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WATER LOSS MANAGEMENT IN NORTH AMERICA – JUST HOW GOOD IS IT?

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1. Introduction:

A 1996 overview of water production and delivery statistics, in 469 US Water Utilities, showed Metered Water Ratios averaging 84%, implying Unaccounted for Water (UFW) of 16% of production, on average. The range of UFW was very large, from over 50% down to 1%, with a 13% modal (most frequently occurring) value. So how does this compare to other countries worldwide? An international data set of 27 systems from 20 countries, assembled by the International Water Association Task Force on Water Losses which included two of the authors, showed a range of Non-Revenue Water (NRW) from 2% to 40%, with an average of 17.5% and a 13% modal value.

These overall statistics seem fairly similar. However, technical committees in many countries – including the AWWA's Leak Detection and Water Accountability Committee – have realized over recent years that expressing UFW or NRW as a % of production is only a very crude measure of true performance in managing water losses, because it is strongly influenced by differences in consumption.

The IWA Water Losses Task Force, working in conjunction with an IWA Task Force on Performance Indicators, has recently reviewed the traditional measures for comparing UFW/NRW/Water Losses. They recommended improved measures for comparing performance, applicable to a wide variety of different situations between, and within, countries.

Key features of this internationally recommended approach are:

- a standard approach to Water Balance calculations used for performance comparisons
- different NRW and Water Losses performance indicators for different purposes
- a component-based equation for predicting unavoidable annual real losses, taking key local system operating characteristics into account.

These IWA Task Force recommendations were mentioned in a presentation to the DSS in Reno in 1999. As a result of the interest this generated, the Leak Detection & Water Accountability Committee encouraged a number of utilities to volunteer water audit and other data, to apply the approach to some North American supply systems. This presentation:

- Outlines the recommended IWA approach
- Compares the IWA equations for unavoidable real losses with approaches previously used to estimate unavoidable losses in North America
- Compares the recommended performance indicators for Real Losses for the volunteer North American supply systems with the international data set

2. An International Approach to Water Balance Calculations

Before attempting any performance comparisons, Water Balance data need to be re-allocated into the IWA standard terminology and water balance components (Ref. 1), as shown in Figure 1. These are based on international best practice, and include terms familiar to AWWA members such as 'Authorized Consumption'. However, the IWA has dropped the term 'Unaccounted for Water' in favor of 'Non-Revenue Water', because there is no internationally accepted definition of UFW, and all components of the Water balance can be accounted for using the above process

Figure 1: International Standard Water Balance

Own Sources	System Input	Water Exported	Authorised Consumption	Billed Authorised Consumption	Revenue Water	Billed Water Exported
		Water Supplied				Water Losses
Apparent Losses	Billed Unmetered Consumption					
	Real Losses		Unbilled Metered Consumption			
Unbilled Unmetered Consumption						
Unauthorised Consumption						
Customer Metering Inaccuracies						
Leakage on Mains						
Leakage and Overflows at Storages						
Leakage on Service Connections up to point of Customer Metering						
Water Imported	(allow for known errors)					

All data are expressed as a volume per year. The calculation procedure is as follows:

- Obtain system input volume and correct for known errors
- Obtain components of Revenue Water (right hand column), calculate Revenue Water
- Calculate Non-Revenue Water (System Input – Revenue Water)
- Assess Unbilled Authorized Consumption
- Calculate Authorized Consumption (= Billed + Unbilled) Authorized Consumption
- Calculate Water Losses (= System Input – Authorized Consumption)
- Assess components of Apparent Losses (right hand column), calculate Apparent Losses
- Calculate Real Losses (= Water Losses – Real Losses)
- Assess components of Real Losses from first principles (e.g. burst frequency/flow rate/ duration calculations, night flow analysis, modeling) and cross-check with calculated volume of Real Losses

Particular points to note, in comparison with the AWWA M36 Audit procedure (Ref. 2), are:

- Authorized Consumption is separated into Billed and Unbilled components, to allow both Financial and Operations Performance Indicators to be calculated
- Authorized metered consumption does not include customer meter errors, which are part of Apparent Losses in the IWA Water Balance
- Authorized consumption does not include volumes of losses from known (discovered) leaks, breaks and storage tank leakage/overflows, or estimates of unavoidable losses – these are all part of the ‘Real Losses’ in the IWA methodology
- An IWA standard water balance can easily be derived for components of an M36 Water Audit using the cross-referencing system in Appendix 1.

3. Recommended Performance Indicators for Non-Revenue Water and Real Losses

Table 1 shows the PIs for Non-Revenue Water and Real Losses recommended by IWA (Ref.1) converted to North American units. The PIs are categorized by Function and by Level, defined as follows:

- **Level 1 (basic):** a first layer of indicators that provide a general management overview of the efficiency and effectiveness of the water undertaking.
- **Level 2: (intermediate)** additional indicators, which provide a better insight than the Level 1 indicators for users who need to go further in depth.
- **Level 3 (detailed):** indicators that provide the greatest amount of specific detail, but are still relevant at the top management level.

Table 1: IWA Recommended Performance Indicators for Non-Revenue Water and Water Losses

Function	Ref.	Level	Performance Indicator	Comments
Financial: Non-Revenue Water by Volume	Fi36	1 (Basic)	Volume of Non-Revenue Water as % of System Input Volume	Can be calculated from simple water balance.
Financial: Non-Revenue Water by cost	Fi37	3 (Detailed)	Value of Non-Revenue Water as % of annual cost of running system	Allows different unit costs for NRW components
Inefficiency of Use of Water Resources	WR1	1 (Basic)	Real losses as a % of system input volume	Unsuitable for assessing efficiency of management of distribution systems
Operational: Real Losses	Op24	1 (Basic)	Gals/service line/ day, when system pressurized	Best 'traditional' performance indicator
Operational: Real Losses	Op25	3 (Detailed)	Infrastructure Leakage Index	Ratio of Current Annual Real losses to Unavoidable Annual Real Losses

Particular points to note from the above table are as follows:

- Fi36: % of Non-Revenue Water is the basic Financial PI
- Fi37: This detailed Financial PI is very similar to the recommendation of the AWWA Leak Detection and Water Accountability Committee (3)
- WR1: Real losses as % are unsuitable for assessing efficiency of management of distribution systems for control of real losses (because of influence of consumption)
- Op24: Gallons/service line/day is the most reliable of the traditional PIs for Real Losses, for all systems with Service line densities of > 30/mile
- To improve on Op24, need to take account of 3 key system-specific factors:
 - Average operating pressure
 - Location of customer meter relative to property line
 - Density of service connections
- By expressing Op 24 as 'Gallons/service line/day/psi of pressure, the influence of pressure can be allowed for in 'Intermediate' (Level 2) comparisons
- Infrastructure Leakage Index (ILI) is a measure of how well the system is being managed for the control of Real Losses, at the current operating pressure
- ILI is the ratio of Current Annual Real Losses to Unavoidable Annual Real Losses
- Unavoidable Annual Real Losses (UARL) are calculated from an equation (4) which takes into account average operating pressure, length of mains, number of service lines, and location of customer meters relative to the property line

4. Previous North American Approaches to Estimating Unavoidable Losses

4.1 J.C.Smith's M.Sc Thesis: this thesis (4), written in 1987, provides a convenient summary of North American practice some 13 years ago. Smith found that the most commonly used method for estimating unavoidable leakage in North America was based on the Kuichling equation (published in 1887), which takes account of length of mains, number of pipe joints, hydrants and stop valves, and number of service connections.

However, Smith's thesis concluded that this equation was 'an inadequate and inappropriate method for estimating unavoidable leakage in modern distribution systems', because:

- It does not allow for the influence of pressure on leakage rates (Smith considers this to be the single most important factor influencing unavoidable leakage)
- The 'drip rates' used by Kuichling may not be representative or valid
- Kuichling's equation was developed for cast-iron pipes, with jointing techniques (particularly on mains) much inferior to present practice
- Kuichling's equation does not consider the effect of material type or age
- Modern electronic leak detection equipment can locate hidden leaks which would have remained undiscovered 100 years ago

Smith's definition of unavoidable leakage, as 'that part of system leakage which is lost but is not economical to locate and repair', includes:

- Small, non-surfacing leaks which cannot be found by conventional leak detection methods (these are the only type which Kuichling considered as 'unavoidable')
- Leaks which do not have a high enough flow rate to make the cost of repair economical

An equation was proposed by Smith for calculating a threshold value of an individual leak flow rate (Q gallons/minute), given average repair cost and an assumed economic return period. However, he acknowledged that most of the repair costs are in excavation costs, that it is difficult to know the flow rate until the excavation has taken place, and once a leak has been excavated it is always sensible to repair it, whatever the size.

Smith then considered the two main alternatives to the Kuichling equation used in the USA. These are the 'Flat Rate' method (an allowance per mile of mains), and the AWWA standard method for calculating allowable leakage on new water mains. He concluded that:

- The Flat Rate methods 'neglect the effects of pressure, pipe materials, pipe size, system age, pipe location, frequency of service connections and other system appurtenances'
- The AWWA standards provide reasonable methods of unavoidable leakage for new water mains, have the advantage of including for the effects of pressure, pipe material and diameter, pipe joint frequency, but do not allow for the effects of age or the frequency of connections or appurtenances to the system, so 'they tend to provide overly conservative estimates for older pipe networks'.

To try to overcome these deficiencies, Smith developed an equation for calculating an 'Unavoidable Leakage Index', by modifying the AWWA Standard for new water mains. Factors were added for age, number of service connections, fire hydrants, valves and other system appurtenances, and pressure (assuming a square root relationship between unavoidable leakage rate and pressure). Smith states that 'Data is presently not available to test the assumptions used to develop the index equation consequently some adjustment may be necessary to the equation before it can be uniformly applied to all water distribution systems. However, it does take account of the main factors which influence leakage..... the only reasonable method available to a water utility manager to reduce unavoidable leakage is to reduce the system pressure and employ a comprehensive system maintenance and pipe replacement/rehabilitation program. Reduction of pressure is often resisted by the water customers'

It is not clear if Smith was aware of published research in the UK (5) and Japan (6), which had shown that the relationship between leakage rate and pressure in sectors of distribution systems is, on average, approximately a linear (rather than a square root) relationship.

Smith's conclusions were accepted and included almost word for word in the AWWA Research Foundation Report 'Water & Revenue Losses: Unaccounted for Water' in 1987 (7).

3.2 US Practice, 1987-2000 Material provided to the authors by members of the AWWA Leak Detection & Water Accountability Committee, shows that 'Flat Rate' assessments of unavoidable losses still predominate in US practice. In 1997, Boston Water & Sewage Commission, using the same definition of unavoidable losses as Smith, considered that 'the figures derived by Kuichling's formula and its derivatives, although dated, remain an accurate method to estimate the Commission's unavoidable leakage'.

In a discussion of the AWWA Leak Detection & Water Accountability Committee of June 1997, on the subject of unavoidable and 'non-economic' leakage, which included reference to developing UK practice, the Committee commented on the 'wide array of terminology which seems to exist to describe a specific occurrence'. In a later meeting typical figures of 1000 to 3000 Gallons/mile/day were quoted. These appear to originate from a Report of AWWA Committee 4450D (Revenue Producing Water) (Ref. 9). This 1957 Report provides the definition of unavoidable leakage later used by Smith (Ref. 4), and states that 'experience has shown that the value can range from 1000 to 3000 gpd per mile of pipe (main), depending on the age of the system, ground conditions, type of pipe and services, type of community, pressures and source of supply. a larger unaccounted-for figure is permissible where high pressures exist than under low-pressure conditions.'

From the above, it would appear that Smith's attempts to introduce a more rational approach to assessing unavoidable losses do not appear to have been taken up. This may be because the equation he proposed needs to be applied to many individual sections of different pipe diameter, before the aggregate figure for unavoidable losses for a particular system can be calculated. Or, it may be that as his equation had not been widely tested, practitioners are reluctant to depart from traditional 'Flat Rate' methods. So North American practice in 2000 regarding assessment of unavoidable real losses can perhaps be summarized as follows:

- The AWWA definition of unavoidable losses includes not only undetectable small leaks, but also those which are considered uneconomic to repair
- For over 40 years it has been recognized that several key factors are influential – notably pressure, density of service connections, age and type of pipe etc – but attempts by Smith and the AWWA Research Foundation to rationalize these in an equation do not appear to have been implemented to any significant extent
- In N. America, unavoidable real losses are usually expressed in 'Gals per mile of mains per day' (although we now know from the work of the IWA Task Force on Water Losses that 'Gals per service line per day' would be a better and more rational scaling factor)
- 'Flat Rate' allowances of between 1000 to 3000 gals/mile of mains/day are widely used, with no clear guidance as to how the key factors influence the achievable values
- No allowance is made for customer meter locations in the Southern States being located close to the property line, whereas in Northern States they tend to be distant from the property line (with additional propensity for leakage on customers' private pipes upstream of the meter)

5. The IWA Water Losses Task Force Approach to Calculating Unavoidable Real Losses (UARL)

The IWA approach is described in detail in the December 1999 issue of IWA 'AQUA' Magazine (Ref. 10), and can be seen as a natural development of previous North American attempts to take key local factors into account. The UARL component-based equation is based on auditable assumptions for break frequencies/flow rates/durations; it uses Background and Breaks Estimates concepts (Ref. 11) to calculate the unavoidable real losses for a system with well-maintained infrastructure, speedy good-quality repairs of all detectable leaks and breaks, and efficient active leakage control to locate unreported breaks.

The parameters used in the calculation, taken from Ref (4) and converted to North American Units are shown in Table 3 (Gal = US Gallon).

Table 3: Parameters Values Used for Calculation of Unavoidable Annual Real Losses UARL
(all flow rates are at a reference pressure of 70 psi)

Infrastructure Component	Background (undetectable) losses	Reported Leaks and Breaks	Unreported Leaks and Breaks
Mains	8.5 Gals/mile/hr	0.20 breaks/mile/yr. at 50 Gpm for 3 days duration	0.01 breaks/mile/yr. at 25 Gpm for 50 days duration
Service Lines, Main to Curb-Stop	0.33 Gals/service line/hr	2.25/ 1000 service line/year. at 7 Gpm for 8 days duration	0.75/1000 service line/year. at 7 Gpm for 100 days duration
Service Lines after Curb-Stop (for 50ft ave. length)	0.13 Gals/service line/hr	1.5/ 1000 service line/year. at 7 Gpm for 9 days duration	0.50/1000 service line/year. At 7 Gpm for 101 days duration

Table 4 shows these in a user-friendlier format for calculation purposes. The ‘UARL Total’ values, in the units shown in Table 4, provide a rational yet flexible basis for predicting UARL values for a wide range of distribution systems, taking into account, length of mains, number of service lines, location of customer meters relative to property line, and average operating pressure.

An important aspect of Table 4 is the value assigned to Unavoidable ‘Background’ (Undetectable) Real Losses, shown in Column 2. These figures are based on international data, from analysis of night flows in sectors just after all detectable leaks and breaks have been located and repaired. This component of unavoidable real losses has, to the best knowledge of the authors, never previously been quantified in North American practice; yet it accounts for at least 50% of the Unavoidable Real Losses components in Table 4.

Table 4: Unavoidable Annual Real Losses in Component Format

Infrastructure Component	Background Losses	Reported Bursts	Unreported Bursts	UARL Total	Units
Mains	2.87	1.75	0.77	5.4	Gals/mile mains/Day/psi of pressure
Service Lines, mains to property line	0.112	0.007	0.030	0.15	Gals/service line/day/psi of pressure
Underground pipes between edge of street and customer meters	4.78	0.57	2.12	7.5	Gals/mile u.g. pipe/Day/psi of pressure

There are many different ways to present the UARL equation.

Figure 2 shows UARL in Gals/mile/day/psi of pressure (Y-axis) plotted against Density of Service Lines. The large variation with density of service lines shows why it is not recommended to use ‘per mile’ for comparisons of real losses.

If the Table 4 UARL values are plotted as a graph of Gal/service line/day/psi of pressure Vs Density of Service Lines, the relatively flat curves show why ‘per service line’ is preferred to ‘per mile’ as the basic Performance Indicator, except at low densities of service lines.

Figure 2: Unavoidable Annual Real Losses (Gal/mile of mains/day/psi) Vs Density of Service Lines

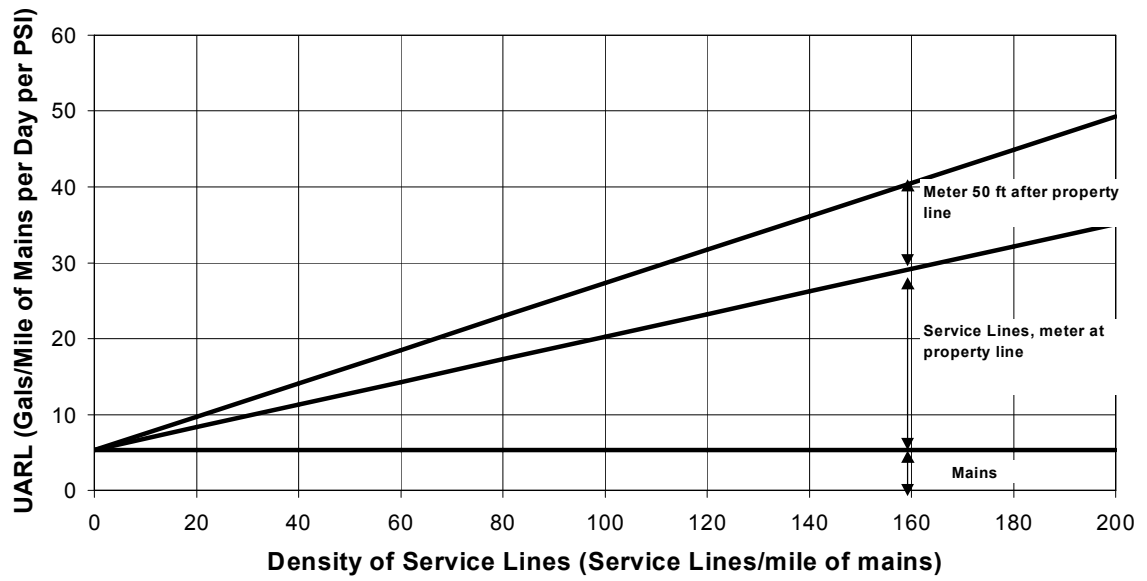
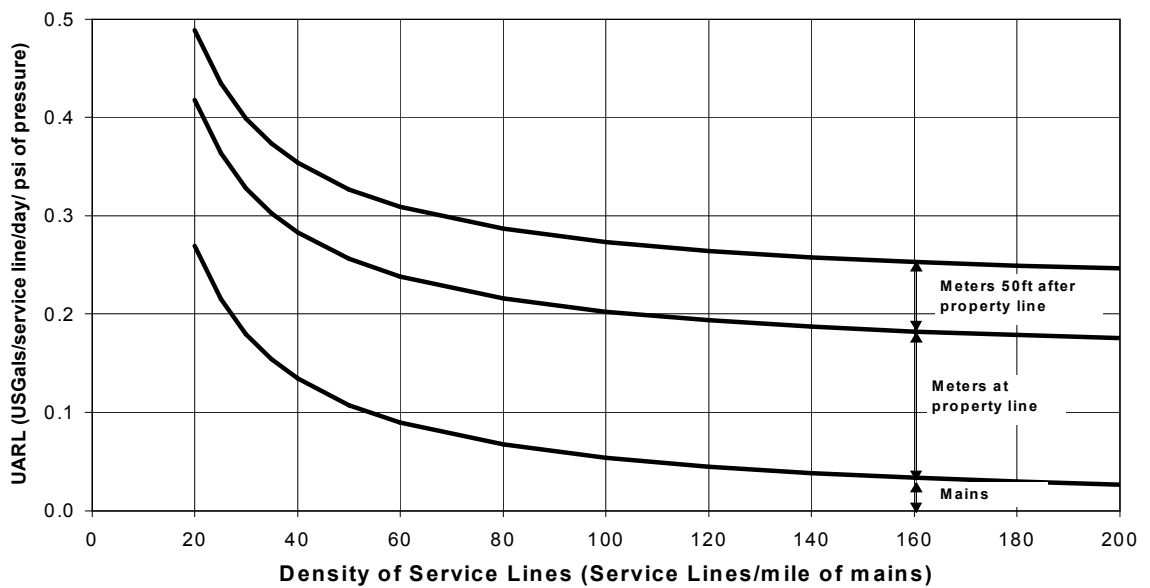


Figure 3: Unavoidable Annual Real Losses (Gal/Service Line/day/psi) vs. Density of Service Lines



6. Application to Data from North American Supply Systems

Three methods have been used to check the application of the IWA methodology to North American water supply systems:

6.1 Comparison of IWA predicted range of Unavoidable Annual Real Losses with typical range quoted for USA systems

Figure 2 can be used to calculate system-specific UARL in Gals/mile/day, by assuming upper and lower limits for density of service lines, customer meter location and pressure.

Lower limit: rural, meter 50 ft after property line; 30 service lines/mile; pressure 50 psi
Unavoidable Annual Real Losses = 12 Gal/mile of mains/day/psi x 50 = **600 Gal/mile/d**

Upper limit: urban, meter at property line, 160 service lines/mile, pressure 100 psi
Unavoidable Annual Real Losses = 40 Gal/mile of mains/day/m x 100 = **4000 Gal/mile/d**

Values predicted from the IWA equation span the typically quoted range of 1000 to 3000 Gal/mile/day in the USA, but allow the estimates to be made on a system-specific basis.

6.2 Comparison of remaining background loss following leak detection surveys in small USA systems, with IWA unavoidable background loss predictions based on Table 4, 2nd column. Data so far limited, but initial comparisons are encouraging, and more comparisons are sought.

6.3 Comparison of IWA Recommended Performance Indicators for Real Losses for a number of North American systems, with the IWA International Data Set

Eleven North American Water Utilities volunteered data for this comparison. Analysis was complicated by

- each water balance being in a different format with different terminologies
- lack of availability of average system pressures

Seven of the systems provided sufficient data for the analysis in **Table 5 below**.

Table 5: Summary of Statistics for 7 North American Systems

TRADITIONAL STATISTICS	A	B	C	D	E	F	G	Average
Metered Water Ratio %	81.2	84.7	67.6	76.0	78.0	78.6	66.5	76.1
Non-Revenue Water %	18.8	15.3	32.4	24.0	22.0	21.4	33.5	23.9
Real Losses Gals/Mile/day	3652	3558	4975	13378	13960	13105	20686	10473
Consumption Gal/service line/day	337	551	358	466	772	756	444	526
KEY SYSTEM FACTORS								
Service Line Density/mile	86	67	40	104	85	80	145	87
Average meter location, feet after property line	0	23	7	24	25	0	12	13
Average pressure, p.s.i.	75	75	85	70	72	65	55	71
UNAVOIDABLE ANNUAL REAL LOSSES,								
Gal/service line/day/p.s.i	0.21	0.26	0.29	0.24	0.25	0.22	0.20	0.24
Gal/service line/day	16.0	19.7	25.1	16.5	17.9	14.2	11.2	17.2
NEW PIS FOR REAL LOSSES								
Basic: Gal/service line/day	42	53	124	129	163	165	143	117
Intermediate: Gal/sl/day/psi	0.57	0.70	1.46	1.84	2.27	2.53	2.59	1.71
Detailed: Infrastructure Leakage Index	2.66	2.69	4.96	7.80	9.13	11.63	12.69	7.37

The values of the Non-Revenue Water % and the 3 new Real losses performance indicators for the 7 North American systems in Table 3 were entered alongside the values from the 27 systems from 20 countries in the IWA International Data set. The North American systems are shown in black in the following bar charts:

Fig. 4.1 Non-Revenue Water ,% of System Input

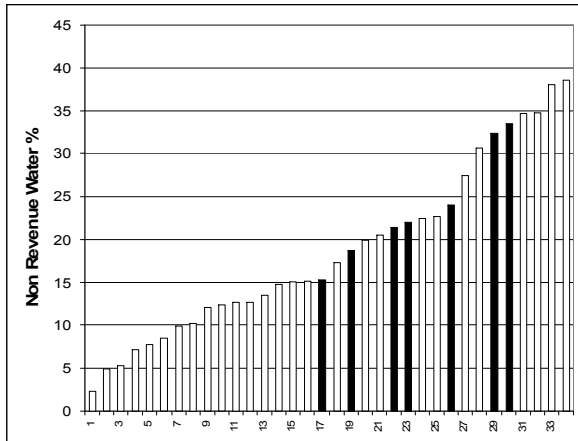


Fig. 4.2 Real Losses in Gals/Service Line/day

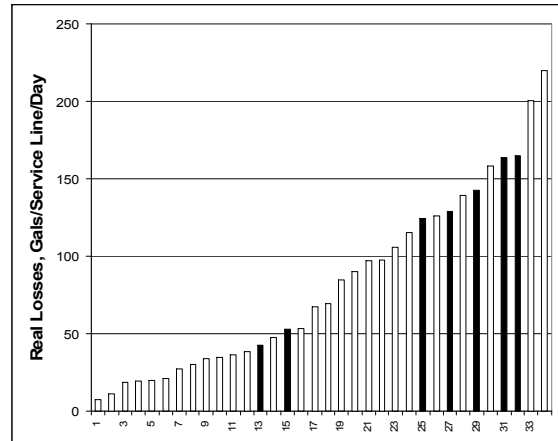


Fig. 4.3 Real Losses in Gals/Service Line/day/psi

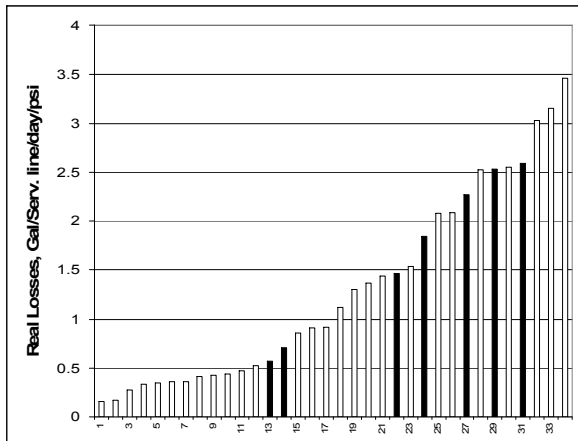
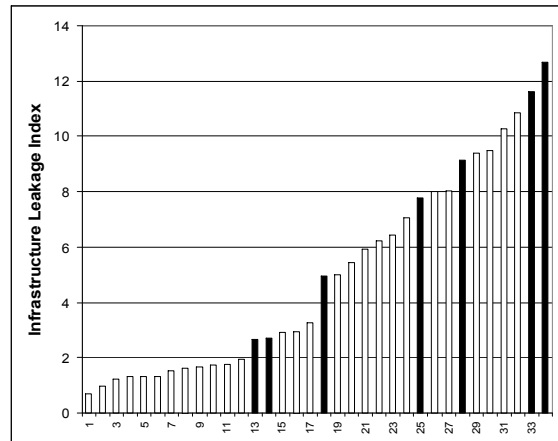


Fig. 4.4 Infrastructure Leakage Index



The fact that almost all the seven North American systems in the data sample have NRW% values greater than 16% (the average for the large 1996 sample referred to in the introduction) means that these systems cannot be considered as a representative comparison of North American performance against international performance; a wider range of system data would be needed for such a comparison.

When expressed as %NRW (Fig 4.1) the North American data bunches together in the ‘worst’ 50%ile of the extended data set; but when the new performance measures are used, in Figs 4.2 to 4.4, a clearer discrimination of performance results, and it is seen that two of the North American systems are just within the ‘best’ 50%ile of the extended international data set.

In one of the North American systems, the IWA performance measures were calculated for 3 discrete sub-systems, known to have very different leakage characteristics, and the individual ILI values ranged from 1.6 to over 10, reflecting the local situation reliably, but in greater detail than had previously been possible with the cruder % Non-Revenue water approach. The methodology can be used for sub-systems down to around 5000 service connections.

7. Concluding Comments

By expressing the outputs of the IWA task Forces in units familiar to AWWA members, it is hoped that this paper will stimulate further interest in the 'state of the art' for Water Losses performance indicators. The methodologies may be viewed as a continuation of the work of North American researchers who have been seeking a more rational basis for comparisons, which takes into account key system-specific factors, notable pressure, density of service lines and location of customer meters relative to the property line.

There is no indication from the applications described in this paper to suggest that the methodology is not applicable to North American systems, although further testing is of course recommended. Potential problems likely to be encountered in further applications are:

- the wide diversity of formats and terminology used for water balance calculations
- training in a standard methodology for calculating average pressure

but both these problems have been overcome in countries outside North America.

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Appendix 1: Identifying IWA Water Balance Components from an M36 Audit Worksheet (2nd Ed., 1999)

IWA Water balance component	M36 Audit	M36 description
System Input Volume	Line 4	Adjusted total water supply to the distribution system
Authorized metered consumption	Line 5	Uncorrected total metered water use
Authorized unmetered consumption	Line 12	Total authorized unmetered water
Apparent losses	Line 9	Corrected total metered water deliveries
	- Line 5	Uncorrected total metered water use
	+ Line 14A	Accounting procedure errors
	+ Line 14B	Unauthorized connections
	+ Line 14H	Unauthorized Use
Real losses	Line 14C	Malfunctioning dist. system controls
	+ Line 14D	Reservoir seepage and leakage
	+ Line 14E	Evaporation
	+ Line 14F	Reservoir overflow
	+ Line 14G	Discovered leaks
	+ Line 16	Potential water system leakage