 2**		**25-50**	**40-75**	**50-100**	**60-125**
	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**
Low and Middle Income Countries	**A1**	**< 2**	**< 25**	**< 50**	**< 75**	**< 100**	**< 125**
	A2	**2 - 4**	**25-50**	**50-100**	**75-150**	**100-200**	**125-250**
	B	**4 - 8**	**50–100**	**100–200**	**150–300**	**200–400**	**250–500**
	C	**8 -16**	**100–200**	**200–400**	**300–600**	**400–800**	**500–1,000**
	D	**> 16**	**> 200**	**> 400**	**> 600**	**> 800**	**> 1,000**

Figure 4: NEW Physical Loss Assessment Matrix

Development of a tool for initial NRW Assessment

The problem with these matrices is that the volume of Physical Losses has to be known (which rarely is the case) and they are therefore not suitable for a first crude assessment prior to the availability of a water balance. In order to create a simple tool for a very first and basic NRW level assessment (as a simple alternative to the commonly used percentages) the methodology has been taken a step forward and the result is the suggested **"International NRW Assessment Matrix"** (Figure 5).

This NRW assessment matrix is based on an extreme simplification – apparent loss allowances are based on an assumed average billed consumption per connection of 1,000 litres per day. This means that in systems with substantially higher average consumption the values in especially the "A" categories might be difficult to achieve.

The values in the matrix were calculated as follows:

The physical loss volumes were taken from the New Physical Loss Assessment Matrix and allowances for commercial losses were added as per Table 2 and Table 3 respectively.

Table 2: Commercial loss allowances for water utilities in high income countries

Category	Commercial Losses	
	% of billed consumption	Litres per connection per day
A1	< 2.5%	< 25
A2	2.5% - 5%	25 - 50
B	5% - 10%	50 - 100
C	10% - 15%	100 - 150
D	> 15%	> 150

Table 3: Commercial loss allowances for water utilities in low and middle income countries

Category	Commercial Losses			
	% of billed consumption			Litres per connection per day
	Provision for meter under-registration and data handling errors	Additional Provision for water theft	Total	
A1	< 2.5%	< 0.5%	< 3%	< 30
A2	2.5% - 5%	0.5% - 1%	3% - 6%	30 - 60
B	5% - 10%	1% - 2%	6% - 12%	60 - 120
C	10% - 15%	2% - 5%	12% - 20%	120 - 200
D	> 15%	> 5%	> 20%	> 200

Combining the physical and commercial loss components of NRW, the values for the matrix (Figure 5) were calculated.

NRW Management Performance category		**Non-Revenue Water in Litres/connection/day** when the system is pressurized at an average pressure of:				
		10 m	**20 m**	**30 m**	**40 m**	**50 m**
High Income Countries	**A1**		**< 50**	**< 65**	**< 75**	**< 85**
	A2		**50-100**	**65-125**	**75-150**	**85-175**
	B		**100-200**	**125-250**	**150-300**	**175-350**
	C		**200-350**	**250-450**	**300-550**	**350-650**
	D		**> 350**	**> 450**	**> 550**	**> 650**
Low and Middle Income Countries	**A1**	**<55**	**<80**	**<105**	**<130**	**< 155**
	A2	**55-110**	**80-160**	**105-210**	**130-260**	**155-310**
	B	**110-220**	**160-320**	**210-420**	**260-520**	**310-620**
	C	**220-400**	**320-600**	**420-800**	**520-1000**	**620-1200**
	D	**> 400**	**> 600**	**> 800**	**> 1000**	**> 1200**

Figure 5: International NRW Assessment Matrix

- **Category A1:** World class NRW management performance; the potential for further NRW reductions is small unless there is still potential for pressure reductions or the accuracy improvement of large customer meters
- **Category A2:** Further NRW reduction may be uneconomic unless there are water shortages or very high water tariffs; a detailed water audit is required to identify cost-effective improvements
- **Category B:** Potential for marked improvements; establish a water balance to quantify the components of NRW; consider pressure management, better active leakage control practices, and better network maintenance; improve customer meter management, review meter reading, data handling and billing processed and identify improvement potentials
- **Category C:** Poor NRW record; tolerable only if water is plentiful and cheap; even then, analyze level and causes of NRW and intensify NRW reduction efforts
- **Category D:** Highly inefficient; a comprehensive NRW reduction program is imperative and high-priority

Summary

The intention of this paper is to provide an extremely simplified but robust NRW assessment methodology which has the potential to kick-start the long overdue improvement of the NRW investment decision making in general and in low and middle income countries in particular.

Expressing NRW as a percentage of system input volume is in general an often misleading and imprecise method but particularly in systems with intermittent supply and very low operating pressures – and this means in the vast majority of LAMIC water utilities.

It is hoped that the simple “Initial NRW Assessment” methodology in combination with the “International NRW Target Matrix” will in future become a useful tool for water sector professionals and funding institutions.

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Appendix 1: Water Balance and Definitions

A standard template[6] and terminology for categorizing and quantifying NRW, based on the initial version of the International Water Association (IWA), is shown below.

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
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<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
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</table>

Figure 6: The International Water Balance

Water Balance Definitions

In the following, all terms used in the water balance are listed in hierarchical order – as one would read the water balance form from left to right. Some of the terms are self-explanatory but are still listed and briefly explained in order to having a complete list available.

- **System Input Volume** - The volume of treated water input to that part of the water supply system to which the water balance calculation relates; it may come from own sources and treatment facilities or from external bulk suppliers. It is important to note that water losses at raw water transmission schemes and losses during the treatment process are not part of the Annual Water Balance calculations. In case the utility has no distribution input meters, or they are not used and the key meters are the raw water input meters, the system input has to be based on the raw water meters but has to be adjusted by treatment plant water use. In either case, the measured volume has to be corrected for known systematic bulk meter errors.

[6] Similar water balance templates have become (or are becoming) national reporting standards in a growing number of countries (for example, Australia, Canada, Germany, New Zealand, South Africa) and in the United States in selected states (for example, Texas and California), and they are promoted by the American Water Works Association (AWWA) Water Loss Control Committee.

- **Authorized Consumption** - The volume of metered and/or unmetered water taken by registered customers, the water utility and others who are implicitly or explicitly authorized to do so by the water utility, for residential, commercial and industrial purposes. It also includes water exported across operational boundaries. Authorized consumption may include items such as fire fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered or unmetered.
- **Water Losses** - The difference between System Input and Authorized Consumption. Water losses can be considered as a total volume for the whole system, or for partial systems such as transmission or distribution schemes, or individual zones. Water Losses consist of Physical Losses and Commercial Losses[7].
- **Billed Authorized Consumption** - Those components of Authorized Consumption which are billed and produce revenue (also known as Revenue Water or Billed Volume). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.
- **Unbilled Authorized Consumption** - Those components of Authorized Consumption which are legitimate but not billed and therefore do not produce revenue. Equal to Unbilled Metered Consumption plus Unbilled Unmetered Consumption.
- **Commercial Losses** - Includes all types of inaccuracies associated with customer metering as well as data handling errors (meter reading and billing), plus unauthorized consumption (theft or illegal use). (IWA term: Apparent Losses)
- **Physical Losses** - Leakage and other physical water losses from the pressurized system and the utility's storage tanks, up to the point of customer use. In metered systems this is the customer meter, in unmetered situations this is the first point of use (stop tap/tap) within the property[8]. (IWA term: Real Losses)
- **Billed Metered Consumption** - All metered consumption which is also billed. This includes all groups of customers such as domestic, commercial, industrial or institutional and also includes water transferred across operational boundaries (water exported) which is metered and billed.
- **Billed Unmetered Consumption** - All billed consumption which is calculated based on estimates or norms but is not metered. This might be a very small component in fully metered systems (for example billing based on estimates for the period a customer meter is out of order) but can be the key consumption component in systems without universal metering. This component might also include water transferred across operational boundaries (water exported) which is unmetered but billed.
- **Unbilled Metered Consumption** - Metered Consumption which is for any reason unbilled. This might for example include metered consumption by the utility itself or water provided to institutions free of charge, including water

[7] The terms "Physical" and "Commercial" losses are preferred by the World Bank. The International Water Association uses "Real" and "Apparent" losses.

[8] Although physical losses, after the point of customer use do by definition not form part of the volume of Physical Losses in the water balance, this does not necessarily mean that they are not significant or worthy of attention for demand management purposes.

transferred across operational boundaries (water exported) which is metered but unbilled.

- **Unbilled Unmetered Consumption** - Any kind of Authorized Consumption which is neither billed nor metered. This component typically includes items such as fire fighting, flushing of mains and sewers, street cleaning, frost protection, etc. In a well run utility it is a small component which is very often substantially overestimated. Theoretically this might also include water transferred across operational boundaries (water exported) which is unmetered and unbilled – although this is an unlikely case.
- **Unauthorized Consumption** - Any unauthorized use of water. This may include illegal water withdrawal from hydrants (for example for construction purposes), illegal connections, bypasses to consumption meters or meter tampering and under-reading of customer meters because of meter reader corruption.
- **Customer Metering Inaccuracies and Data Handling Errors** - Apparent water losses (water that is only "apparently" lost but causes a loss in revenues) caused by customer meter inaccuracies and data handling errors in the meter reading and billing system.
- **Leakage on Transmission and/or Distribution Mains** - Water lost from leaks and breaks on transmission and distribution pipelines. These might either be small leaks which are not visible at the surface (e.g. leaking joints) or large breaks which were reported and repaired but did leak for a certain period before that and contribute therefore to the annual volume of physical losses in a particular year.
- **Leakage and Overflows at Utility's Storage Tanks** - Water lost from leaking storage tank structures or overflows of such tanks caused by e.g. operational or technical problems.
- **Leakage on Service Connections up to point of Customer Metering** - Water lost from leaks and breaks of service connections from (and including) the tapping point until the point of customer use. In metered systems this is the customer meter, in unmetered situations this is the first point of use (stop tap/tap) within the property. Leakage on service connections might be sometimes visible but will predominately be small leaks which do not surface and which run for long periods (often years).
- **Revenue Water** - Often called Billed Volume, includes those components of Authorized Consumption which are billed and produce revenue (also known as Billed Authorized Consumption). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.
- **Non-Revenue Water** (NRW) - Those components of System Input which are not billed and do not produce revenue. Equal to Unbilled Authorized Consumption plus Physical and Commercial Losses.
- **(Unaccounted-for Water)** - Because of the widely varying interpretations and definitions of the term 'Unaccounted-for Water' (UfW), it is strongly recommended that this term be no longer used. IWA recommends that countries which, for historic reasons, want to continue using UfW it should be defined exactly as NRW.